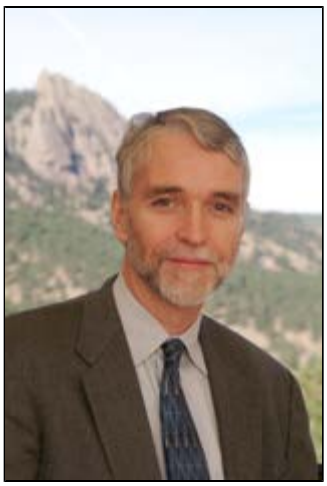
Director's Message

Dear Colleagues:



I am very pleased to introduce the web-based 2004 Annual Scientific Report for the National Center for Atmospheric Research. As you will read, NCAR has had another very productive year of science and service.

Working with our many partners, we have made significant progress on the development and use of NCAR's community models for climate, chemistry, weather, and solar-terrestrial science. We have upgraded our supercomputing facilities and have led vigorous national efforts to ensure that such community-serving, supercomputer systems are not compromised by "computer hackers". We have almost completed the structural modifications to the High-Performance Instrumented Airborne Platform for Environmental Research (HIAPER) aircraft and are looking forward to the first scientific research flights in 2005. The High-Resolution Dynamics Limb Sounder (HIRDLS), a joint US-UK satellite instrument, was launched this year on the NASA AURA satellite and, at the time of writing, is just beginning to acquire data. Our scientists and engineers deployed a new "eye-safe" LIDAR sensor in a successful "Pentagon Shield" project for the Department of Homeland Security.

NCAR researchers and university collaborators participated in several challenging and successful field experiments including the Airborne Carbon in the Mountains Experiment (ACME), Ocean Horizontal Array Turbulence Study (OHATS), Antarctic Tropospheric Chemistry Investigation (ANTCI), the North American Monsoon Experiment (NAME). Our scientists and engineers have initiated work on the new Megacity Impacts on Regional and Global Environments program (MIRAGE).

For the past three years, NCAR has made investments in several strategic initiatives and we are now seeing significant results from this investment. All the initiatives involve extensive collaboration with external scientists and are generally focused on muliti-disciplinary scientific challenges (e.g., water cycle across spatial scales and the biogeochemical cycles) or on generative tools (e.g., the Geographic Information System and Data Assimilation initiatives). You can learn more about all the initiatives at the following link: http://www.ncar.ucar.edu/stratplan/initiatives.html

We've added a new search engine specific to the ASR this year which we hope will help you find topics of your particular interest. The search box appears on each page. For each division, this report provides executive summaries and detailed reports of our activities. We welcome your input on the report. If you have input please email Catherine Shea at cshea@ucar.edu.

Facilities and Community Support

Supercomputing

We have aggressively augmented our supercomputing facilities, supporting the ever-growing demand for high-end computational facilities for the atmospheric and related sciences. We now manage more than 2 *petabytes* of data in the NCAR mass store and the total computing capacity provided routinely to the community now exceeds 12 *teraflops* – these are large numbers by any reckoning. However, community demand continues to outstrip our ability to deliver end-to-end high performance computing and we will therefore continue our commitment to provide robust, capability-based

supercomputing (“cyberinfrastructure”) for the next generation of simulation codes and their developers.

HIAPER

We continue to make progress, on schedule and within budget, in the acquisition of the High-Performance Instrumented Airborne Platform for Environmental Research (HIAPER). This year, we have made great strides in the development of HIAPER - staying on schedule and within budget. HIAPER will arrive at Jeffco Airport early next calendar year and will provide the community with a long-planned enhancement in capabilities for long-duration, high-altitude atmospheric sensing. Our new (draft) Earth Observing Laboratory (EOL) strategic plan refers to the upcoming period as “the golden age of research aviation” – I think with more than a touch of poetic license - but certainly with great pride and anticipation!

CCSM and IPCC Runs

We have also been very busy with the development of new community user “facilities” that are based on complex software systems, rather than hardware platforms. Under NSF and DOE sponsorship and with tremendous community involvement, we released a new version of the Community Climate System model (CCSM-3) this year. CCSM-3 runs carried out for the International Panel on Climate Change (IPCC) assessment feature 10-member ensembles for the various socio-economic scenarios, plus many new features, such as coupled carbon cycles and significantly higher resolution simulations. We believe that CCSM-3 truly represents the “state of the art” in climate system models.

Community Models

With NASA sponsorship, and again in partnership with many other organizations, we released a new version of the Earth System Modeling Framework (ESMF). ESMF is becoming the “lingua franca” for earth system model component developers and will enable facile model intercomparisons through the use of modern software engineering practices and principles.

We released a new version of the Weather Research and Forecast Model (WRF) this year, and this code became operational at the National Centers for Environmental Prediction (NCEP) on September 27 th, a major milestone for NCAR. This transition marks a new era in the relationship between the research and operational communities responsible for weather prediction. As with our other community models, the WRF source code is available to all from the NCAR web site. Additional features are being added continuously, and a 4km, cloud-resolving, version of WRF was deployed in real time to simulate the landfalls for the sequence of hurricanes experienced in Florida and Alabama this year.

Community Interactions and Visitors

This year, we hosted close to 1000 visitors from over 400 different national and international institutions for visits ranging from one day to over six months. NCAR scientists and staff also played host to more than 20 SOARS students over the summer. We highly value our visitors and the excitement and enthusiasm they bring to our scientific and facilities programs and continue to look for new ways to increase the flow. This year, we created a new centralized NCAR visitor fund which we hope to grow over the next few years. During FY 2004, 31 postdoctoral fellows conducted research at NCAR in the Advanced Study Program. You can read brief examples of contributions to NCAR science in our section on Postdoctoral Research Summaries. A description of the fellowship program can also be found in the ASP Postdoctoral Fellowship Announcement. This year, ASP also supported the work of four graduate fellows and more information about this program can be found in the ASP NCAR Graduate Fellowship Announcement.

We are grateful to the many community members that helped us this year by serving on our numerous advisory and review committees. Each NCAR division has an advisory committee to provide the division input on strategic direction of the division. Advisory panel membership lists can be found at: http://www.ncar.ucar.edu/Director/SAC.html. This year, we also had enthusiastic participation in the review of our strategic initiatives. Lists of strategic initiative review panels can be found on some initiative home pages via the following link: ttp://www.ncar.ucar.edu/stratplan/initiatives.html

Education and Outreach

During the months of June – August, visitors participated in three workshops convened by UCAR- EO. The NCAR Undergraduate Leadership Workshop (ULW) welcomed 22 college juniors from 22 universities in the US and Canada . The goal of this program is to encourage students to continue their studies into graduate programs and to enter STEM careers. Teachers from across the nation convened in groups of 20 for the NCAR Climate and Global Change Workshop and the Workshop on Modeling in the Geosciences. Careful evaluation and attention to lessons learned from past summer workshops made these two-week, intensive professional development opportunities for middle school master-educators particularly effective this year.

I hope you visit this Web report to learn more about NCAR's contributions to areas of your research interests as well as other aspects of our program.

Tim Killeen
NCAR Director

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2004 Division Highlights

Please click on a division name below to go directly to its highlights:
ACD | ASP | ATD | CGD | ESIG | HAO | MMM | RAP | SCD

ATMOSPHERIC CHEMISTRY DIVISION

Long-range Transport of CO Emissions from Russian Fires

Studying satellite data on global air pollution levels, David Edwards and MOPITT team members at NCAR and other institutions noticed an unusual surge in CO concentrations in late 2002 and early 2003 that affected the entire Northern Hemisphere. Further analysis pointed to two Russian sources: massive peat fires smoldered near Moscow in the late summer and fall of 2002, and unusually intense Siberian wildfires broke out in the spring and summer of 2003. During the peat fires, Russian colleagues working with spectrometer data from the Obukhov Institute of Atmospheric Physics in Moscow (Leonid Yurganov and Evgeny I. Grechko) took air quality measurements from Moscow and a nearby site at Zvenigorod. This ground-based research was combined with observations of atmospheric pollutants from two instruments on the Terra satellite: CO levels from MOPITT, and aerosol optical depth from MODIS. The results showed that smoke and pollutants from the fires had been carried over much of the Northern Hemisphere, affecting CO levels as far away as North America.

Edwards and colleagues also looked at the impact of emissions from Siberia and other parts of eastern Russia. Massive fires in the giant boreal forests and on the tundra, often started by farmers, typically rage throughout the spring and summer. The 2003 fire season was particularly intense. Satellite data showed plumes from Asia following the jet stream, with high levels of CO crossing the Pacific Ocean, reaching western Canada, and traveling down to the U.S. East Coast-evidence of the global impacts of large-scale fires (Figure 1).

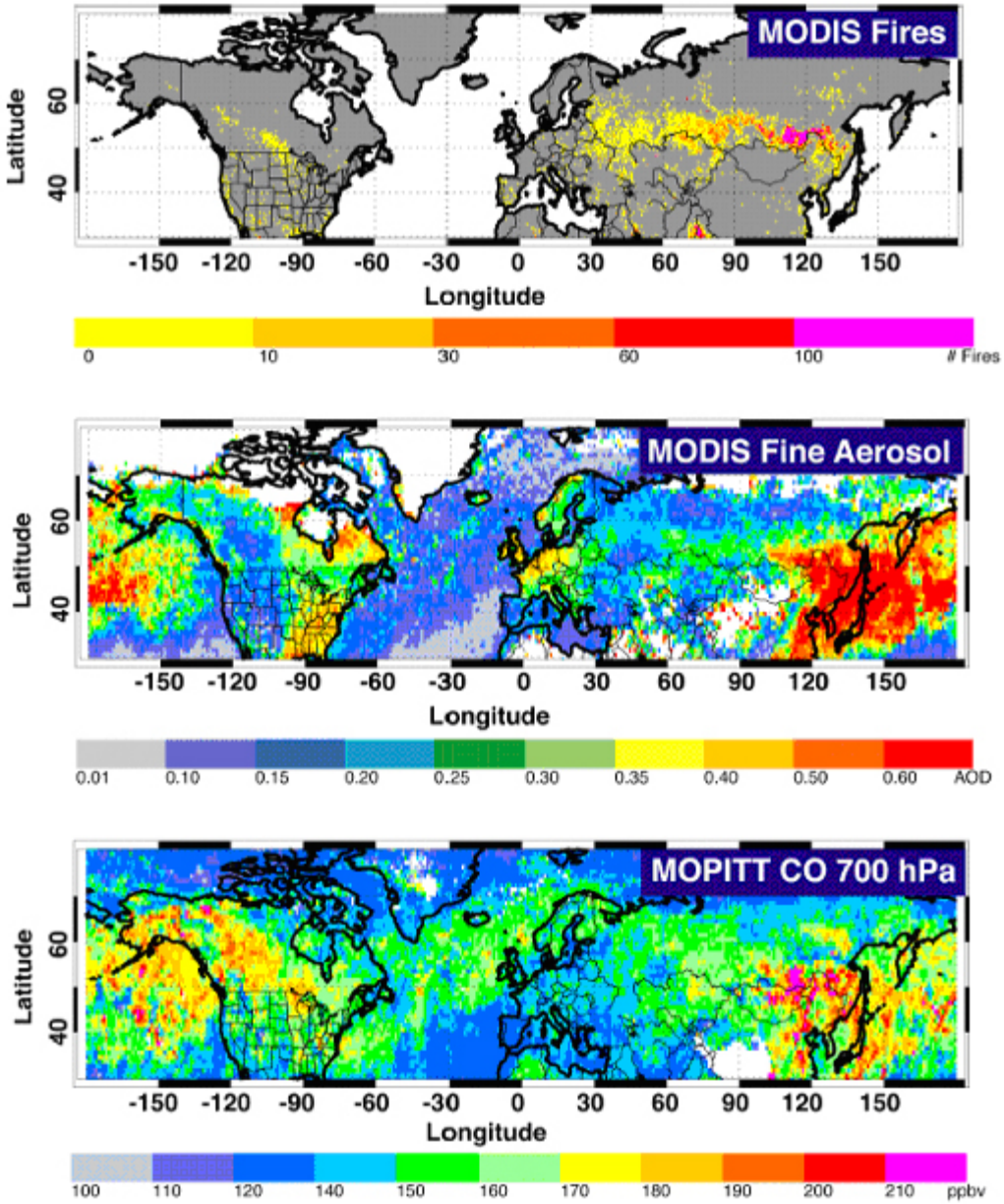

Figure 1: In the spring of 2003, the MODIS instrument on the Terra satellite detected a large number of fires in Siberia, especially in the Baikal region (top). These fires produced large amounts of fine carbon aerosol, also detected by MODIS, that spread over the Pacific Ocean but lasted only a few days (center). They also produced CO, which was detected by the MOPITT (bottom). CO can last over a month, which allowed it to cross the Pacific Ocean and reduce air quality over North America before continuing on around the globe.

Quantification of Tropospheric Aerosols over China using Satellite Data

Stephen Massie used satellite measurements to quantify tropospheric aerosols and pollution and their variability over time. An analysis of Total Ozone Mapping Spectrometer (TOMS) satellite data showed a significant increase (up to 17.3%) in tropospheric aerosols over China and India during 1980-2000 (Figure 2). These increases were expected, due to large increases in population and SO_2 emissions (converted to sulfate aerosols) in China and India, but this is the first study to quantify the changes based on satellite observations. This analysis was in collaboration with Omar Torres (Joint Center for Earth Systems Technology, University of Maryland Baltimore County and the NASA Goddard Space Flight Center) and Steven Smith (Pacific Northwest National Laboratory, Joint Global Change Research Institute).

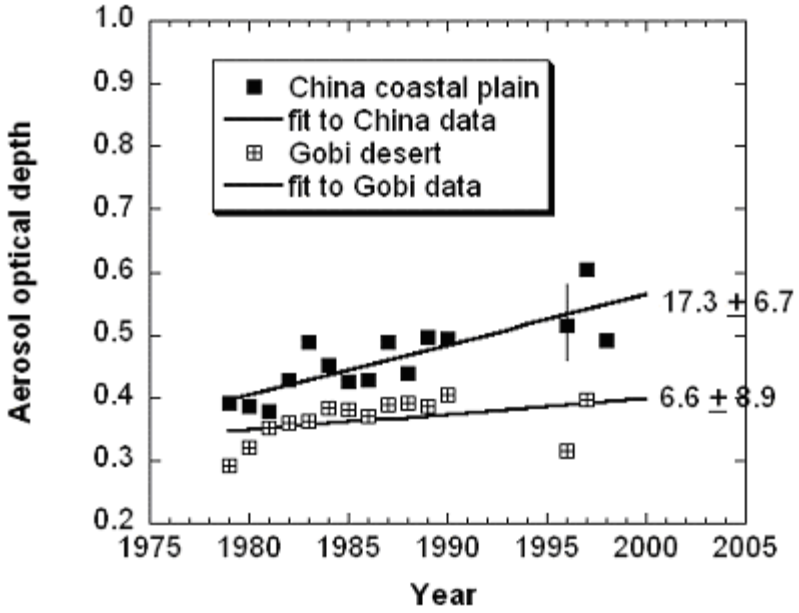

Figure 2: Winter averages of TOMS total aerosol optical depths, averaged for consecutive months from November through February for the China coastal plain and the Gobi desert. Aerosols over the Gobi desert are mainly due to desert dust, while aerosols over the coastal plain have a large contribution from sulfate. Linear fits and decadal trends are indicated.

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ADVANCED STUDY PROGRAM

The Advanced Study Program is pleased to highlight the Junior Faculty Forum and two summer colloquia held in the summer of 2004.

Junior Faculty Forum

ASP supported the Early Career Scientists Assembly second annual Junior Faculty Forum on 23-25 June 2004. This year 40 participants from 19 universities and institutions of the U.S., Switzerland, Canada and the United Kingdom discussed the sun-climate connection and the role of coastal zones in global biogeochemistry. New this year, the ECSA invited representatives of the National Science Foundation and NASA to discuss issues regarding funding opportunities, grants and ethics.

Summer Colloquia

ASP co-hosted two summer colloquia in 2004. The first, on atmospheric remote sensing using the global positioning system (GPS), was held from 21 June to 2 July 2004, coordinated with the UCAR Office of Program's COSMIC program, and organized by Ying-Hwa Kuo (NCAR/UCAR), Chris Rocken and Sergey Sokolovskiy (both of UCAR), E. Robert Kursinski (University of Arizona), and George Hajj (Jet Propulsion Laboratory). This two-week colloquium brought together 51 student participants and 31 lecturers for tutorials and discussion sessions. The students represented 36 universities and institutions from 11 countries and the 18 outside lecturers came from 12 universities and institutions plus an additional 13 lecturers from within NCAR/UCAR, so the colloquium had a strong international character. Following the colloquium, 10 U.S. students, under the sponsorship of the NSF International Programs grant, participated in a special 10-day field trip to visit key GPS atmospheric remote sensing facilities in Taiwan and Japan, including the National Space Program Office of Taiwan and the Meteorological Research Institute and the Geological Survey Institute of Japan.

The second colloquium was held 21-28 July 2004 on climate and health and was coordinated by Linda Mearns of the NCAR Environmental and Societal Impacts Group, Doug Nychka of the NCAR Geophysical Statistics Project and Jonathan Patz of Johns Hopkins Bloomberg School of Public Health. Thirty-one lecturers from 16 organizations and universities of the U.S. and the United Kingdom presented talks and hands-on interactive exercises to the 43 participants representing 26 universities and institutions of the U.S., Canada, Germany, Austria, Kenya, Israel, Spain, the West Indies and the United Kingdom.

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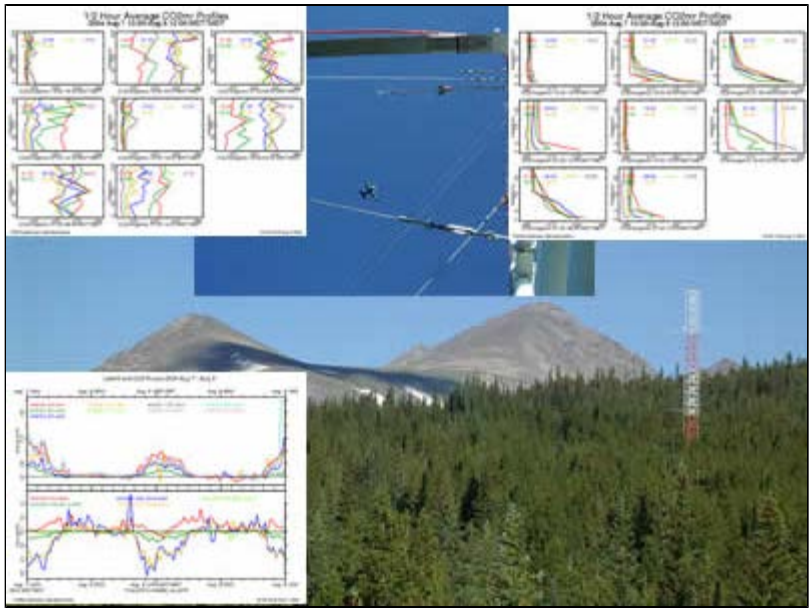
ATMOSPHERIC TECHNOLOGY DIVISION

Carbon in the Mountain Experiment (CME)



The overarching objective of NCAR's Biogeosciences Initiative is to incorporate relevant aspects of the biological sciences into geophysics and atmospheric research. In FY04, ATD has contributed in a number of ways to the objectives outlined in the Initiative, which is a 5-year NSF-funded collaborative project involving the University of Colorado, Colorado State University, University of Miami as well as NCAR's ATD, CGD and MMM.

For the Carbon in the Mountains Experiment (CME), conducted at the Niwot Ridge Research Site, ATD deployed instrumentation to investigate the local forest CO2 exchange. These observations will be used to resolve the atmospheric transport of CO2 in order to accurately measure the net ecosystem carbon exchange, and as input to a regional-scale data-assimilation model to improve our understanding of the processes controlling carbon cycling by mountain forests.

ATD developed an autonomous, inexpensive, and robust CO2 analyzer [AIRCOA]. RAF's Britt Stephens constructed 4 AIRCOA units after our initial design testing and deployed three of these in the field during the CME campaign. Diagnostics and Results. A key component in the robustness of these analyzers is near real-time data processing with extensive automated diagnostic tests to verify normal operation, with new results available from a web interface every day. In addition, ATD conducted the first Airborne Carbon in the Mountains Experiment (ACME I) in May and July of this year to explore methods for constraining regional-scale CO2 fluxes over complex terrain and to collect measurements useful for devising and testing strategies for long-term monitoring of these fluxes.

Raman-Shifted Eye-safe Aerosol Lidar (REAL)

FY04 saw exceptional advances for REAL. REAL now stands as a uniquely capable eye-safe aerosol and atmospheric structure detecting system, capable of both long range (up to 10km) and fine scale sensing (as small as 3 m features can be detected over full range). Its eye-safe design and relatively high laser power per laser pulse provides a flexibility unique in lidar systems. REAL's defining strength is that it can be deployed in support of scientific field experiments without concern for population density or aircraft presence. As a result of this capability REAL is participating in plume identification testing in support of a potential homeland security application scanning heavily populated areas. As a testament to the wisdom of the choice to develop a lidar in the eye-safe wavelength band, REAL is poised to further evolve into a system that can detect water vapor concentration, Doppler or structure-tracking-basded velocity, carbon dioxide concentration and methane concentration. This development has resulted in multiple patent filings, peer-reviewed publications and was recently honored with the cover of the optics journal, Applied Optics, and, finally, has been nominated for Outstanding Accomplishment Award for Scientific and Technical Advancement.

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CLIMATE AND GLOBAL DYNAMICS

Release of CCSM 3.0

Scientists in the Climate and Global Dynamics (CGD) Division, with strong external collaboration, spent much of the past year improving the Community Climate System Model (CCSM). Enhancements to versatility and sophistication have been made in all individual model components: atmosphere, land, ocean and sea ice. The latest version of the model, CCSM3, is being used to unravel the complex interactions and feedbacks among climate, atmospheric chemistry, biogeochemistry, and ecosystem dynamics under past, present, and potential future conditions. An extensive suite of CCSM3 simulations (Figure 1) was made for the next major assessment of the Intergovernmental Panel on Climate Change (IPCC). These simulations were not only done at NCAR, but at several Department of Energy (DOE) labs as well as the Earth Simulator in Japan. Such collaborations allowed for larger ensembles of simulations at higher resolution for longer periods of time than would have otherwise been possible. The IPCC integrations also include provisions for model data needed by groups interested in impacts, mitigation, and regional modeling at high resolution.

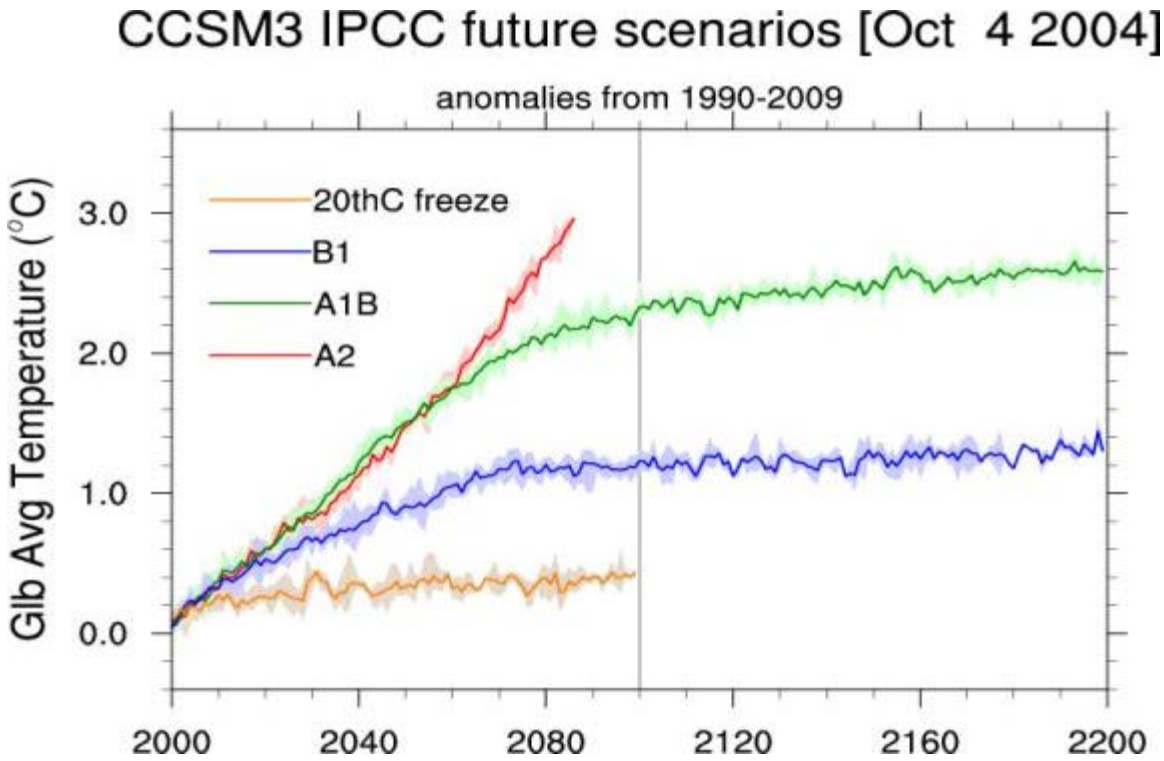
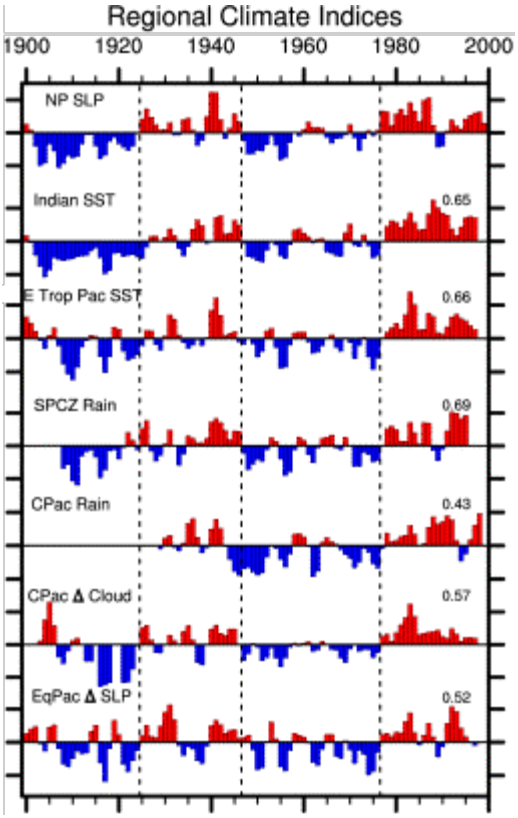


Figure 1: The CCSM3 DOE/NSF IPCC scenario runs as of October 4, 2004 . Observed forcings (solar, volcanoes, greenhouse gases, sulfate aerosols, carbon aerosols, and ozone) are used during the historical period, from years 1870-2000. A variety of future forcing scenarios (20th century freeze, B1, A1B, and A2) are used from years 2000-2200 to simulate the most likely range of future climates. Two of the commitment scenarios (A1B and B1) will be executed out to year 2300.

Climate Diagnostics: The role of tropical oceans in regional climate change

With sponsorship from NSF and NOAA, CGD scientists have found slow (multi-decadal) variations in tropical sea surface temperatures (SSTs) to be important forcings of Northern Hemisphere extratropical climate change over the last half-century. The atmospheric circulation changes include the trend in the leading spatial structure of Atlantic variability, known as the North Atlantic Oscillation (NAO), and decadal-scale climate fluctuations over the North Pacific Ocean and adjacent continents that have substantial impacts upon society and marine and terrestrial ecosystems. The origin of the North Pacific climate variations has been under considerable debate, with some theories proposing a middle latitude origin involving the ocean gyre circulation and others involving air-



sea interaction in the tropics. The recent work (Figure 2) provides the strongest evidence to date that the tropical Indian and Pacific Oceans play an integral role in decadal-scale climate variability over the North Pacific and adjacent continents during boreal winter months. In particular, the decadal variability is present in many different variables and indices: note especially the high correlations of North Pacific sea level pressure (SLP) with tropical Indian and Pacific Ocean precipitation, cloud, and SST.

Figure 2: Various Indo-Pacific climate indices and their correlation (1900-1999) with seal level pressure (SLP) area-averaged over the North Pacific Ocean (November-March). The North Pacific interdecadal variability has significant impacts on North American climate. From *Deser et al. (2004).*

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ENVIRONMENTAL AND SOCIETAL IMPACTS GROUP

Summer Colloquium on Climate and Health

A **Summer Colloquium on Climate and Health**, sponsored by ESIG, NCAR's **Strategic Initiative on the Science of Weather and Climate Impact Assessment**, and NCAR's Advanced Studies Program, brought together 31 senior experts and 30 international graduate and postgraduate students from 21-28 July 2004 to shape a program for research and professional training in climate and health. Linda Mearns and Johns Hopkins scientist Jonathan Patz invited health scientists and students to an intensive series of lectures and hands-on computer labs, which helped students and scientists learn more about the conceptual and methodological challenges for defining the possible effects of climate change on health. Top NCAR climatologists and statisticians, along with health scientists from the CDC (US Centers for Disease Control and Prevention), Johns Hopkins University, and other institutions around the globe presented selected case studies (e.g., heat mortality and vector-borne diseases). Statistical methods, such as time-series analysis and extreme value theory, demonstrated ways to analyze climate data. Modelers and risk assessment experts taught integrated modeling and strategies to communicate scientific findings and uncertainties. This event was the first step in a long-term program integrating climate and health recommended by the National Academy of Sciences/National Research Council. For more information, see the website at **www.asp.ucar.edu/colloquium/2004/CH/.**

"Communicating Urgency, Facilitating Social Change: New Strategies for Climate Change" Workshop

More than 40 participants from different disciplines convened in Boulder on 8-11 June 2004 to exchange ideas about ways to achieve successful communication between the climate science and climate policy communities. The workshop on **Communicating Urgency, Facilitating Social Change: New Strategies for Climate Change** was designed to maximize communication among participants from different fields. Organized by Lisa Dilling and Susi Moser of ESIG and sponsored by NSF and the MacArthur Foundation, the workshop explored ways to improve the exchange of information and ideas between different disciplines, took stock of what is known in pertinent fields and identified connections between them, and developed a research and action agenda within the context of climate change. Workshop participants and other invited experts are currently writing an edited volume on climate change communication and social change. The book will highlight effective strategies for communication and for facilitating social change at all levels and in all sectors of society. The book is currently scheduled to be released in late 2005. An article on the workshop, written by Moser and Dilling, appeared in *Environment* in December 2004. For more information, see the website at **www.esig.ucar.edu/changeworkshop/.**

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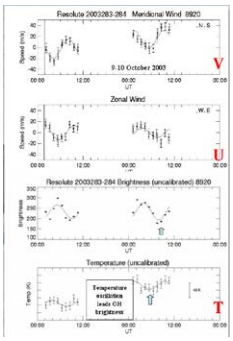
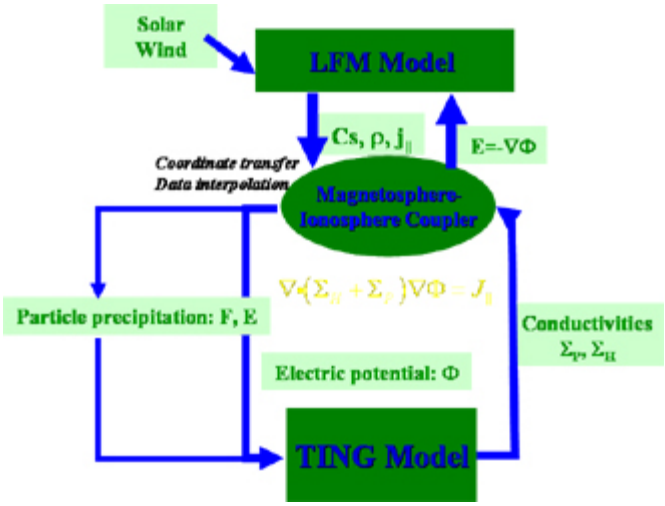
HIGH ALTITUDE OBSERVATORY

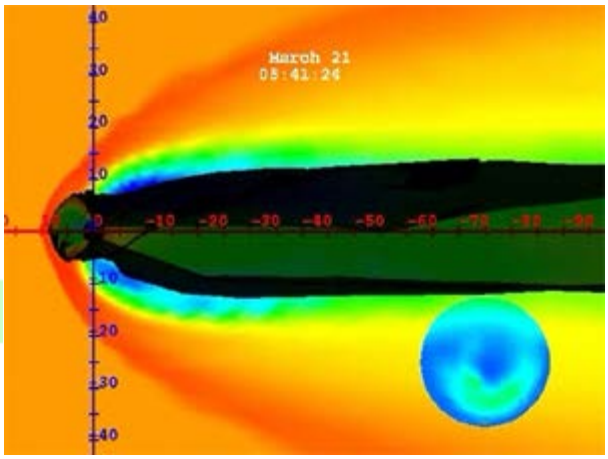
The NCAR/HAO Fabry-Perot Interferometer at Resolute Bay



NCAR HAO operates a state-of-the-art Fabry-Perot interferometer (FPI) at the Early Polar Cap Observatory (EPCO) in Resolute Bay to observe mesospheric, lower thermospheric, and upper thermospheric neutral wind, temperature, and airglow brightness. The EPCO FPI observations provide evidence of high latitude planetary, tidal, and gravity wave activity. In the accompanying illustration the 87-km results provide clear evidence of strong 8-hour wave activity in the upper mesosphere during 9-10 October 2003. Qian Wu and colleagues noted that he shift in phase (i.e., time of maximum perturbation) between the temperature and the brightness oscillations is consistent with the behavior of a terdiurnal tide.

Coupled Magnetosphere Ionosphere Thermosphere Model

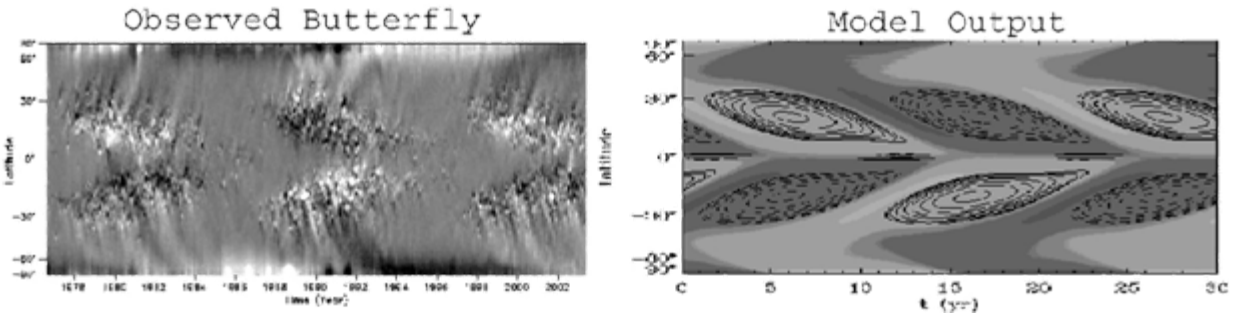


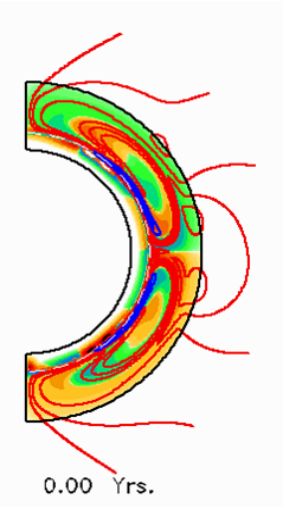


Under the auspices of the NSF Science and Technology Center for Integrated Space Weather Modeling, the NCAR HAO TISO team coupled the Lyon-Fedder-Mobarry (LFM) magnetospheric model to a high-resolution version of the thermosphere-ionosphere nested grid (TING) model. Michael Wiltberger, Webin Wang, and Alan Burns led the

development of this coupled model known as CMIT. The CMIT coupling involves passing the fluxes, the characteristic energy of precipitating particles, and the high latitude convection pattern from the LFM to the TING model. The TING model then uses these inputs to recalculate ionospheric conductivities and the high latitude electric potential. Thereafter, the potential is used to advance the magnetospheric solution in the LFM. This coupling process is nonlinear in that the calculation of the conductivities depends upon the electric potential. An accompanying animation illustrates some results from a CMIT simulation, including the dynamic response of the magnetosphere to a solar coronal mass ejection and the associated magnetic cloud which propagates toward the Earth. The insert illustrates the enhanced auroral production over the North Pole in the Earth's ionosphere in response to the ensuing geomagnetic storm.

Evolution of solar magnetic fields in a predictive Flux-transport Dynamo Model

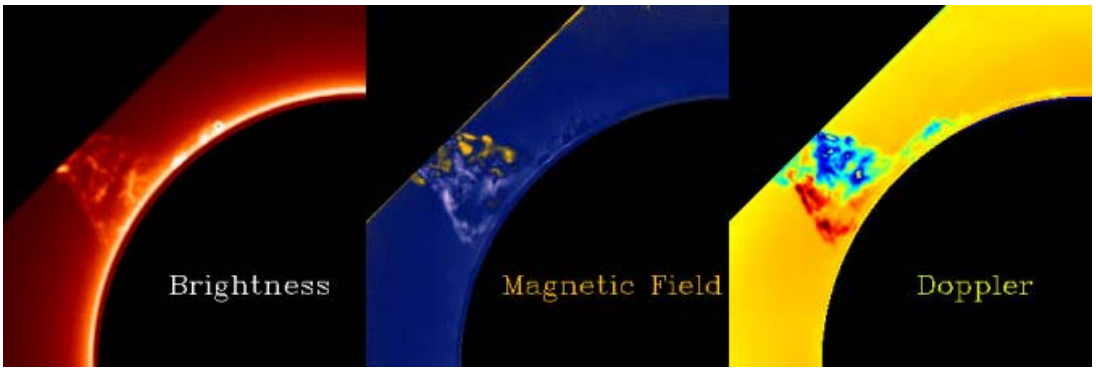




An HAO team led by Dikpati has recently built a model, based on physical simulations for the first time, that can predict the upcoming sunspot cycle features. Sunspots appear approximately every 11 years. Sunspots have been observed for over 2000 years, but the spot-count started in 1750. The exact period and strength of the solar cycle have always been difficult to predict.

The HAO team demonstrated that the surface flow patterns in the Sun, like winds on the Earth, have a profound effect on the deep interior of the star. Sunspots are tied to the solar magnetic field, which is generated by motions deep inside the Sun, interacting with a global surface flow from the equator to the poles. The solar cycle period and strength are determined by the surface flow. Using the observed flow pattern since 1996 until the present, HAO team predicts that the onset of the upcoming cycle 24 will be in late 2007 or in early 2008, with 6-12 months' delay compared to normal start of a cycle.

The Coronal Multi-channel Polarimeter (CoMP)



The Coronal Multi-channel Polarimeter (CoMP) is filter-based polarimeter optimized for the measurement of magnetic fileds in the solar corona. The instrument observes the coronal emission lines of FeXIII at 1074.7 and 1079.8 nm as well as the chromospheric HeI emission line at 1083 nm. The instrument consists of a polarimeter allowing complete Stokes I,Q,U,V measurement followed by a Lyot birefringent filter with dual passbands to measure simultaneously the coronal emission and background signals. Both the polarimeter and filter employ liquid crystals for rapid electro-optical tuning.

The circular polarization signal (Stokes V) in the vicinity of the emission lines carries information about the line-of-sight component of the magnetic field through the Zeeman effect. Linear polarization signal (Stokes Q and U) provides

information on the plane-of-sky magnetic fielddirection through the resonance scattering of the plasma. The line-of-sight component of the plasma can also be measured precisely through the Doppler effect.

This instrument was deployed to the 20-cm "Coronal One Shot" coronagraph at NSO's Sacramento Peak Observatory in January of 2004. Measurements of solar prominences and the corona were obtained during observing runs in March and May of 2004.

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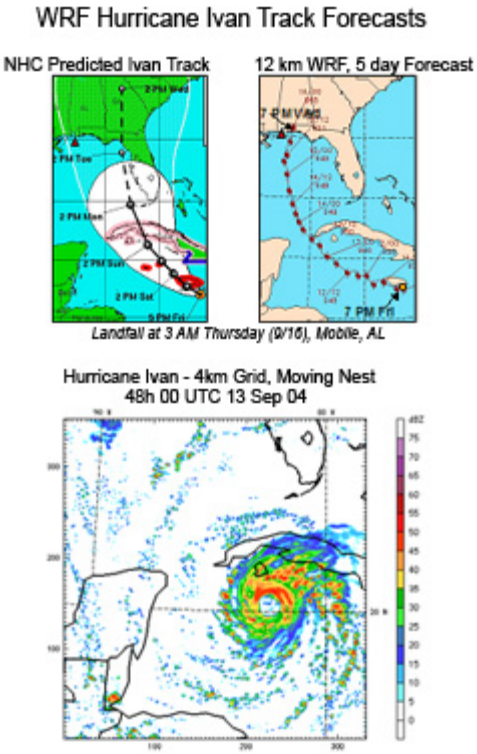
MESOSCALE AND MICROSCALE METEOROLOGY

WRF Hurricane Ivan Track Prediction



Click on hurricane image to play animation.

MMM scientists conducted a series of real-time forecasts of hurricanes during the 2004 season (Charley, Frances, Ivan, and Jeanne) using the updated capabilities of the Weather Research Forecast Model (WRF). Results show that WRF forecasts exhibit realistic structure and intensity from coarse initial data without bogusing. The WRF hurricane track forecasts have accuracy similar to or better than the current operational models, and moving nested grids yield high-resolution forecasts with greatly enhanced efficiency (smaller fine-grid domains). The WRF model is being developed as a collaborative effort with NOAA/NCEP, NOAA/FSL, AFWA, NRL, CAP at U of OK, and the FAA. Significant research was carried out in FY2004 including collaborations with the UK Met Office, U of Munich (Germany), Yonsei U (Seoul, Korea), U of CA at Davis, Hebrew U of Jerusalem (Israel), Pacific Northwest National Laboratory, Iowa State U, San Francisco State U, U of WA, and Ohio State U. Interdivisional collaborations included ASP, RAP and CGD.

OHATS: The Ocean Horizontal Array Turbulence Study

MMM scientists planned, implemented and carried out the Ocean Horizontal Array Turbulence Study (OHATS) utilizing an air-sea interaction tower operated by Woods Hole Oceanographic Institute. This field campaign was held off the coast of Martha's Vineyard from August through September 2004 and led to the collection of 2000 hours of turbulence and wave data from 18 sonic anemometers and 3 laser altimeters. In collaboration with ATD and Penn State University, MMM scientists constructed subfilter-scale (LES) fluxes in the marine surface layer and examined the couplings between atmospheric turbulence and surface gravity waves, using the OHATS and HATS databases to build new subgrid scale

parameterizations for LES (large-eddy simulations). Further information, including a gallery of photographs and preliminary data, can be found at: http://www.atd.ucar.edu/rtf/projects/OHATS04

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RESEARCH APPLICATIONS PROGRAM

Maintenance Decision Support System

In 2002, the Federal Highway Administration (FHWA) launched a scientific research and development program aimed at improving the safety and efficiency of winter road maintenance operations. Its goal was to bridge the gap between existing information systems that merely monitored road conditions and the needs of its operations and maintenance personnel for true decision support in fighting snow and ice on the nation's highways. Development of a new decision support system was entrusted to a consortium of five national laboratories - NCAR, NOAA/FSL, NOAA/NSSL, MIT Lincoln Laboratory (MIT/LL), and the Cold Regions Researchand Engineering Laboratory (CRREL) - each of which had specialized winter weather expertise. NCAR/RAP was chosen to lead the project and was tasked with the development of the operational concept, system design, software development, integration, testing, verification, dissemination, technology transfer and outreach of what would become the Maintenance Decision Support System (MDSS). Photo courtesy of Morris Richardson II, *Detroit News.*

Working with limited budgets over the past two years, the development team designed and built the MDSS, operationally demonstrated the system in field campaigns in Iowa and Minnesota, and in 2004 successfully transferred the system to the stakeholder community comprised of representatives from FHWA, State Departments of Transportation, commercial weather services, universities, and national laboratories within and outside the U.S.

The MDSS represents the first successful integration of advanced weather and road condition prediction systems, numerical model output, chemical concentration algorithms, and anti-icing and de-icing rules of practice in a single decision support system. It is a scientifically-based, user-tailored guidance system that allows DOT personnel to better understand and plan for the interplay of complex variables (e.g., road and bridge temperatures, precipitation type, chemical type and concentration) and their own anti-icing and de-icing decisions. State Departments of Transportation officials who have used the system conclude that MDSS is changing the paradigm for the control of snow and ice on

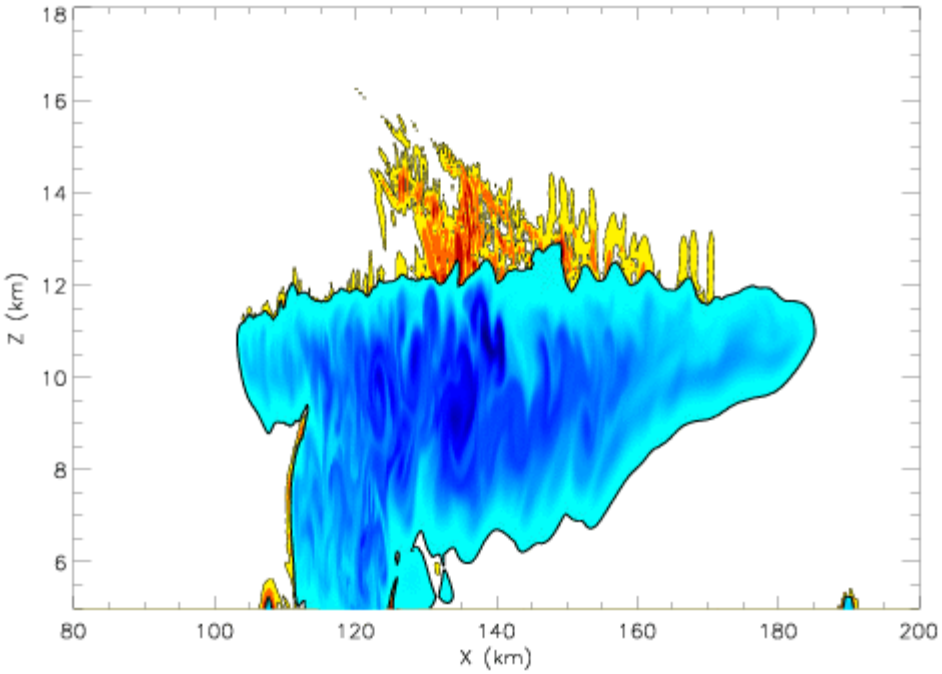
roadways. Iowa DOT officials, for example, indicated that the MDSS would conservatively save their state approximately 10% of their annual winter maintenance budget - a savings of $650,000 to $1,000,000 per year. Extrapolating this to all of the states that perform winter road maintenance, the savings could be in the $10s of millions per year.

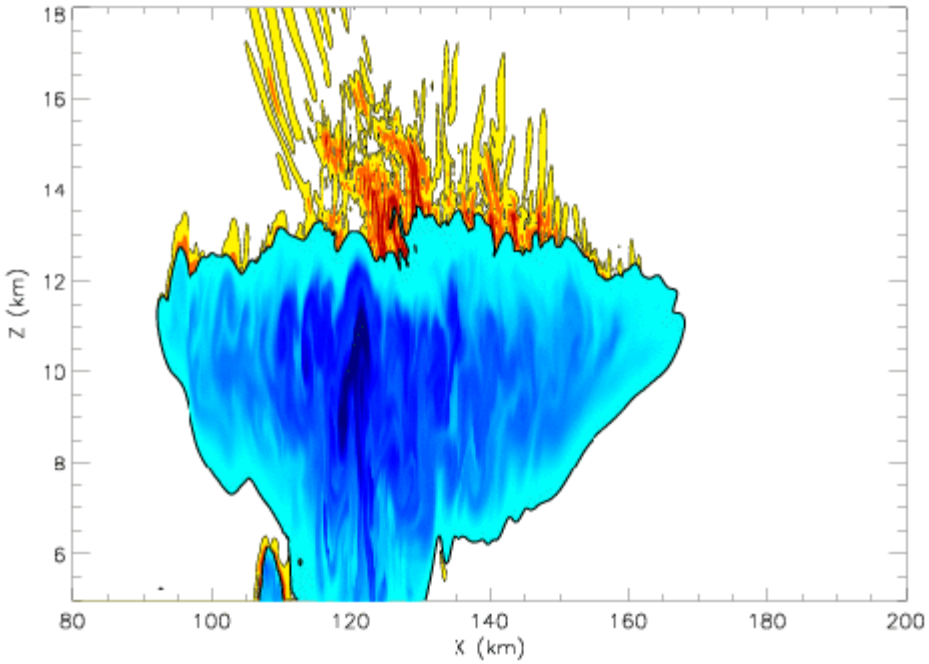
In developing the MDSS, significant scientific and technical advances were made in five areas: 1) Operational use of an ensemble of high resolution models running on an hourly update cycle using a "hot start" diabatic initialization process; 2) Refinement and implementation of a heat balance model tailored for road temperature and road condition prediction; 3) Further development and implementation of the Dynamic, Integrated Forecast System (DICast) for use in the Road Weather Forecast System (RWFS) for the MDSS; 4) Development of a road condition and treatment module that generates anti-icing and de-icing treatment recommendations specific to each plow route based on chemistry and physics; and 5) An aggressive technology transfer and outreach effort to put the new technologies into the hands of the transportation community.

The MDSS effort is also significant for advancing the need for a national surface transportation research and development program. This multidisciplinary program has bridged a longstanding gap between the meteorological research, civil engineering, and surface transportation communities, demonstrating that weather technologies can and should be an integral part of new transportation systems and programs.

Convectively-Induced Turbulence (CIT)

Deep convective clouds generate turbulence both in-cloud and out-of-cloud. The latter phenomenon, out-of-cloud convectively-induced turbulence (CIT), is poorly understood. A recent study by Lane et al. (2003) examined a single case of above cloud CIT, and found that it was possible for the turbulence to extend far above the convective cloud. It was also shown that the turbulence was due to breaking gravity waves aloft, and the breaking of these waves was controlled in part by the wind shear above cloud top. The results of the Lane et al. study also suggested that the current FAA guidelines for above cloud CIT avoidance may be insufficient to avoid turbulence in all cases.





In 2004 RAP scientists Todd Lane and Robert Sharman expanded the results of the Lane et al. simulations to provide more general conclusions. Specifically a series of high-resolution numerical simulations with background flow conditions, including wind speed, wind shear, and stability, were systematically varied to evaluate their effect on the turbulence generation processes. The figures above show a sample from the simulation results. Turbulence, as measured by the subgrid turbulent kinetic energy (TKE), obviously extends to high altitudes above the cloud. Preliminary results suggest that:

- The vertical extent of turbulence, and area of turbulence above convection may be approximately inversely proportional to the lower-stratospheric stability.
- The wind speed of the cloud-top jet does not necessarily affect the area or intensity of turbulence above the cloud, but controls the processes that generate the turbulence (i.e., in low-wind speed cases, the turbulence is derived from propagating waves, and in high-wind speed cases, the turbulence is derived from breaking waves). However, the contribution of the propagating waves may be different in a three-dimensional model.
- When the maximum wind speed is constant, high wind shear inhibits deep turbulent layers, and some (moderate) wind shears provide optimum conditions for turbulence to develop over deep layers above cloud top.

Further work is planned for next year to extend the parameter space of simulations to include cases of less intense and shallower convection, and more highly-sheared wind profiles.

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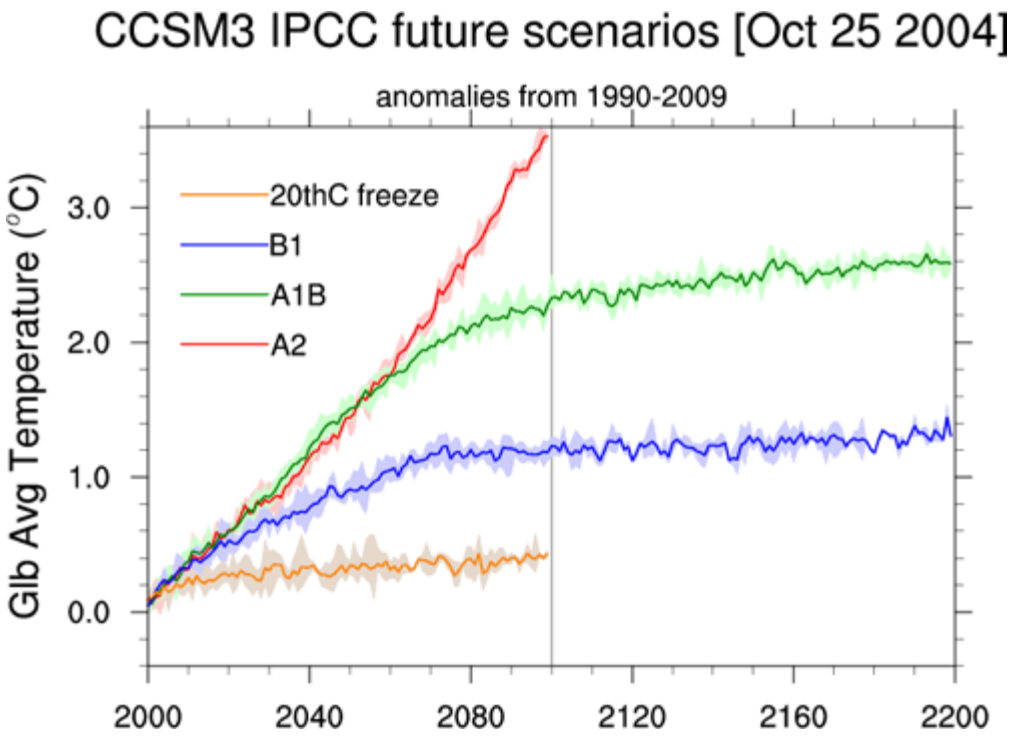
SCIENTIFIC COMPUTING DIVISION

Climate Modeling for IPCC

Phase III of the current Advanced Research Computing System (ARCS) was placed in service in FY2004, increasing net computing capacity by two teraflops. Phase III of ARCS expanded the IBM Cluster 1600 system (bluesky) by fourteen 32-way p690 Symmetric Multi-Processor (SMP) servers. Bluesky is now comprised of 50 POWER4 38 Regatta-H Turbo frames, making it the single largest system of this type in the world.

Twelve of these new servers were initially dedicated to NCAR's participation in the Intergovernmental Panel on Climate Change (IPCC). This new supercomputing capability proved essential in completing the IPCC simulations with the high-resolution version of the new Community Climate Simulation Model (CCSM3). Long control simulations, numerous historical recreations, and a wide range of future scenarios were carried out with NCAR's flagship coupled climate model at much finer horizontal resolutions than has ever been possible before.



The graph shows average global temperature change scenarios that were computed during the IPCC runs on bluesky. The amber line (20thC freeze) shows the temperature trend associated with no change in current worldwide emissions of anthropogenic aerosols. The other three lines show model predictions for other aerosol emission scenarios.

Strong support by SCD staff allowed the CCSM group to run continuously throughout the experiment period, even during determined hacker attacks. The results of this experiment are now being analyzed by NCAR scientists, and the data are being distributed freely to the global climate change research community in time for the Fourth IPCC Assessment Report.

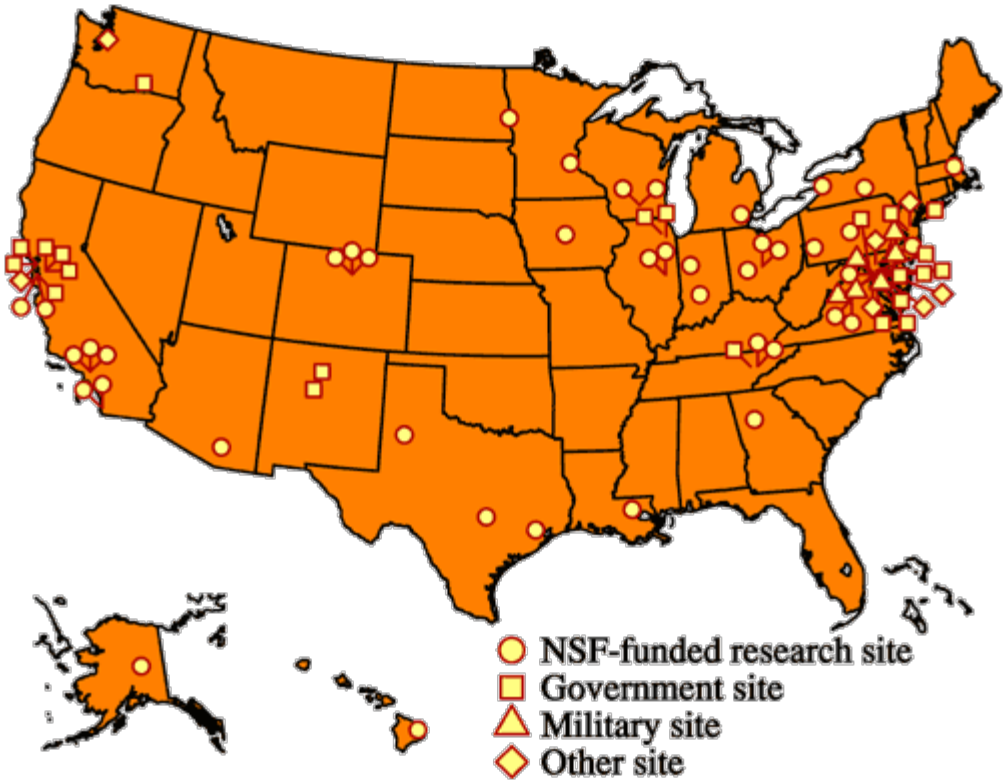
Bluesky contributed over 25 centuries of simulated climate to the IPCC effort -- more than half of all IPCC computing during this campaign. At the conclusion of the IPCC campaign in late FY2004, the 14 new p690 nodes were released to the community to augment SCD's computing capacity for all users. The current aggregate peak capacity of NCAR's supercomputing facility is now 12.1 teraflops distributed across six SMP computers.

Computing Security and Divisional Threat Response

In response to a major cybersecurity incident that involved multiple high-performance computing sites in March 2004, SCD rapidly developed and deployed a long-term solution for protecting the supercomputing and mass storage systems at NCAR. SCD now requires one-time password tokens, arbitrated via encryption devices issued to all users, to access these systems. Security procedures were updated and published to provide all users with guidelines and instructions for working within the secure supercomputing environment.

One of the problems encountered during the March 2004 incidents was a lack of effective communication among the affected institutions. SCD proposed a conference to bring together stakeholders from the nation's research and high-performance computing centers to prepare a coordinated response for future incidents.

With funding from the National Science Foundation (NSF), SCD planned, organized, and hosted a two-day Cybersecurity Summit near Washington D.C. Attended by over 120 cybersecurity experts from some of the nation's leading research institutions, the summit explored the competing needs of having an open, collaborative research environment while protecting the security and integrity of its computing and data assets.



The map shows the locations of the sites participating in the Cybersecurity Summit. This broad-based collaboration aims to coordinate strong response plans for threats against research computing and data.

Cybersecurity Summit 2004 was the first step in laying the foundation for responding to future large-scale security breaches and reducing the disruptive impact of such incidents on the nation's research agenda. These research institutions are increasing their cooperation on security policies, procedures, and incident response to better protect the nation's scientific computing and data resources.

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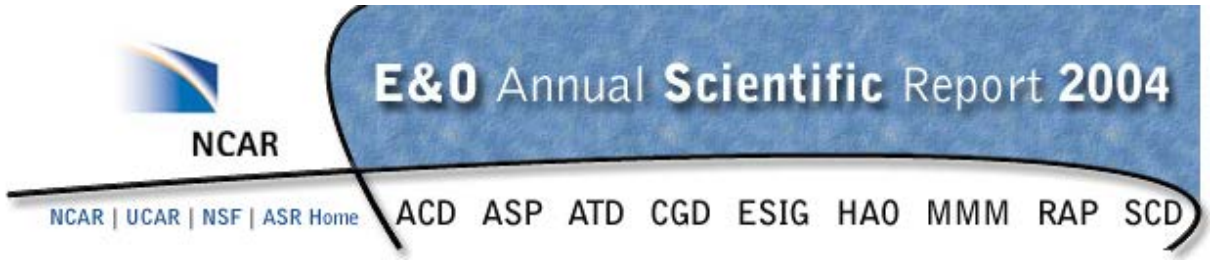
http://www.ucar.edu/educ_outreach/asr2004/ Go



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Overview

Education and Outreach (EO) has attained important milestones this year in the enhancement of exhibits and tour programs reaching K-12 and public visitors at the NCAR Mesa Lab, the expansion of web-based resources, facilitation of professional development workshops for teachers, and collaborations with scientists in implementing education and public outreach components of research programs. These activities further NCAR's mission to partner with the university community to promote scientific literacy and advance all levels of education and training in subjects related to Earth's atmosphere. Ongoing programs such as SOARS® and the NCAR Undergraduate Leadership Workshop continue to provide an important service by attracting undergraduates into the Geosciences. The SOARS program and the translation of Windows to the Universe into Spanish also further our goal to interest diverse populations in our fields of research. EO's activities are guided by the UCAR Education and Outreach Strategic Plan adopted in June 2001 (http://www.ucar.edu/educ_outreach/stratplan.html).

Highlights

Web Outreach - Close collaboration of the UCAR Office of Education and Outreach (UCAR- EO) with the institution-wide WORD committee has resulted in smooth integration of the new NCAR/UCAR umbrella web site with the NCAR Education and Outreach web site (www.ucar.edu/eo), developed with support from the NCAR Strategic Initiative. Visitors can now easily navigate to educational resources for the public, children, K-12 teachers, science enthusiasts, and undergraduate to graduate students by clicking on a conspicuous Education "tab" on the umbrella site's home page. The home page for Windows to the Universe Web (W2U) site (www.windows.ucar.edu) has been redesigned in 2004 to facilitate more efficient navigation to its immense content areas spanning the Earth and space science, with arts and humanities connections. Over one half of the web site has been translated into Spanish, drawing 10 – 20 percent of site traffic as new pages are unveiled in Spanish. NCAR SI funding has enabled a major push to expand and update the climate, weather, and global change pages. Content about space weather has been consolidated, revised, and expanded, especially with a focus on a new audience, students in undergraduate survey courses. An exciting new interface has been developed to allow scientists at NCAR and around the world to collaborate with W2U staff on the development of new content.

Educational Workshops - The UCAR campuses were energized during the months of June – August by visitors participating in three workshops convened by UCAR- EO. The NCAR Undergraduate Leadership Workshop (ULW) welcomed 22 college juniors from 22 universities in the US and Canada. The goal of this program is to encourage these gifted students, nominated and co-sponsored by their faculty, to continue their studies into graduate programs and to enter STEM careers. Teachers from across the nation convened in groups of 20 for the NCAR Climate and Global Change Workshop and the Workshop on Modeling in the Geosciences. Careful evaluation and attention to lessons learned from past summer workshops made these two-week, intensive professional development opportunities for middle school master-educators particularly effective this year.

Public Visitor and Exhibits Programs - The Mesa Lab continues to be a magnet to people of all ages who wish to learn about our science and enjoy the building's architecture. The *Climate Discovery* exhibit reached its first anniversary in July 2004, with accolades from visitors completing satisfaction surveys. The audiotour has conveyed information about weather, climate, technology, computing, and the societal impacts of weather and climate change to nearly 2,700 visitors

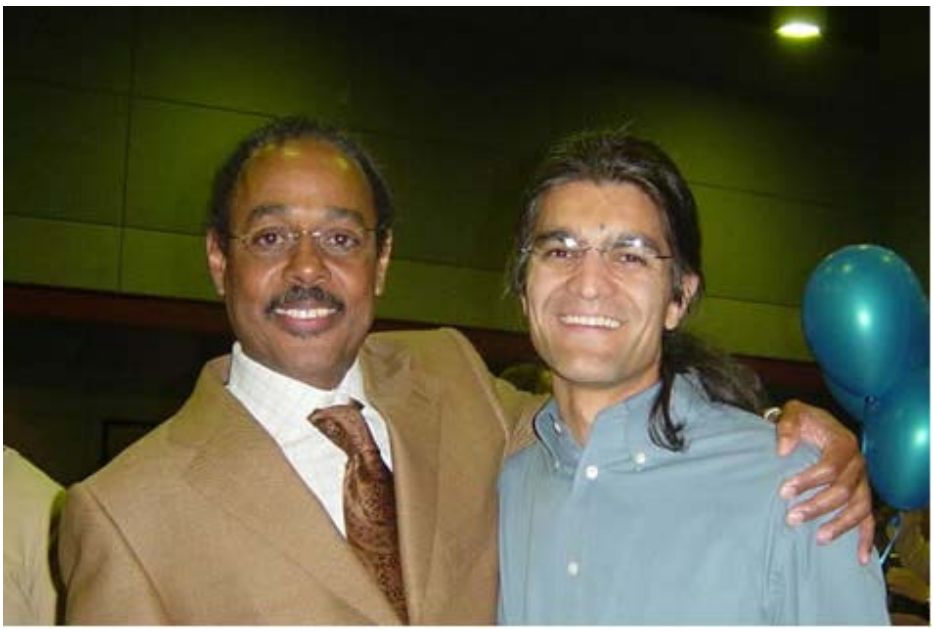
(27% children and 73% adults). Teachers from local public schools serving large numbers of students from the Hispanic community have participated in a workshop about the Spanish language resources available through the audiotour and the Windows to the Universe web site, and opportunities for further collaborations to advance diversity in education are growing. Collaborations with NCAR scientists and funding for education within research grants in ACD, ESIG, and HAO have allowed UCAR- EO to draft units about “The Little Ice Age” and “The Sun-Earth Connection” for a new Teachers Guide to the *Climate Discovery* exhibit. These resources will be field tested in classrooms and evaluated by teachers before their dissemination in the coming year.

Undergraduate Education

SOARS

SOARS® (http://www.ucar.edu/soars) was launched in 1995 to support the national goal of “a diverse, internationally competitive, and globally engaged workforce of scientists, engineers, and well-prepared citizens.” SOARS is dedicated to increasing the number of students from historically under-represented groups enrolled in graduate programs in the atmospheric and related sciences, with the goal of increasing ethnic diversity within the scientific community of the future. Since 1996, DOE-Global Change Education Program, NASA Goddard Space Flight Center, NASA Education and Public Outreach through NCAR HAO, NOAA Office of Global Programs, and the University of Colorado Cooperative Institute for Research in Environmental Sciences have joined NSF and UCAR as program sponsors.

In February of 2004, Rajul Pandya succeeded Thomas Windham as director and principal investigator of SOARS. Dr. Windham left SOARS to become the senior advisor for science and engineering workforce at NSF. Among other duties, Dr. Windham oversees NSF's efforts to broaden participation in S&E careers and serves as NSF's principal liaison to minority-serving institutions. Dr. Pandya was chosen by UCAR in an internal search presided over by the SOARS Steering Committee. He has been involved with SOARS for several years, acting as both a science and writing mentor for two SOARS protégés. He holds a Ph.D. in Atmospheric Science and brings experience with curriculum development and pedagogy. His recent research has explored the use of visualization technologies to enhance teaching and learning in the geosciences. In that capacity he has been involved in the DLESE project, where he served as the community and outreach liaison for the DLESE Program Center before joining SOARS.



Tom Windham, left, and Raj Pandya

At the heart of SOARS is a ten-week summer immersion program at UCAR/NCAR/UOP or the laboratories of a SOARS sponsor, where SOARS students (protégés) are provided opportunities to experience working as research scientists. Each summer, protégés conduct research projects and participate in a nine-week scientific writing and communication workshop. Protégés help define their individual project, conduct research, write a formal research paper, and present their results at a colloquium. Protégés receive a competitive stipend, housing, local transportation, and round-trip airfare to participate in the summer program.

Protégé and scientist in the lab

2004 Summer Highlights. Twenty-four protégés from across the United States and Puerto Rico completed the 2004 summer program. Nineteen protégés returned for their second, third, or fourth SOARS summer; five were new to SOARS. Eighteen protégés worked on projects at NCAR, two within the UCAR Office of Programs, two at the University of Colorado-Boulder, and two at NOAA. Each protégé was paired with a science research and a scientific writing and communication mentor. First-year protégés were also paired with a community mentor and a peer mentor. Six of the 19 returning protégés served as peer mentors to new protégés.

Each protégé conducted an individual research project, prepared a written research report, and presented their research results at the August 9-11 SOARS Protégé Colloquium. Seven protégés have had abstracts of their summer research results accepted for presentation at the Society for Advancement of Chicanos and Native Americans in Science (SACNAS) National Conference. In addition, 20 abstracts have been or will be submitted for presentation at upcoming student or professional meetings during the 2004-2005 academic year. A listing of summer 2004 protégés, mentors, and research topics is available online at: http://www.ucar.edu/soars/research/04researchtop.htm.

1996-2004 Program Results. Since the 1996 inaugural summer, 90 protégés have participated in SOARS. Participants' ethnicity and gender are outlined in Table 1.

Ethnicity and gender	Number of protégés	Percent of protégé population
African American/Black	38	42%
Hispanic/Latino/Chicano	29	32%
Native American/Indian	13	14%
Asian American & Pacific Islander	4	4%
European American	6	7%
Female	54	60%
Male	36	40%

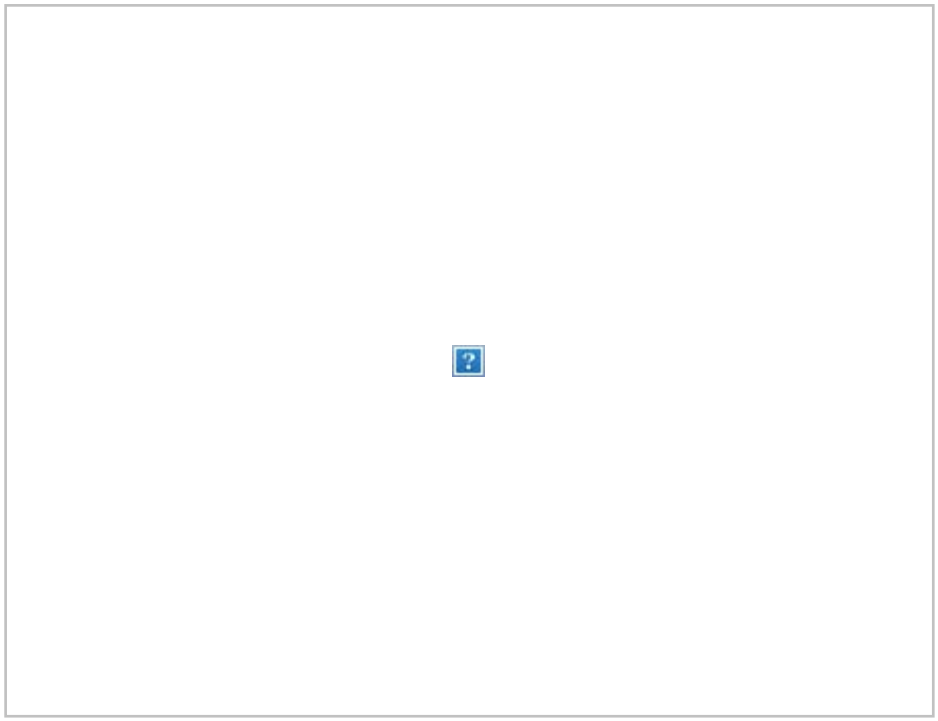
Table 1. Ethnicity and Gender Representation of SOARS Protégés, 1996-2004

As of fall 2004, twenty-nine protégés have completed their masters' degrees and one has successfully defended her PhD (in Computational and Applied Mathematics). Fifty-eight protégés have completed bachelor's degrees in an

atmospheric or related science; two have completed associate's degrees and are now enrolled with a science major at a four-year research university. Sixteen protégés are currently in the professional scientific or engineering workforce.

Thirty-four SOARS protégés are enrolled in graduate programs in an atmospheric or related science. Three are AMS graduate fellows; three are NSF graduate fellows. Twenty-three are enrolled in master's programs, and 11 are pursuing doctoral degrees—nine of these 11 have completed master's degrees. Eighteen protégés are currently enrolled in bachelor's programs in the atmospheric or related sciences. Over the program's nine years, 17 protégés have left the program, five to pursue careers in other fields, 11 due to unsatisfactory performance, and one for personal reasons.

Since its inception, SOARS protégés have presented more than 90 posters and more than 50 oral papers at regional, national, and international scientific conferences, with several receiving awards. The summer research of at least eight protégés has resulted in coauthored papers published in peer-reviewed journals. A listing of oral presentations is available online at: http://www.ucar.edu/soars/presentations.htm, and a listing of poster presentations is available at http://www.ucar.edu/soars/posters.htm. An online list of publications is available at: http://www.ucar.edu/soars/publications.htm



2004 SOARS Protégés: *Front Row (L to R): Rebecca Chan, Erik Noble, Carlos Medina, Anthony Didlake, Melanie Zauscher, Erick Adame. Back Row (L to R): Tamara Singleton, Braxton Edwards, Shanna-Shaye Forbes, Andro Ríos, Deanna Hence, Bret Harper, Cherelle Blazer, Tanya Craft, D. Matthew Coleman, Roberto Cancel, Clarence Mann, Dione Rossiter, Melissa Burt, Damian Mattis. Not Pictured: Atzel Drevón, Garymar dé Rivera Rivera, Nancy Rivera Rivera, Amber Reynolds.*

A Model Program. In December 2001 President Bush announced that SOARS had been selected as one of ten institutions receiving the sixth annual Presidential Award for Excellence in Science, Mathematics, and Engineering Mentoring. The award recognizes SOARS for "embodying excellence in mentoring under-represented students and encouraging their significant achievement in science, mathematics, and engineering."

Jeffrey Gaffney, chief scientist for DOE's Global Change Education Program (GCEP), visited SOARS several times. Gaffney's observations led him and his colleagues to adopt the SOARS model in designing GCEP's Summer Undergraduate Experience program. Other programs across the United States have recognized SOARS as a model and incorporated elements of the SOARS program into their undergraduate internship programs. SOARS is the subject of an NSF-funded study being performed by the Ethnography and Evaluation Research Center to Advance Research and Teaching in the Social Sciences, University of Colorado at Boulder. This study will be completed and a report available in spring of 2005.

In addition, the article, "Significant Opportunities in Atmospheric Research and Science (SOARS â): An Overview of the Program and its First Eight Years," by Thomas L. Windham, Amy J. Stevermer, and Richard A. Anthes was published in the *Bulletin of the American Meteorological Society:* Vol. 85, No. 1, pp. 42–47. The article is available online from the AMS journals online website: http://ams.allenpress.com/pdfserv/i1520-0477-085-01-0042.pdf

NCAR Undergraduate Leadership Workshop

EO hosted the third NCAR Undergraduate Leadership Workshop (ULW) (www.ucar.edu/educ_outreach/ulw) on June 21 – 25 with the purpose of informing undergraduates in the geosciences about exciting opportunities for graduate study, research, and careers in the atmospheric and related sciences. The five-day program established informal dialogue between students and research scientists as they explored laboratories, instrumentation, and computing facilities that support studies on weather, climate, solar physics, the Sun-Earth system, and impacts of weather and climate on societies across the globe. The students were initially presented with a model of leadership and later engaged in activities to stimulate consideration of the qualities of recognized leaders and methods for nurturing their own personal leadership attributes. Throughout the week, scientist shared personal anecdotes with the students highlighting the importance of developing personal and professional leadership skills necessary to succeed in and support the atmospheric sciences in the coming decades. Over the past three years, 23 UCAR member universities and 8 academic affiliates have co-sponsored a total of 64 student participants to the ULW by covering their travel costs, with NCAR providing funding for their lodging, meals, and workshop activities. The vast majority of the students are either planning or are currently engaged in graduate studies. The annual AMS meeting serves as a venue in which they enjoy coming together to meet the most recent “alums” of the ULW and to catch up with each other on recent developments in their studies and career plans.

Professional Educator Workshops

EO disseminates UCAR’s science, mathematics, engineering, and technology to the nation’s K-12 schools by bringing a select and diverse group of geoscience educators to NCAR to learn about our educational resources developed for classroom use. Acceptance to a workshop requires a commitment from each teacher to provide outreach and training to a minimum of 40 other teachers in their school district or region through which they share the new science content and resources accessed and experienced in the summer workshop.

NCAR Geoscience Education Workshop (http://www.ucar.edu/educ_outreach/gew/). The Global and Climate Change Geoscience Education Workshop was held from July 26 to August 6, 2004, enrolling 19 master science teachers of grades 6 through 12 from across the nation. In addition to lectures from scientists on climate topics, teachers explored relevant computer software, web-based resources, and curriculum and inquiry-based activities. They also participated in field trips, received instruction on numerous

hands-on activities and demonstrations of fundamental scientific and pedagogical principles, and engaged in dialogue about how climate change science can be brought into the classroom.

Modeling in the Geosciences Workshop (http://www.ucar.edu/educ_outreach/gew/). Between June 21 to July 2, 2004, EO presented the second workshop on modeling in the geosciences. Teachers selected from a national applicant pool spent two weeks with scientists from the UCAR community, GIS and modeling experts, and EO staff to explore the context of modeling in the geosciences. They used STELLA software to build models and develop applications of these and other tools to enhance classroom practice and student achievement in the sciences, technology, and mathematics. They will provide training for colleagues in their home districts, participate in a fall virtual workshop, and reconvene in Boulder in Spring 2005 to present modeling resources they have developed for implementation in their classrooms.

Collaborations with Scientists in Educational Programs

During 2004, EO wrote letters of thanks to 100 NCAR scientists who volunteered to support various education programs. This represents an exceptional level of interest and collaboration bridging research and education. Scientists participate in EO as content advisors on web sites, exhibits, and curriculum; speakers in workshops and tours; community ambassadors at special events and conferences; and partners in grant proposals.

Research Grants Supporting EO. Examples of EO activities funded by scientists' research proposals include:

- *Sun-Earth Connection Teacher in Residence Program*: Over three years two teachers are funded by a NASA E/PO to work with PI Art Richmond to develop standards-based lessons supporting basic concepts taught in high school physics, chemistry, earth science and astronomy courses.
- *Presentations on Sun-Earth Science for Scientists in K-12 classrooms:* With three years of funding from a NASA E/PO grant (Gang Lu PI), a teacher is developing tips, background information, and inquiry activities and PowerPoint presentations for scientists to use when they visit K-12 classrooms.
- *Global Carbon Cycle Research Laboratory Experiences* - An NSF Biocomplexity grant to ATD's A nalytical Photonics & Optoelectronics Laboratory (APOL) is supporting two high school students and teachers over three summers in hands-on laboratory experiences and the creation of web-based educational content about the Carbon cycle for grades 9 – 12.

HIAPER Education and Outreach Program. NCAR has funded an EO effort to document in High Definition TV film the major milestones in the modification of the new NSF-funded Gulfstream V aircraft known as HIAPER. EO has a goal of bringing the story of how science, technology, engineering, and technology (STEM) interplay in the story of HIAPER to national audiences through educational television programming and exhibit partnerships with major museums across the nation. An ambitious grant writing effort is under way to fund the HIAPER EO program. NCAR's support has enabled EO to contract Geoffrey Haines Stiles, producer of LIVE FROM and PASSPORT TO KNOWLEDGE PBS programs to interview scientists about their vision for HIAPER's contributions to the future of atmospheric and climate research; engineers on the challenges of modifying the aircraft for service to science; technicians who have built the aircraft and applied their skills to follow engineers' instructions; and NSF staff who have advocated for HIAPER's development. These interviewees, some representing diversity in the workforce, offer compelling stories about why people love their STEM careers and what preparation is required for students to enter these fields. Haines-Stiles flew this summer on the C-130's ACME mission to capture the contrasts between the capabilities of this important and long-standing member of the NSF fleet and the new HIAPER aircraft. The HIAPER EO programs will be accompanied with classroom lessons for K-12 students in addition to fascinating web-based information about science campaigns, possibly including access to real time data and discussions with scientists while the aircraft is deployed to the far reaches of the earth on science missions.

Community and Public Services

Informal Science Education and Public Programs

NCAR's public education programs aim to increase the scientific literacy of the nation through numerous efforts reaching the general public, teachers, and students who visit the Mesa Laboratory for a tour or partake in other EO online resources. The focus is on enhancing understanding among all ages about the atmosphere as part of the Earth system, the impact of weather and climate on society, and the application of scientific knowledge to decision making about careers, lifestyles, and public policies. In addition to coordinating exhibits, tours, classroom programs, and public events, the Public Visitor and Exhibits Programs frequently recruit NCAR scientists to demonstrate scientific principles underlying the atmospheric sciences. An estimated 80,000 visitors a year come to the NCAR Mesa Lab to enjoy such activities and the Mesa Lab's science center.

Events and Exhibits

Super Science Saturday. For the eighth consecutive year, EO has been preparing for the its largest, annual public science event, the late October Super Science Saturday which attracts several thousand families and young children to the Mesa Lab. This daylong science celebration features multiple science presentations, demonstrations, and special workshops designed to facilitate understanding of the scientific process and student participation in school science fairs. The theme of this year's SSS event is "Super Cool Science." These programs are funded in part by Friends of UCAR and supported by numerous other science institutions and programs which collaborate to make this a memorable day for the local community.

Wild Science Saturdays . A new collaboration with the Wild Bear Discovery Center and Colorado's Scientific and Cultural Facilities District (SCFD), promoter of science and art literacy in the Boulder County community, has broadened EO's schedule of public events in 2004. Two new *Science Saturdays, "*Nature's Architects" and "Avalanches," and Wild Earth Day*,* a multi-program Earth Day celebration, allowed NCAR to leverage its outstanding reputation in the community for Super Science Saturday (a fall event) to open its doors on winter and spring week-ends to even more students, teachers, and adults.

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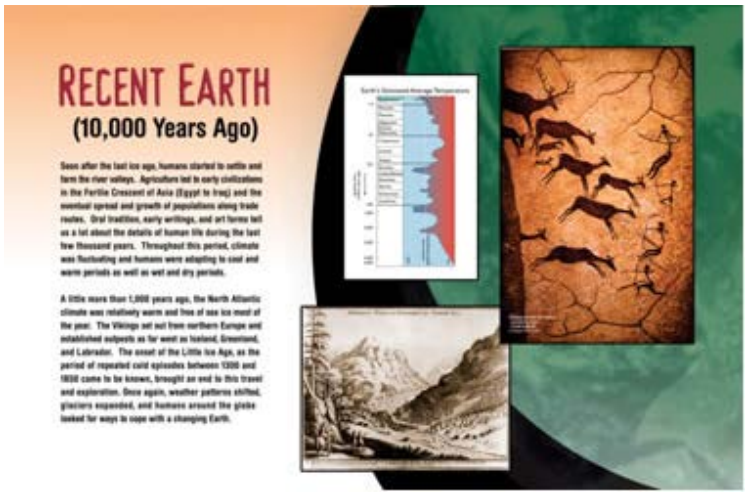
Science Exhibits. This year EO has worked to implement goals in its five-year plan (2002- 2007) for the Mesa Lab Exhibits that includes annual assessment of science content, the replacement and enhancement of current exhibits, and development of new ones. A survey of 50 visitors who completed a questionnaire after viewing the Climate Futures Exhibit in July found that 98% would recommend the exhibit to friends or family members. A scientific advisory group with representation from all NCAR divisions advises the Exhibits Program as it implements the plan. With support from NCAR's Strategic Initiative fund, a number of the plan's recommendations have been accomplished this year. Development of "Climate Future," the final gallery of NCAR's new, multi-media exhibit on climate and climate change, has been the central focus of discussion. The new exhibit component will feature in-depth information about climate change research and the impacts and responses anticipated under several model scenarios for future global climate change. A GI projection sphere will display NCAR climate models and a plasma display will highlight NCAR researchers' perspectives on the challenge of studying and predicting Earth's future climate. Plans are to obtain public feedback and suggestions on a prototype exhibit and install the "Climate Future" exhibit in early 2005.

Multiple updates of "Climate Now" and "Climate Past" exhibit content and components have been completed. A slideshow on meteorological optics has been added to the upgraded ML Theater exhibit, and a new exhibit, "Real-time Lighting," which displays Unidata's lightning site on a large plasma, was installed this spring. The Exhibits Program is working closely with scientists and other EO staff to develop a teacher's guide to the Climate Discovery exhibit for which several units have been drafted and will be revised for publication in 2005 with support from Friends of UCAR.



Art Exhibits. The community art program is facilitating the displays of 18 exhibitions a year in the two galleries of the NCAR cafeteria. In December 2003, a highly successful special exhibition of artwork by staff artists or their family members was presented. In the month of April 2004, special invitational murals by Boulder Valley School District and the St Vrain Valley School District K-12 classes graced the walls of the Mesa Lab as a part of NCAR's *Wild Earth Day* activities.

Education and Tour Program

Over the past year, visitors have returned to the beautifully refurbished Mesa Lab, which required a 6-month closure and interruption of public programs in the previous year. The estimated 80,000 people who visited the Mesa Lab, included approximately 12,000 students and 3,000 adults who were scheduled for tours, and several thousand more took advantage of the new audiotour program.

Module Development. EO staff have implemented seven new interactive/multimedia modules which PVP staff now use to format the visits of K-12 school groups. These resources augment the range of students' inquiry-based classroom learning experiences and are compatible with state and national science education content standards. Modules developed in 2004 include:

- Wild Weather: Hurricanes
- Wild Weather: Thunderstorms
- Convection Connection
- Computer Modeling and Scientific Visualizations
- In a New Light: The Color of Weather and Climate
- Water and Weather – The Two Go Together
- What's the Difference? Weather and Climate

Resource Dissemination. Beyond dissemination within UCAR and on the web, the new educational units are now regularly presented at local (University of Colorado

Water Festival), state (Colorado Science Convention), and national (National Science Teachers Association) teachers' conferences. A workshop entitled *Climate Change - In a New Light* was presented to middle-school educators at the National Science Teachers Association conference in Atlanta. *Water and Weather* was presented at the 2004 CU Water Festival, which hosts 700 fifth-grade students. *What's the Difference? Weather and Climate* will be presented in early October as a Saturday workshop for Northern Colorado Jr. Girl Scouts with collaboration of NCAR female scientists and post-docs. Additional educational involvements of PVP staff include attendance and presentations at high school career fairs, science fairs, and school community assemblies. Staff also look forward to training in Unidata's IDV and Gempack programs, as well as GIS, and subsequent inclusion of such resources in future modules. Global Imagination, Inc.'s "Magic Planet," a large sphere that projects Earth and space science visualizations purchased in 2004 with funds from Friends of UCAR now helps PVP staff visually convey Earth system science to the general public. In addition, staff frequently share NCAR visualizations within the SCD Visualization Laboratory and work with SCD staff to ensure scientifically accurate content for these presentations which must be adapted for audiences from difference ages, interests, and backgrounds.

Staff Development. The professional development and networking of PVP staff continues to be a priority. One was selected as a participant in an 18-month professional development program for museum-based educators, which is offered by the NSF-funded Center for Informal Learning (CILS). Emphasis is on the policies, research, and learning theories driving science education reform, while creating a community of educators that cross-institutional lines, including museums, school districts, universities, and policy communities. Our other staff educator has completed a professional credentialing program for NCAR science content with the National Association for Interpretation.

Audiotour. Summer 2004 represents the first-year anniversary of the Mesa Lab audiotour, which exists in two versions, one for adults, and one for children. This significant lobby resource was made possible by funding from the National Science Foundation's Geoscience Education Program and from Friends of UCAR, which contributed funds for the audiotour's Spanish translations. Between July 2003 and September 2004, nearly 2700 individuals and families (1,967 adults and 695 children) chose this as their primary way to learn about UCAR and to experience the exhibits. The audiotour narrations have also provided us with the opportunity to address a long-observed need of many visitors for whom English proficiency is limited. The scripts of the audiotour have been adapted as paper translations for use by visitors who may prefer Spanish, German, Italian, French, Chinese, or Japanese wording to English. EO staff continue to seek new ways to extend atmospheric science education to area children who comprise a

significant Spanish-speaking population. We are currently in the process of carrying out a series of after school workshops in which bilingual educators learn how to disseminate the availability of the audiotour's Spanish translations to families in their schools, as well as the Spanish translation of the "Windows to the Universe" website in classroom use.

Community Outreach. Unique PVP activities that welcome adults with both science and nonscience backgrounds have continued. Examples include arranging a several-day visit for staff from SENAMHI, Peru's National Meteorological and Hydrological Service; helping a legislative aide to the French National Assembly establish a contact with UCAR staff; creating a two-day visit for University of Arizona graduate students to interact with NCAR scientists; and running the annual Rocky Mountain Weather and Climate Workshop with NOAA and Colorado State University's Colorado Climate Center staff for volunteer weather observers.

Spanish bi-lingual science education resources available through UCAR were highlighted in September in an after-school workshop for bilingual educators. A model for future workshops, it focused on sharing information about the recently developed and NSF-supported audiotour, as well as the Spanish translation of the "Windows to the Universe" website (see below). The workshops will provide opportunities for educators to tour the exhibit and experience the audiotour, obtain training about on-line resources and activities available through the Windows to the Universe project, and gain information about related programs available through UCAR.

Web-based Resources

NCAR EO Web Site

Close collaboration of UCAR-EO with the institution-wide WORD committee has resulted in smooth integration of the new NCAR/UCAR umbrella web site with the NCAR Education and Outreach web site (www.ucar.edu/eo), which has been developed by UCAR-EO staff with support from the NCAR Strategic Initiative. Visitors can now easily navigate to educational resources for public visitors, children, K-12

teachers, science enthusiasts, and undergraduate to graduate students by clicking on a conspicuous Education “tab” on the umbrella site’s home page. New pages in the *Kids Crossing* section of the NCAR EO web site entitled “Water Water Everywhere” and “Living in the Greenhouse” offer children in upper elementary through middle school grades with a wealth of whimsical, didactic explanations and diagrams about the water cycle, climate, and climate change. “Watch Out for Dangerous Weather!” provides young visitors with stories about dramatic weather events and information about the causes of thunderstorms, tornadoes, blizzards, and hurricanes. Resources for those seeking work and educational opportunities in the atmospheric and related sciences will soon be updated and unveiled. Members of the public who wish to know more about tours and exhibits can easily access information they need for planning a visit and scheduling a guided or audiotour at the Mesa Lab.

Windows to the Universe

The home page for Windows to the Universe Web (W2U) site (www.windows.ucar.edu) has been redesigned in 2004 to facilitate more efficient navigation to its immense content areas spanning the Earth and space science, with arts and humanities connections, through the use of new color schemes, page headers, and navigation toolbar. One half of the web site including information about all of the planets has been translated into Spanish, and user logs indicate that ~20 percent of site traffic (roughly 7,200 visitors per day) is going to Spanish pages. Outreach to the local Spanish speaking community and bilingual educators has produced excitement about this

new resource. We are now developing plans to collaborate with educators to support them in their use of W2U in formal and informal settings. NCAR SI funding has enabled a major push to develop and expand a section of the website on Climate and Global Change. Content about space weather has been consolidated, revised, and expanded, especially with a focus on a new audience, students in undergraduate survey courses. An exciting new interface has been developed to allow scientists at NCAR and around the world to collaborate with W2U staff on the development of new content. During the 2004 calendar year, we anticipate serving ~6 million users from around the world with our educational resources through W2U.

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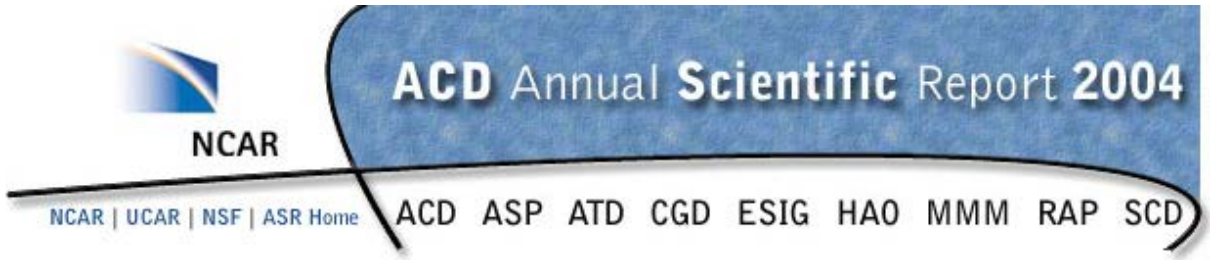

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Director's Message

Sue M. Schauffler, Deputy Director and Daniel S. McKenna, Division Director

It has been another busy year for ACD personnel and I would like to take this opportunity to thank all staff for their dedication and hard work over the year. Aligned with and supportive of the NCAR mission, ACD's mission is to understand the role of chemistry in the atmosphere and related components of the Earth system, to lead and support community endeavors in advancing scientific understanding of atmospheric chemistry, to make unbiased information in support of decision-making processes available to society, to engage society in the science behind atmospheric chemistry, and to help train the next generation of atmospheric scientists. In fiscal year 2004, ACD has made contributions in each element of this mission.

As in previous years, ACD has been involved in a number of community field campaigns supported by NSF, NASA, and other agencies. These campaigns have ranged from the Arctic lands of Greenland to the South Pole, from Tropical rain forests to downwind of urban centers in the U.S. Notable among these was the ACD leadership of the Antarctic Tropospheric Chemistry Investigation (ANTCI), funded by a grant provided by the National Science Foundation's Office of Polar Programs, and of the Chemical Emission, Loss, Transformation and Interaction within Canopies in New England (CELTIC-NE)

experiment. ACD has begun preparations to lead a major community field deployment near Mexico City involving several agencies and NSF-supported university groups in early 2006; the first Megacity Impacts on Regional and Global Environments (MIRAGE) experiment will focus on the outflow and atmospheric fate of pollution from Mexico City and will combine airborne, satellite, and ground-based measurement programs. This research activity is particularly suited to ACD, as it integrates these varied ACD measurement capabilities with regional and global modeling. As we move into a new century where the human population is predicted to shift from predominantly rural to urban dwelling, the urbanization of the atmosphere will continue, making the role of megacities increasingly important to the understanding of climate change and air quality impacts. This program is important to NCAR as it integrates such diverse scientific topics as land-use change, economics, human health, urbanization, global change, and climate variability. ACD has begun and will continue to invest in instrument development, pre-deployment and deployment support of MIRAGE, and model development and simulations. The Weather Research and Forecast (WRF) model with interactive chemistry (WRF-Chem) has been implemented with typical dry season emissions in Mexico City and is being used to plan ground-site positions and aircraft flight paths.

Another important scientific activity in ACD involves the study of the upper troposphere and lower stratosphere, which will become increasingly relevant with the availability of the NSF G-V to reach the mid-latitude lower stratosphere and the Tropical transition layer. ACD is preparing for this by contributing to the construction of a suite of chemical sensors, and ACD scientists are developing concepts for future G-V deployments, including collection and analysis of in situ and remotely- sensed measurements of the atmospheric layers near the tropopause. Additionally, ACD scientists are performing simulations of the chemistry and dynamics of this region with several numerical models, including WACCM (the Whole Atmosphere Community Climate Model) and WRF. In addition, development of global tropospheric chemical modeling continues. A version of the Model for Ozone and Related Chemical Tracers (MOZART) Chemistry Transport Model (CTM), with an updated and expanded chemical reaction scheme and a multi-component aerosol code, has recently been released to the community. MOZART-4 will now be frozen and future CTM development will continue within the framework of a new CTM, combining the best elements of MOZART and the Climate and Global Dynamics Division (CGD) CTM Model for Atmospheric Chemistry and Transport (MATCH). The new Community Atmosphere Model (CAM)-Chem is fully compliant with NCAR's CCSM (Community Climate System Model) coding requirements and is capable of being run in off-line mode with either climate model or re-analysis datasets.

The Aura satellite was successfully launched in 2004, carrying the HIRDLS (High-Resolution Dynamics Limb Sounder) instrument developed collaboratively by ACD, the University of Colorado, and the University of Oxford, with joint NASA and U.K. funding. The launch was the culmination of more than a decade of dedicated work by the HIRDLS team which prepared a thoroughly-calibrated instrument and state-of-the-art data processing algorithms. Soon after launch, anomalous radiances were observed by the instrument detectors; the source and correction of these anomalous radiances is still under investigation. ACD and the community await final resolution of this anomaly and have high hopes for a successful HIRDLS science program.

Particularly noteworthy among an array of impressive results this year include observation of emissions from biomass burning events encountered over Amazonia that far exceed conventional model emission inventories. ACD scientists have also been investigating

anomalous chemistry at the South Pole, and, in particular, the unique observation of changes in fast photochemical radical chemistry during the time of a solar eclipse.

Change continues to be the only constant of the research landscape and ACD staff have adapted and remained flexible in the face of uncertainty. However, with change come new opportunities, most significantly, the new laboratory office facility for ACD and the new NSF research aircraft.

An ACD landmark occurred in the fall of 2004: the ground-breaking for the new, custom-built chemistry laboratory to house ACD experimental, remote sensing, and modeling activities, which will reunite ACD staff for the first time since 1990. This 21st-century building will implement modern laboratory safety protocols and equipment, including state-of-the-art air handling. These considerations will improve efficiency and enable enhanced scientific interactions, provide improved opportunities for community collaborations both within the laboratory setting and more generally, and will help the new building (FL0) become a hub for interdisciplinary science at NCAR. All ACD staff have had many opportunities to review and provide input to the draft plans for the new facility. This process has led to a design that will enhance both laboratory and office functions, which in turn improves staff investment.

Another significant landmark is expected in the next few weeks, when a modified Gulfstream-V (G-V) research aircraft will be delivered to NCAR. ACD scientists and research engineers are building several state-of-the-science community instruments to be deployed on the G-V. This work is supported through a combination of special funding from NSF and the NCAR Director, augmented with ACD core funds. Additionally, ACD scientists will assist NCAR's Earth Observing Laboratory (EOL) in the management of several chemistry instruments being developed in the community.

And, finally, in 2004 NCAR has reorganized at two levels, creating three new interdisciplinary institutes and organizing existing divisions into five interdisciplinary laboratories. The new institutes are the Institute for Mathematics Applied to Geosciences (IMAGe), the Institute for the Study of Society and Environment (ISSE), and The Institute for Multidisciplinary Earth Studies (TIMES). ACD scientists contribute significantly to the scientific program of TIMES through support of the Biogeosciences and Wildfire initiatives.

NCAR's reorganization into five laboratories will more closely align the organizational structure with components of the NCAR mission. ACD, along with NCAR's Mesoscale & Microscale Meteorology (MMM) Division, High Altitude Observatory (HAO) Division, CGD, and TIMES, collectively comprise the Earth and Sun Systems Laboratory (ESSL). The intent of this new laboratory is to increase the affinities between the disciplinary activities represented by the NCAR divisions, and to enable integrative science to arise and be more easily fostered. This will be achieved by reducing the administrative barriers to divisional interactions. This will occur under guidance by the Division Directors, who will operate under the leadership of the Laboratory Associate Directors, who, in turn, will have a special role in promoting affinities between the laboratories via their service on the NCAR Executive Committee.

ACD is well-poised to take scientific advantage of this new configuration. The WACCM model provides a bridge between ACD, HAO, and CGD. This new structure will enable ACD to work more effectively with MMM on WRF, and ACD has already forged strong links to TIMES through participation in the Wildfire and Biogeosciences Initiatives. Meanwhile, ACD will continue to strengthen ties to the new Earth Observing Laboratory

(EOL) through support of community instrumentation and field campaigns and will explore opportunities to study environmental and societal impacts of atmospheric composition changes through collaborations with the Institute for the Study of Society and Environment (ISSE). More information on NCAR's re-organization may be found at www.ncar.ucar.edu/directorate/Reorg/.

As we look ahead and plan for the future, this Annual Scientific Report reflects the commitment, energy, and accomplishments of all ACD staff during this past fiscal year. We are pleased to play important roles in the reorganized NCAR.

I invite you to read this report, and, if you have any questions or comments, please contact me, Daniel McKenna, or any of our scientific or administrative staff.

Yours sincerely,

Daniel McKenna

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Executive Summary

Regional and Global Air Quality

Chemistry in the Climate System

Summary

A major portion of ACD's mission is to understand the chemical composition of the atmosphere, the processes that modify and control the composition, and potential changes that may result from natural and human induced forcings. Another important aspect of ACD's mission is development of new measurement capabilities and methodologies, development and application of numerical models, and the planning and execution of complex field experiments. The Division fulfills its mission through collaborative efforts with colleagues from the university, government, and international communities to measure atmospheric chemical composition and controlling processes from satellite, airborne, and ground-based platforms and to examine those measurements synergistically with laboratory studies and modeling efforts.

I. Regional and Global Air Quality

The main goal for this area of study is to understand and quantify the impact of urban emissions on air quality. Priority is given to studying the large-scale impacts of intense emissions originating from megacities, and the multiphase (gas-aerosol-cloud) processes that transform pollutants in the atmosphere.

A. Influence of Urban Pollution on Regional and Global Air Quality (Influence of Urban Emissions on Atmospheric Composition)

The ACD MIRAGE science team submitted a science plan to NSF and a proposal to OFAP requesting deployment of the C-130 to Mexico City. In anticipation of MIRAGE-Mex, preliminary modeling with WRF-Chem to study the interaction of urban outflow plume with the surrounding region found that this interaction leads to more regional O_3 production than would be expected from three sources (urban, biogenic, and biomass burning) taken in isolation (Figure 15; all figures in this Executive Summary correspond to the same figure numbers found in the "ACD Achievements" section of this 2004 ACD Annual Science Report). Several ACD scientists participated in field campaigns that are complementary to MIRAGE. Preliminary results of ozone, NOx, and peroxyacetyl nitrate (PAN) measurements collected downwind from New York City during the NOAA New England Air Quality Study (NEAQS) in the summer showed a significant degree of structure, likely due to air masses of different photochemical age and different initial pollution levels, and an excellent correlation down to the fine time scale of seconds between ozone and PAN as a result of photochemical activity (Figure 13). These ACD PAN measurements are the first reliable high temporal resolution measurements made from an aircraft and the instrument will be available for MIRAGE-Mex. Emissions from fires as well as urban areas may impact regional as well as global air quality. The MOPITT science team measured an unusual increase in CO levels in late 2002 and early 2003 that affected the entire Northern Hemisphere. Further investigation indicated a Russian source: massive peat fires smoldered near Moscow in the late summer and fall of 2002, and unusually intense Siberian wildfires in the spring and summer of 2003. Finally, an analysis of Total Ozone Mapping Spectrometer (TOMS) satellite data showed a significant increase in tropospheric aerosols over China and India during 1980-2000 (Figure 37). These increases were expected, due to large increases in population and SO_2 emissions (converted to sulfate aerosols) in China and India, but this was the first study to quantify the changes based on satellite observations.

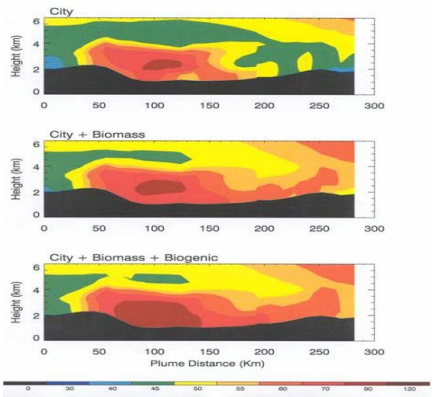
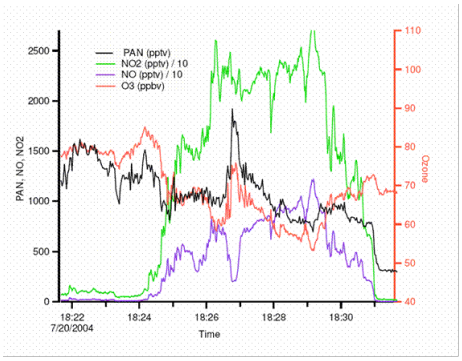


Figure 15: Ozone (O_3) concentrations simulated with the WRF-Chem model, showing the interaction between the Mexico City pollution plume with regional biomass burning and biogenic emissions. Upper panel shows the O_3 resulting from urban emission only. Middle panel includes effects adding biomass burning emissions, which contribute NOx in the NOx-limited regime (far-field, ca. 200-300 km). Lower panel adds biogenic emissions, which contribute hydrocarbons in the hydrocarbons-limited regime (near-field, 50-150 km).

Figure 13: Preliminary data from the 7/20/2004 flight through the



NY City Plume, ~120 km downwind, ~1 km altitude, during the ICARTT program.

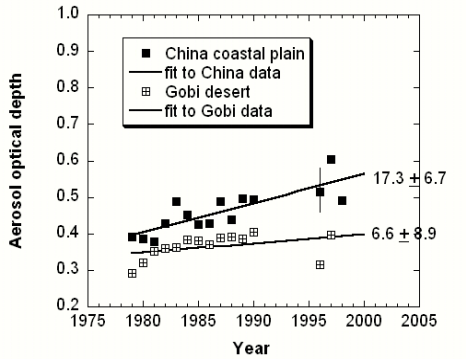


Figure 37: Winter averages of TOMS total aerosol optical depths, averaged for consecutive months from November through February for the China coastal plain and the Gobi desert. Aerosols over the Gobi desert are mainly due to desert dust, while aerosols over the coastal plain have a large contribution from sulfate. Linear fits and decadal trends are indicated.

Additional achievements include:

1. Continued development and improvements were made to several ACD instruments, including the PAN CIMS instrument, the actinic flux spectroradiometer, the laser spectrometer for measurement of CO2 isotopic ratios, and the TDLAS and DFG instruments for measurement of formaldehyde.

2. The MOPITT science team completed a study on the CO budget over Europe using MOPITT CO measurements, ground based data, and simulations from MOZART. The results showed that, on average, the majority of surface contributions to the anthropogenic CO load were from regional sources with a significant contribution from North America and Asia. With altitude the influence of CO from other continents gained in importance with Asian emission showing the highest contributions during most months and at most altitudes.

3. A steady state photochemical model reproduced observed peroxy radical concentrations during the NASA TRACE-P campaign except during encounters with clouds or air masses with high aerosol surface density and when NO mixing ratios were very high. These results provide indirect evidence for heterogeneous update of radicals by clouds and aerosols and also imply missing or misrepresented processes involving high levels of NO.

B. Reactive Carbon Research

Reactive carbon research involves the study of a number of complex chemical, physical,

and biological processes that control the surface emissions of these species, their chemical transformations in the atmosphere (in both gas and condensed phases), and their eventual removal from the atmosphere via deposition. Collaborative studies that include ACD measurements of isoprene nitrate, suggest that this compound, which has not been considered in the past, may play a role in sequestering atmospheric NOx and may serve as a source of nitrogen for nitrogen-limited forests. The study concludes that isoprene nitrates should be measured as part of future field campaigns to adequately determine their impact on nitrogen cycling.

Additional achievements include:

1. Distributions of oxygenated VOCs in the Pacific during springtime and their relationships to tracer species such as CO, acetonitrile, and methyl chloride, are being investigated with respect to source relationships. These compounds are important because of their potential role in HOX chemistry and in secondary organic aerosol formation.

2. The TDCIMS instrument for characterizing organic compounds in ultrafine aerosol has undergone several improvements over the past year and was successfully tested over a several months at NCAR and at the Marshall Test site. Plots of particle size distributions may be found at http://acd.ucar.edu/~jimsmith/POP/ under Field Activities.

3. Laboratory studies examined oxidation pathways for alkyl iodides, nitrate production from toluene oxidation, and oxidation mechanisms of methyl formate and methyl acetate. Understanding these reactions is a necessary aspect of understanding the details of photochemistry in a given region.

C. Multiphase Processes in the Troposphere

Multiphase processes are an important, but not well understood, part of atmospheric chemical processes. Multiphase processes include aerosol formation and growth, interactions between clouds (aqueous and ice), aerosols, and chemical species, and photochemical processing in snow. In order to determine if ion inducted nucleation has a role in the formation of new atmospheric particles, ACD scientists have developed an instrument for measuring very low concentrations of ion clusters that would be expected to be present in the atmosphere. These ions were observed and studied this past summer at the NCAR Marshall field site. The results are still being analyzed but appear to be supportive of an ion-inducted nucleation model recently developed by colleagues at the NOAA Aeronomy Laboratory. ACD and MMM scientists implemented a simple gas and aqueous-phase chemistry mechanism into the WRF model to begin investigations on the effect of convection on the chemical environment. Initial results show redistribution of CO and formaldehyde (CH2O) from convective transport (Figure 22). A nearly total solar eclipse occurred during the NSF sponsored Antarctic Tropospheric Chemistry Investigation (ANTCI), which was designed to study photochemical processing across the polar plateau. Since the sun height normally changed little during the study period, the eclipse was a rather unique opportunity to observe changes in photochemically-generated compounds with nearly an order of magnitude change in UV light as shown in Figure 28.

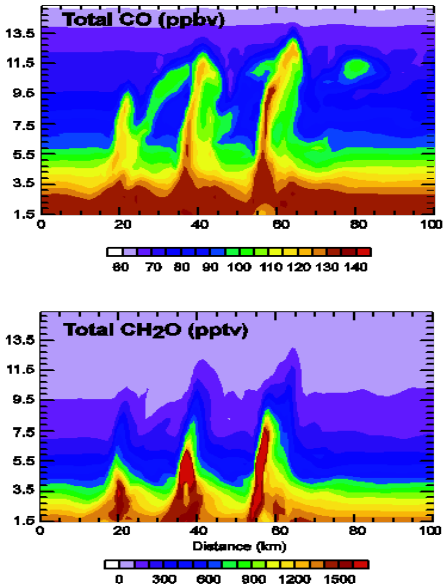


Figure 22: Cross-section of the total (gas + cloud water + rain + ice + snow + hail) mixing ratio of carbon monoxide (CO) and of formaldehyde (CH_2O). Both species are found in high concentration near the surface and lower concentration above the boundary layer. Carbon monoxide, an insoluble species, is primarily transported to the upper troposphere, while CH_2O, a soluble and reactive species, has a fraction reacted or precipitated to the ground.

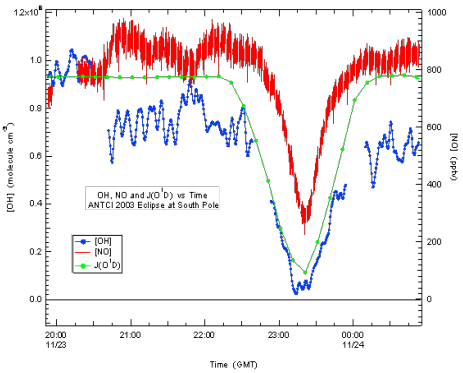


Figure 28: Some interesting South Pole boundary layer photochemistry observed during the near total solar eclipse that occurred on November 23, 2003. Since the sun only sets and rises once a year at the South Pole, this unique and rapid photochemical transient will be the basis for a modeling case study.

Additional achievements include:

1. Differences in depth profiles among various VOCs are being analyzed to characterize consumption and production processes in the snowpack at Niwot Ridge in order to quantify emissions.

2. An intercomparison study for convective cloud chemistry models was conducted as part of the 6th International Cloud Modeling Workshop, Cloud Chemistry Case. The intercomparison case focused on the 10 July 1996 STERAO storm for which observations of carbon monoxide, ozone, and nitrogen oxides (NO_x) were available. Initial results showed passive tracer transport was similar among the models and agreed fairly well with observations. The intercomparison of NO_x produced from lightning and of the soluble species is currently being pursued.

3. The NCAR large-eddy simulation (LES) was coupled with gas and aqueous chemistry by ACD and MMM scientists and used to determine that cloud chemistry has a significant impact on the distribution of OH and isoprene, which are two species involved in ozone production.

II. Chemistry in the Climate System

Atmospheric chemistry and transport are key factors in determining the abundance and distribution of trace gases and aerosols that determine the Earth's radiation budget and climate. We are evaluating this system through model development and simulations of various climate states. In addition, we are conducting focused studies of biogenic emissions on a broad range of spatial scales from leaf, plant, and canopy scales, through to regional scales. Finally, we are investigating chemical and transport characteristics that influence the distributions of radiatively important trace gases in the UTLS and middle atmosphere.

A. Climate Simulations

Model simulations and data analysis of ozonesondes have shown that the interannual variability of ozone during the Northern Hemisphere springtime is strongly related to the phase of the North Atlantic Oscillation (NAO). Simulated ozone fields from MOZART covering the time period 1890 to 1990 were used in CCSM simulations of the 20th century climate for the next IPCC Assessment.

Additional achievements include:

1. An offline-transport version of the Community Atmosphere Model (CAM) was successfully developed. This model imports meteorological fields from other sources (e.g., NCEP, ECMWF) into the CAM model, which provides the opportunity to simulate the transport and chemistry of trace constituents using meteorological analysis.

2. Interactive chemistry has been implemented from the MOZART model into CAM3 using the WACCM framework. The radiative coupling is done through the ozone distribution and the aerosol distributions.

3. The MOZART model was updated with improved chemical mechanisms, reaction rates, emissions, and aerosol parameterizations. The new version is MOZART-4 and will be included in the online and offline CAM with chemistry.

B. Biogeochemical Cycles

Biogeochemical studies in ACD are focused on the role of biosphere-atmosphere interactions in the Earth system and predictions of the response to human perturbations. We are conducting multidisciplinary field, laboratory and modeling studies of the processes controlling these interactions on various scales.

Laboratory based biomass burning studies demonstrated that oxygenated volatile organic compounds (VOC) and nitrogen compound emissions from fires are higher than most

previous estimates and likely have an important role in fire dynamics (i.e., fuel ignitability) and regional air quality. The Chemistry And Production Of Smoke (CAPOS) study in the Brazilian Amazon used airborne and ground measurements to characterize the primary emission composition of VOCs and other gases from tropical fires and within aging plumes. The aircraft observations generally confirmed the emission profiles measured in the laboratory studies as shown in Figure 32. Results from the Chemical Emissions, Losses, Transformations and Interactions with Canopies (CELTIC) study indicate that isoprene emission increases with elevated ozone and, on a canopy scale, with elevated CO_2. Future changes in ozone and CO_2 could thus change regional isoprene emission rates leading to feedbacks. Global modeling studies showed that uncertainties in biogenic VOC emissions are a significant contributor to the total uncertainty associated with estimates of global radiative forcing of aerosols. Also, climate and land cover-driven changes in biogenic VOC emissions impacted simulated regional surface ozone concentrations by as much as -30% to 50% under certain emission and climate scenarios. A biogenic VOC model was integrated into the NCAR Community Climate System Model [CCSM] Land Surface Model [LSM] and simulation results showed that biogenic VOC emissions were sensitive to climate, and the estimated interannual variability exceeded 10% of the estimated annual anthropogenic emission estimates used for the IPCC emission scenarios.

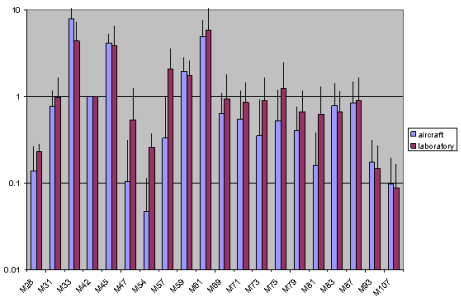


Figure 32: Comparison of emission profiles of identified compounds obtained by the PTRMS instrument between laboratory experiments (average of 30 experiments) conducted at the USFS fire lab in October 2003 and airborne measurements (35 samples from 10 fires) in 2004. All data are normalized to the biomass burning marker acetonitrile.

Additional achievements include:

1. Laboratory studies have shown that isoprene emission recovers relatively quickly from drought, sesquiterpene emission rates from some important tree species are comparable to monoterpene emission rates and exhibit similar temperature dependence, and methanol emission rates were observed to vary across and within plant species by at least an order of magnitude.

2. Measurements of trace gas fluxes over a Colorado grassland showed that the grassland was a significant source of methanol and a sink for acetic acid and methyl acetate.

3. Development of a regional air quality monitoring system and emission scenarios was initiated to study the impact of future climate and land cover on regional air quality in the Pacific Northwest and north central U.S. Biogenic and fire emission models and databases were developed for the scientific and air quality regulatory communities.

C. Integrated Study of Dynamics, Chemistry, Clouds, and Radiation of the Upper Troposphere and Lower

Stratosphere (UTLS)

The upper troposphere and lower stratosphere (UTLS) is a region where ozone is an effective greenhouse gas, and where water vapor, cirrus clouds, and aerosols each make a significant contribution to the radiation budget. ACD scientists are involved in studying various aspects of transport and chemistry that influence the distributions of these gases in the UTLS as well as developing models and instruments to support these studies.

Results from high vertical resolution temperature profiles derived from GPS radio occultation measurements demonstrated that the global-scale Kelvin waves are directly forced by transient deep convection over Indonesia. Furthermore, the Kelvin waves show strong coupling to the background winds. Chemical tracer distributions and correlations from aircraft measurements and model output were used to quantify mixing of stratosphere and troposphere air near the subtropical jet as shown in Figures 36 and 39. An analysis of Total Ozone Mapping Spectrometer (TOMS) satellite data showed a significant increase in tropospheric aerosols over China and India during 1980-2000. These increases were expected, due to large increases in population and SO_2 emissions (converted to sulfate aerosols) in China and India, but this was the first study to quantify the changes based on satellite observations. Transport characteristics of the Asian monsoon complex and impacts on the upper troposphere and lower stratosphere were examined using observations from aircraft and global chemical and climate models. Modeled fluxes of water vapor indicate that the Asian Monsoon circulation may contribute 75% of the total net upward water vapor flux in the Tropics at tropopause levels from July to September. Some of this air may enter the tropical stratosphere and bypass the tropical tropopause altogether. In situ measurements during the NASA CRYSTAL-FACE campaign revealed an unusual circumstance of near-zero mixing ratios of gas-phase HNO_3, in the absence of ice particles, at and just above the tropical tropopause. This removal was interpreted as HNO_3 uptake on sulfate aerosols in an ice-supersaturated environment, which may have significance for the subsequent evolution of the reactive nitrogen balance in the air mass, as well as for the potential role of these aerosols as sites for ice nucleation in subsequent cirrus cloud formation.

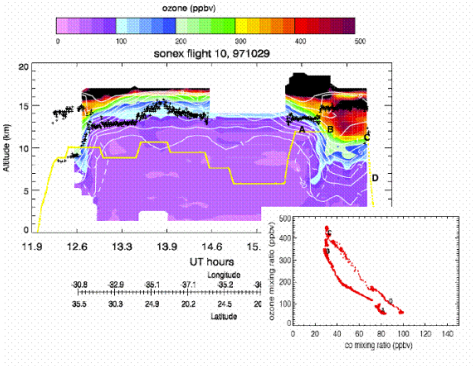
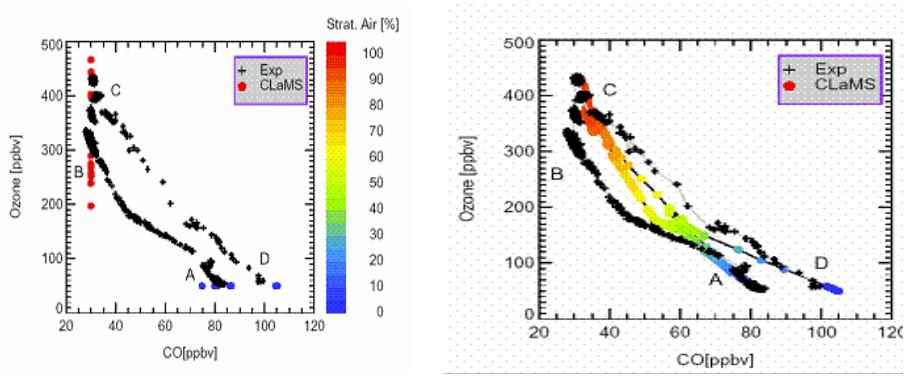


Figure 36: Color image shows the NASA Langley LIDAR measurements of ozone onboard NASA DC-8 research aircraft, October 29, 1997, during the SONEX campaign. The black dots are the thermal tropopause as measured by the Microwave Temperature Profiler. The ozone measurements show an intrusion of stratospheric air into the troposphere near the right edge of the image. The inset shows a scatter plot of CO-O_3 measurements near the intrusion, provided along the aircraft flight track. The letters A, B, C, and D indicate the measurement locations for the “mixing line.”

Figure 39: CLaMS simulation of mixing in the vicinity of the subtropical jet (color points), compared with observations (black points, from DA Figure 2). The colors denote the fraction



of stratospheric air in each parcel. The left panel shows a simulation with mixing, and the right panel is a simulation with no mixing.

Additional achievements include:

1. ACD scientists coauthored a SPARC-IGAC white paper describing Chemistry Climate Interactions, which will form the basis for joint scientific activities during the next decade.

2. An idealized model of the TTL was used to simulate the distribution of water isotopes, which were compared against observations from in-situ aircraft measurements. The model reproduced the range of isotopic depletions observed in the data and suggested the importance of detrained ice in the TTL, as hypothesized from previous work.

3. Several instruments will be built by ACD staff for community use on the HIAPER GV aircraft. These include the Trace Organic Gas Analyzer (TOGA), HIAPER Radiation Package (HARP), NO/NOy and O3. Additional ACD instruments that will be built for HIAPER include OH and FTIR instruments.

D. Middle Atmosphere Science

The HIRDLS (HIgh Resolution Dynamics Limb Sounder) instrument is onboard NASA's AURA satellite, which was launched from Vandenberg AFB on a Delta II booster at 3:02 a.m. on Thursday, July 15, 2004 (Figure 54). Quantities to be measured by HIRDLS include temperature, ozone, water vapor, methane, nitrous oxide, nitrogen dioxide, dinitrogen pentoxide, nitric acid, CFC 11 & 12, chlorine nitrate and aerosol properties.

Figure 54: (Credit and copyright: Brian Lockett, Goleta Air & Space Museum) NASA's AURA satellite launched from Vandenberg AFB at 3:02 A.M on Thursday, July 15. It will examine the Earth's atmosphere in unprecedented detail.

WACCM/MOZART-3 simulations were compared with satellite and ground-based observations of temperature and water vapor. Model results were generally in good

agreement with HALOE observations (1992-2002), both for temperature and water vapor. WACCM tended to underestimate temperature trends only in the upper stratosphere; this discrepancy appears to be related to an underestimate of ozone in that region (Figure 51).

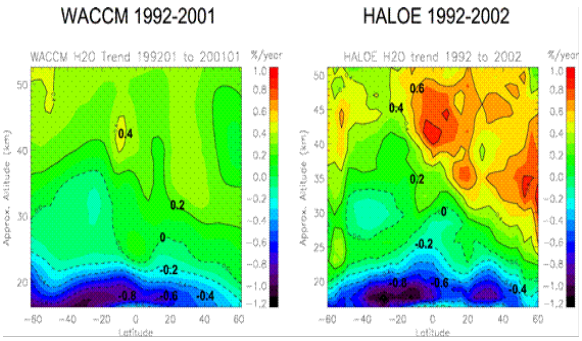


Figure 51: Comparison of WACCM vs. HALOE trends in water vapor. WACCM reproduces HALOE trends in the lower and middle stratosphere. HALOE trends are larger in the upper stratosphere, especially in the northern hemisphere.

WACCM was used to study the response of the middle atmosphere to ENSO. The results show zonal mean anomalies associated with ENSO are significant in early and late winter in the middle atmosphere. A chemical/transport simulation was carried out using output from the WACCM run and showed that when the lower stratosphere is colder (as during La Niña events), some ozone depletion takes place in Northern Hemisphere winter. Conversely, when the lower stratosphere is warmer and more disturbed, as is the case during El Niño events, heterogeneous chemical processes are inhibited.

Additional achievements include:

1. Additional studies with WACCM included stratospheric influence on seasonal cycles of tropospheric tracers, parameterization of gravity wave fluxes due to convective excitation, and stratosphere-troposphere coupling associated with the monsoon circulations.

2. A comprehensive study of the 6-hour tidal oscillation in the middle atmosphere found that this tidal frequency is a persistent feature of the variability in winds at the Esrange radar station (Sweden). The prediction gives largest amplitudes at high latitudes and indicates that the tide at a given site is composed of migrating and nonmigrating contributions.

3. Numerical model simulations were used to interpret observations of hydroxyl airglow made by the SABER instrument on the TIMED satellite. Results indicate that variations in the airglow are strongly affected by the diurnal tide.

ACD Achievements

Overview

Regional and Global Air Quality

Influence of Urban Pollution on Regional and Global Air Quality (Influence of Urban Emissions on Atmospheric Composition)

Community Involvement and C-130 Deployment (Megacity Impacts on Regional and Global Environments [MIRAGE] Planning)

Instrument Development

- Improvements to PeRCIMS instrument
- Peroxyacyl Nitrates (PAN) instrument
- Actinic flux Spectroradiometer
- Analytical Photonics & Optoelectronics Laboratory (APOL) Technology Development in Airborne Observing Systems and Chemical Sensor Systems
  - Continued Development of a New Laser Spectrometer for High Precision Measurements of $^{13}CO_2/^{12}CO_2$ Isotopic Ratios
  - Continued Development of New High Performance Airborne DFG Instrument for the Measurement of CH_2O
  - Continued Improvements to Present Airborne TDLAS System Hardware and Software

Community Instruments, Measurement, and Science Support

- Chemistry Community Instruments
- MSI Group measurement support
- Managing the National Science Foundation Atmospheric Chemistry Program

Field Campaigns Complementary to MIRAGE

- International Consortium for Atmospheric Research on Transport and Transformation (ICARTT)
- NASA The Intercontinental Chemical Transport Experiment (INTEX-NA)
- NOAA New England Air Quality Study – Intercontinental Transport and Chemical Transformation (NEAQS-ITCT 2004) (formerly Northeast-North Atlantic [NENA] 2004)

Measurement of Pollution In The Troposphere (MOPITT)

- **MOPITT Accomplishments**
- Operational Data Production
- MOPITT Data Validation
- MOPITT Education and Outreach
- **MOPITT Science Studies**
- MOPITT Participation in INTEX-A
- Long-range Transport of CO Emissions from Russian Fires
- The CO Budget over Europe
- Pollution from Mega-Cities
- Involvement with Other Satellite Missions
- Seasonal and Inter-Annual CO Variability
- Data Assimilation and Inverse Modeling
- Comparison of CO and Aerosol Emissions from Biomass Burning

Photochemistry

- Peroxy Radical Studies
- PANS
- Formaldehyde (CH_2O)
- Radiation

Regional and Global Chemical Transport Models and Air Pollution Studies

- Weather Research Forecasting with Chemistry (WRF-Chem)
- HANK Regional Transport Model
- Global chemical transport models and air pollution studies

Reactive Carbon Research

Emissions of Primary Organic Compounds

Reactive Carbon Species as Sources and Reservoirs of Radical Species

Oxygenated Volatile Organic Carbon (OVOC) Contribution to the HOx Cycle

Gas-aerosol Partitioning of Organic Species

Laboratory Kinetics

- Oxidation Pathways for Alkyl Iodides
- Nitrate Production from Toluene Oxidation
- Oxidation Mechanisms of Methyl Formate and Methyl Acetate

Multiphase Processes in the Troposphere

Aerosols
Clouds – Cloud Chemistry Modeling
- Effect of boundary layer processes on chemical species distributions -Segregation of Chemical Reactants in a Shallow Cumulus Boundary Layer
- WRF-AqChem, a coupled meteorology and multi-phase chemistry model- Development and Initial Results of Model

Intercomparison of Convective Cloud Chemistry Models
Cloud Chemistry Process Studies - The Importance of the Cloud Drop Representation on Cloud Chemistry
Snow/Ice
- Mid-latitude Snow Chemistry Experiment
- Deployment of a Snowpack UV Radiation Profiler to Summit, Greenland
- Antarctic Polar Plateau

Chemistry in the Climate System

Climate Simulations

Present-Day Climate
- Tropospheric ozone interannual variability
- Studies of the Arctic Oscillation
- Role of convective versus synoptic transport
- SANTA FE project

Past and Future Climates
- Intergovernmental Panel on Climate Change (IPCC) simulations

Model Development
- Off-line Community Atmosphere Model (CAM)
- Interactive Community Atmosphere Model (CAM3)
- MOZART-4
- Tracer Version of MOZART-4
- Adjoint Version of MOZART

Biogeochemical Cycles

Laboratory Studies
U.S. Field Studies
International Field Studies
Regional Modeling Studies: U.S.
Regional Modeling Studies: International
Global Modeling Studies
Model and Database Development
Instrument Development

Integrated Study of Dynamics, Chemistry, Clouds, and Radiation of the Upper Troposphere and Lower Stratosphere (UTLS)

Satellite Data Analysis
Model Development
UTLS Chemistry and Aerosols
Instrument Development
- Trace Organic Gas Analyzer (TOGA): Measurements, Standards, and Intercomparisons (MSI) Group
- NO/NO_y and O_3: AON Group
- HIAPER Radiation Package (HARP): ARIM Group
- Development of autonomous actinic flux instrumentation for high altitude aircraft – NASA WB-57
- Chemical Ionization Mass Spectrometer (CIMS): LK Group in collaboration with Georgia Institute of Technology (GIT)
- Development of a prototype HIAPER OH instrument
- Fourier-Transform Infrared (FTIR) Spectrometer for HIAPER

Middle Atmosphere Science

WACCM - model development and results
- Impacts of El Niño-Southern Oscillation (ENSO) on the middle atmosphere
- Seasonal variability of trace species in the UTLS region
- Stratospheric influence on seasonal cycles of tropospheric tracers
- Monsoon impacts on stratosphere/troposphere exchange (STE)
- Parameterization of gravity wave fluxes due to convective excitation
- Stratospheric trends in temperature and water vapor
- Chemical transition across the extratropical tropopause
- Structure and variability of the SE Asia monsoon system

Mesospheric Processes
- Chemistry of the middle atmosphere sodium layer
- Atmospheric Tides
- Oxygen – hydrogen chemistry and emissions in the mesosphere

HIRDLS
- Pre-launch Activities
  - Instrument
  - Algorithm Development
- Post-launch activities

Strategic Initiatives

Biogeosciences

Executive Summary
BGS Achievements (Division Narratives)

Atmospheric Chemistry Division: ACD
- Carbon-Nitrogen cycling (Tasks 1 & 2)
- Laboratory studies (Task 2)
- U.S. field studies (Task 2)
- International field studies (Task 2)
- Regional modeling studies, U.S. (Task 2)
- Regional modeling studies, International (Task 2)
- Global modeling studies (Task 1)
- Model and database development (Tasks 1 & 2)
- Instrument development (Task 2)

Climate and Global Dynamics Division: CGD
- Community land model (Tasks 1 & 4)
- Land cover and land use change (Tasks 1 & 4)
- Development of carbon and nitrogen capabilities in CLM (Task 1)
- Community land model diagnostics package (Task 1)
- First results from CCSM3 with coupled C and N cycles (Task 1)
- Multi-century carbon cycle simulations (Task 1)
- Coupled climate carbon cycle model intercomparison project (C4MIP) (Task 1)
- High-resolution carbon cycle model user interface project (Task 1)
- Mineral Aerosols in CCSM (Tasks 1 & 4)

Carbon in the Mountains Experiment: CSME and ACME
- Carbon in the mountains experiment (CME) (Tasks 2 & 3)
- Airborne carbon in the mountains experiment (ACME I) (Tasks 2 & 3)
- CO_2 transport over complex terrain (Tasks 2 & 3)

Atmospheric Technology Division: ATD
- Airborne CO_2 Measurements (Task 2)
- Tower CO_2 measurements: autonomous inexpensive robist CO_2 analyzer (AIRCOA) (Task 2)
- NCAR CO_2 and O_2 calibration facility (Task 2)
- Synthesis of global light aircraft CO_2 data (Task 2)
- Wisconsin Tall-tower atmospheric O_2 measurements (Task 2)

BGS Publications
- Refereed
- In review or in press
- Non-refereed

Wildfires

Laboratory Studies
International Field Study
Modeling Studies

UTLS

MIRAGE

Overview

The ACD (Atmospheric Chemistry Division) mission is (1) to understand the chemical composition of the atmosphere, the processes that modify and control the composition, and potential changes that may result from natural and human induced forcings; (2) to provide relevant, reliable, accessible, unbiased, and timely information on atmospheric chemistry to government and society; and (3) to act as an intellectual resource and enabler to the wider atmospheric sciences community through the development of new measurement capabilities and methodologies, development and application of numerical models that reliably simulate present and future atmospheric conditions, and the planning and execution of field experiments to address specific scientific questions of regional and global significance.

Over the next few years, ACD staff will direct their research efforts at two grand challenges that confront society and where atmospheric chemical processes play a crucial role, namely ***Regional and Global Air Quality*** and ***Chemistry in the Climate System***. The directions and priorities of the division's research efforts have been chosen for their societal relevance and scientific merit. These plans were developed and formalized in the ACD Science Plan and were developed with the recognition that the accomplishment of any of the major goals will require significant collaboration with other NCAR divisions and with the university community. The goals were determined as a result of an iterative process involving the division director, the division internal management and external

advisory committees.

The main goal for ***Regional and Global Air Quality*** is to understand and quantify the impact of urban emissions on air quality. Priority will be given to studying the large-scale impacts of intense emissions originating from megacities, and the multiphase (gas-aerosol-cloud) processes that transform pollutants in the atmosphere. The goals for ***Chemistry in the Climate System*** are to understand the interactions between the physical climate system, the chemical climate system, and the biosphere. Priority will be given to the simulation of the recent past and future chemical climate states based on current climate simulations and to the study of the crucial role of the upper troposphere/lower stratosphere (UTLS) in the physical and chemical climate system.

The two primary research areas, ***Regional and Global Air Quality*** and ***Chemistry in the Climate System***, encompass the research areas outlined in the 2003 ACD program plan. The table below shows the relationship between the 2003 ACD Program Plan, the ACD Science Plan, and the 2004 ACD Program Plan.

ACD Program 2003	Themes and **Priorities** in ACD Science Plan	ACD Program 2004
Atmospheric Trace Gases Tropospheric Photo-oxidants	Regional and Global Air Quality **Influence of urban emissions on regional and global air quality** Reactive carbon research Multiphase processes in the troposphere	Regional and Global Air Quality
Chemistry climate interactions Biogeochemical cycles	Chemistry in the Climate System **Coupled chemistry-climate modeling studies** Biogeochemical cycles	Tropospheric Chemistry Climate Studies
Stratospheric ozone and UV-B	**Integrated study of dynamics, chemistry, clouds, and radiation of the Upper Troposphere and Lower Stratosphere** Middle atmosphere studies	UTLS and Middle Atmosphere Studies

Regional and Global Air Quality

Characterization of air quality is an important issue, not only in urban areas, but also on regional and global scales. Satellite, aircraft, and ground-based observations throughout the global atmosphere are confirming that air pollution can be transported over large distances, e.g., from eastern Asia to the western U.S., from North America to Europe, and from mid-latitudes to the Arctic.

Discussions of air quality generally center on issues related to atmospheric oxidants and particulates. Increases in ozone are of particular concern as this compound may impact humans and natural ecosystems, and is currently ranked as the third most important “greenhouse” gas. Thus, future trends in its concentration have strong links to both global air quality issues and to climate change. Potential global changes in OH radical concentrations are another major concern. OH is responsible for initiating the oxidation of many compounds emitted to the atmosphere into more soluble species that are removed from the atmosphere by wet and dry deposition or adsorbed into aerosols in multiphase processes. Critical challenges within the context of global change will be to determine if the capacity of the atmosphere to remove these gaseous species will be reduced or if climate change will affect the oxidation or emission processes and lead to significant change in the chemical composition of the troposphere.

There is ample evidence for increases in oxidants and other pollutants in urban and regional environments, where air quality is a major issue. Furthermore, transport of ozone and some ozone precursors from densely populated areas has led to increases on the global scale (estimated at 30% since the preindustrial era), and larger increases are expected with the demands of population growth. One of the major research themes within ACD is to investigate the influence of the export of urban pollution on regional and global air quality.

Reactive carbon species, also referred to as volatile organic compounds (VOC), play a

central role in determining tropospheric air quality. Primary VOC emissions are extremely diverse chemically, with both natural and anthropogenic sources, and range in complexity from simple gases such as CO and methane to more complex chemical forms like the terpenes (naturally-occurring isomeric compounds of general formula $C_{10}H_{16}$). Once in the atmosphere, these gases are oxidized to more soluble forms (carbonyl compounds, organic nitrates, organic acids, multi-functional species, etc.) that are more readily removed from the atmosphere by deposition, or that can couple back into the HO_x and NO_x chemical cycles - often at significant distances from the original source regions. The cycle of VOC emission, transformation, and heterogeneous loss is a major topic of research within ACD.

Multiphase processes (gas-aerosol-cloud interactions) are increasingly recognized as important to tropospheric air quality. High particulate concentrations, now common in and around urban centers but increasingly present on continental scales, pose a significant health risk. Many aerosols serve as cloud condensation nuclei and therefore influence cloud particle properties (e.g., albedo) and precipitation. They also scatter or absorb light, thus altering the atmospheric radiation field and reducing visibility. In addition, particles can act as sinks for some atmospheric oxidation products including sulfuric and nitric acid, ammonia, and many products of reactive carbon oxidation. Clouds also influence both tropospheric air quality and climate through their impact on the hydrologic cycle, as transporters, processors, and scavengers of pollutants, and *via* their effects on the tropospheric radiation field. Convective clouds play a particularly important role as transporters of trace species from the polluted boundary layer to the upper troposphere, which enhances ozone production in the upper troposphere where absolute changes in ozone have their largest radiative impact. Elucidation of the many complex physical/chemical processes involved in the multiphase chemistry of the troposphere - from particle nucleation and growth, to impacts of aerosols on gas phase composition, and the impacts of clouds as transporters and processors of trace gases is a major focus of ACD research activity.

Influence of Urban Pollution on Regional and Global Air Quality (Influence of Urban Emissions on Atmospheric Composition)

ACD efforts in this area include planning for the MIRAGE-Mex (Megacity Impacts on Regional and Global Environments, 2005 Mexico City campaign) field campaign, development of instruments to be used for tropospheric chemistry studies, development and deployment of community instruments and continued measurement support, participation in field campaigns that are complementary to MIRAGE, improvements to and use of MOPITT (Measurements of Pollution In The Troposphere) retrievals, photochemical research, and development and use of regional chemical transport models.

Community Involvement and C-130 Deployment (Megacity Impacts on Regional and Global Environments [MIRAGE] Planning)

While the importance of urban pollution to regional and global environments is widely acknowledged, it remains poorly quantified because of the complexity of physical and chemical processes that must be understood over a broad span of spatial and temporal scales.

The MIRAGE program is a new activity under development by scientists at NCAR and the university community, based on the recognized need for an integrated, multidisciplinary approach to this complex environmental issue. Planning is underway for a major field campaign in Mexico City in 2005 (MIRAGE-Mex). Sasha Madronich, Frank Flocke, and John Orlando were involved in preparing and submitting a MIRAGE-Mex proposal to NSF. The proposal will be reviewed by the National Science Foundation's Observing Facilities Advisory Panel (OFAP) in April 2005. Additional information on MIRAGE-Mex logistical and scientific planning is found below under the Strategic Initiatives – MIRAGE section.

Instrument Development

A number of instruments have been developed or improved by ACD staff for use in tropospheric chemistry studies. These include the Peroxy Radical Chemical Ionization Mass Spectrometer (PeRCIMS), peroxyacyl nitrates (PAN), radiation, isotopes, and formaldehyde instruments.

Improvements to PeRCIMS Instrument

Chris Cantrell of the Atmospheric Radical Studies (ARS) Group has developed an instrument to measure peroxy radicals in the atmosphere. The PeRCIMS instrument operates on the principle of chemical conversion of ambient or calibrator-generated peroxy radicals to gas-phase sulfuric acid, followed by chemical ionization by reaction with negatively charged nitrate ions, and separation and detection of the ions via mass spectrometry. Signals for the total peroxy radical concentration [HO_2+RO_2] and for the hydroperoxy radical concentration [HO_2] have been acquired by greatly changing the concentration of the reagent gases, nitric oxide (NO) and sulfur dioxide (SO_2). For HO_2+RO_2 measurements, the reagent concentrations in the inlet were in the tens of ppmv range. For HO_2 measurements, they were in the thousands of ppmv range. This necessitated the use of pure NO and pure SO_2 for the HO_2 quantification. Recently, we have investigated the use of oxygen or nitrogen dilution as an alternative to changing the reagent gas concentrations. The separation of HO_2 and RO_2 exploits the competition between the reaction of alkoxy radicals (RO), which are generated in the reaction of RO_2 with NO, with oxygen and NO. When RO radicals react with oxygen, HO_2 is usually a product (depending somewhat on the structure of RO), which leads to measurement of the RO_2. When RO radicals react with NO, alkyl nitrate stable products (RONO) are formed, which leads to RO_2 not being measured. Thus, the parameter which affects the sensitivity to RO_2 is the NO/O_2 ratio. At low NO/O_2 values, RO_2 radicals are measured efficiently, and at high values they are not.

Dilution of ambient air in a ratio of 1:10 with either oxygen or nitrogen leads to modulation of the oxygen concentration by a factor of 49, allowing RO_2 measurements with high efficiency (>80%) in the HO_2+RO_2 mode or fairly low efficiency (<30%) in the HO_2 mode. The non-ideal responses (100% and 0% in the two modes, respectively) can be corrected using laboratory measurements of RO_2/HO_2 response factors and model estimates of the makeup of RO_2 species. Comparisons of the reagent gas concentration change versus the oxygen modulation method were performed in the laboratory, and representative results are shown in Figure 1, along with a numerical model of the expected results. These preliminary results are promising, and suggest that the oxygen modulation technique may be nearly as efficient at separating HO_2 and RO_2, with the advantage that change between the two modes of operation can be accomplished quickly. Development will continue in FY05, with a design goal to quantify atmospheric HO_2 and HO_2+RO_2 within one minute. This will require modifications to the inlet and the computer control software.

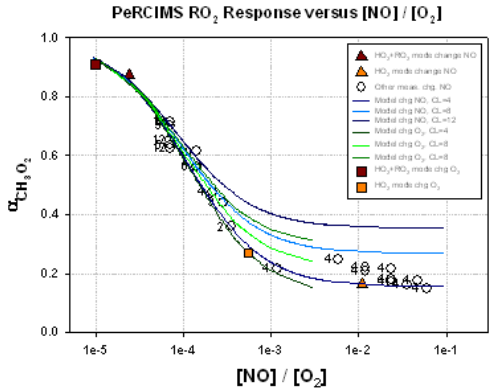


Figure 1: Measured and modeled response of PeRCIMS to RO_2 radicals versus the ratio of the concentrations of NO to O_2. The large colored triangles show normal operating conditions using the method of changing reagent concentrations. The large colored squares show potential operating conditions using oxygen dilution modulation. Open circles show laboratory measurements of sensitivity for other operating conditions, using changing reagent concentrations. The lines represent models of the sensitivity of RO_2 when changing reagent concentrations (blue shades) and oxygen dilution modulation (green shades). The different curves correspond to different SO_2/NO ratios, in which the chain length (CL) is the SO_2/NO ratio divided by five. Implicit in the model is an assumption about the rate of the reaction of RO with SO_2 to form HO_2 (inferred from laboratory studies).

Peroxyacyl Nitrates (PAN) instrument

Frank Flocke and Aaron Swanson (University of Colorado, Boulder (CU); NOAA Aeronomy Laboratory) flew a new instrument for fast (1-2 sec), continuous measurements of PAN and related species on the NOAA P-3B aircraft as part of the NOAA-led International Consortium for Atmospheric Research on Transport and Transformation (ICARTT) and New England Air Quality Study (NEAQS) programs. The instrument, called PAN-CIGAR (PAN-CIMS [Chemical Ionization Mass Spectrometer] Instrument by Georgia Institute of Technology [GIT] and NCAR), has been a joint development with Greg Huey and David Tanner (GIT). Prior to deployment, much of the year was spent on redesigning a prototype instrument to make it ready for unattended aircraft operation. The pump system was redesigned and gas loads were lightened. The operation and data acquisition software was improved as well as some electronics to allow unattended operation and controlled recovery from power outages, etc. Additional instrument characterization (investigation of the sensitivity dependence on humidity, flow, and pressure) was performed. Other instrument improvements were made with help from David Hanson (ACD). From October 2003 to early April 2004, Sandra Lopes, a graduate student from the University of Wiesbaden, Germany worked with Swanson and Flocke. She successfully completed her Master's degree in Chemical Engineering with them by participating in the development and construction of a new in situ calibration source for the instrument, a unit that is 50% smaller than the old unit and has augmented control capabilities for use with PAN-CIGAR.

Actinic Flux Spectroradiometer

Members of ACD's Atmospheric Radiation Investigations and Measurement (ARIM) Group, Rick Shetter, Sam Hall, Barry Lefer, and Edward Riedel, developed a new generation actinic flux spectroradiometer. The ARIM Group has deployed ground-based and airborne Scanning Actinic Flux Spectroradiometer (SAFS) instruments for the determination of actinic fluxes and photolysis frequencies for the last seven to eight years. These have operated well, but have limited time resolution (~10 seconds for a spectrum) and require frequent calibration and maintenance. A new instrument based on a monolithic monochromator with a UV-enhanced windowless CCD detector has been developed. This instrument is smaller and lighter with a new PC-104+ data acquisition and control system. The instrument has been quite reliable and has the ability to collect actinic flux spectra from 280 to 680 nm at 1-10 Hz, allowing for fast photochemistry investigations. The smaller design will allow deployment on aircraft platforms with limited space for instruments and operators including the NSF HIAPER (High-performance Instrumented Airborne Platform for Environmental Research) aircraft and future Unmanned Aerial Vehicles (UAV) platforms. One of these new generation instruments was deployed on the NASA DC-8 for the INTEX-NA experiment.

Analytical Photonics & Optoelectronics Laboratory (APOL) Technology Development in Airborne Observing Systems and Chemical Sensor Systems

Alan Fried, James Walega, and Dirk Richter of the joint Atmospheric Technology Division (ATD)/ACD APOL have developed and improved several instruments.

Continued Development of a New Laser Spectrometer for High Precision

Measurements of CO_2/ CO_2 Isotopic Ratios

The Annual Scientific Report (ASR) last year described this project in detail along with progress achieved in designing and constructing the new instrument (APOL_(ACD/ASR03)). Figure 2, which illustrates a modified version of the optical setup shown last year, has been constructed and a number of tests have been carried out. This new setup allows the sample and reference beams to make two traversals of the absorption cells for improved measurement precision. As discussed in our previous ASR, the absorption signals from the two cells containing the sample gas and an isotopic reference standard are rapidly compared using online fitting analysis. The fitting procedures have been developed and wait further testing on CO_2 absorption features, which should take place within the next month or two.

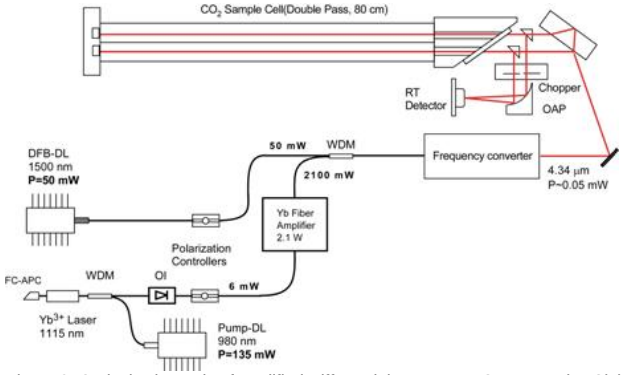


Figure 2: Optical schematic of modified Differential Frequency Generator (DFG)-based system for high precision carbon dioxide isotopic ratio measurements.

Figure 3 shows the design of the inlet system, which represents the second major task associated with high precision CO_2 measurements. This system, which is in the testing phase, allows various combinations of reference standards and ambient samples to be introduced to the absorption cells under closely matched conditions of pressure and flow. Other studies frequently do not take such precautions.

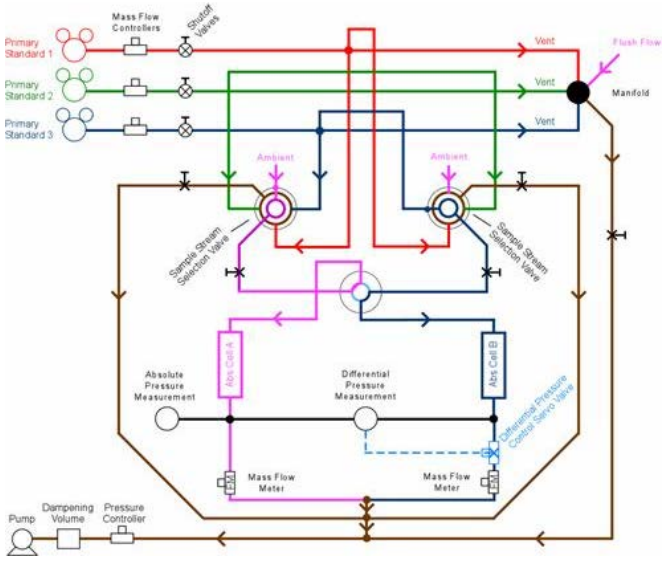


Figure 3: Schematic of inlet and outlet plumbing system. The two absorption cells are designated by Abs Cell A and B in this figure.

As in the previous year, the APOL Group worked in close collaboration with NCAR's Education and Outreach Program to host two teachers and students from local area high schools to help with all phases of this project. The following Web link (http://www.atd.ucar.edu/apol/biocomplexity.htm) further describes the full project and also shows one important aspect of the teacher and student involvement: organization and dissemination of the material to the broader public.

Continued Development of New High Performance Airborne DFG Instrument for the Measurement of CH_2O

As discussed in last year's ASR, the trace gas CH_2O is one of many important atmospheric trace species involved in ozone production and radical formation. The APOL Group has been actively involved in a long-term effort to carry out ever more accurate and precise measurements of this gas throughout the troposphere and lower stratosphere. As discussed previously, such measurements have been exclusively acquired using the APOL Group's liquid-nitrogen cooled tunable diode laser absorption spectroscopy (TDLAS) system. Although the Group has continued to implement a number of significant improvements to this system in terms of hardware and software (to be discussed below) and achieved consequent gains in instrument performance, the Group is fast approaching an ultimate limit to such gains. The present instrument sensitivity (15 – 50 pptv, 1s precision for 1 minute of averaging) needs to be further improved for routine CH_2O measurements in the background atmosphere, particularly in the upper troposphere/lower stratosphere where CH_2O decomposition becomes a major source of reactive hydrogen radicals. In addition, the instrument is large and requires periodic operator intervention. To address this critical need as well as the need to develop smaller, lighter, and autonomous-operation instruments for future HIAPER campaigns, the APOL Group has been developing a new high performance airborne CH_2O instrument based upon difference frequency generation. A comprehensive description of this approach, as well as its many advantages over lead-salt TDLAS systems, has been discussed in last year's ASR and will not be repeated here. ("Technology Development in Airborne Observing Systems and Chemical Sensor Systems," at TDLAS_(ACD/ASR03)).

However, for size comparison purposes, APOL Figures 3 and 4 show the present airborne TDLAS system and the compact new DFG system. The Herriott absorption cells in both systems are approximately the same size. With this in mind, a comparison of these two figures immediately reveals that the DFG system is significantly smaller than the TDLAS system; the DFG-Herriott cell configuration in Figure 5 has replaced the entire optical setup of the TDLAS system in Figure 4. A further advantage of the DFG system is that no liquid cryogens are required, in stark contrast to the present TDLAS system. Although laboratory tests with the new DFG system are not yet complete, evidence strongly indicates that this new system will ultimately achieve higher performance than the TDLAS system for CH_2O and other molecules.

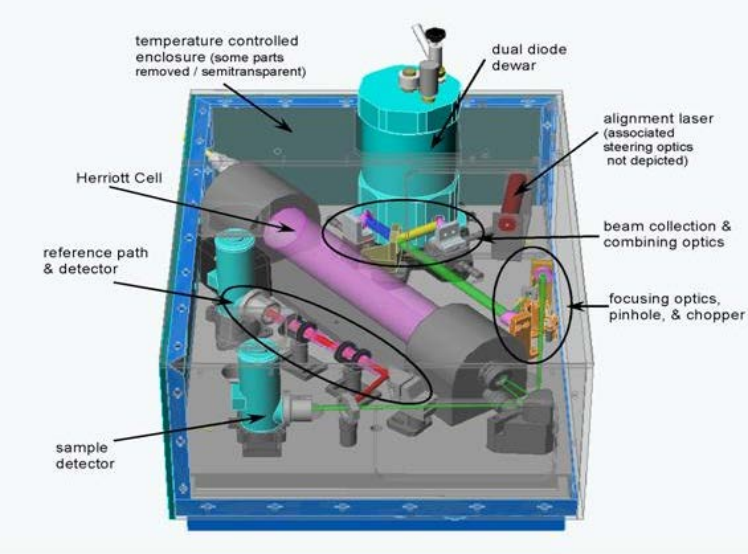


Figure 4: Schematic of optical system with cutaway view of temperature-stabilized enclosure employed during INTEX-A. Two separate laser channels with separate beam collection optics are shown. However, during INTEX-A only one laser channel was employed. The enclosure dimensions are approximately 33" long x 24" wide x 12" high.

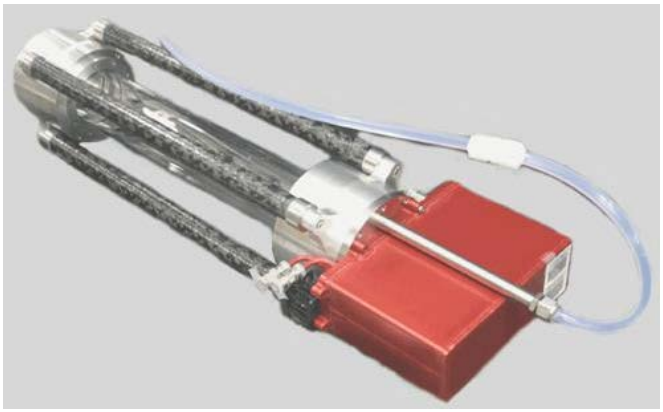


Figure 5: Photograph of the APOL Group's DFG stage mounted to a new, more stable Herriott cell. The size of the DFG stage with enclosure is 7"long x 9.5" wide x 3.5" high. For comparative purpose, the cell here is the same size as the cell in Figure 4.

Continued Improvements to Present Airborne TDLAS System Hardware and Software

Despite the significant progress achieved in the DFG development, the laboratory prototype system has not yet been tested on airborne platforms. Rather than risk flying such a system for the first time during a critical field mission, the APOL Group decided to pursue the more prudent course of action by employing the TDLAS system during the 2004 summer INTEX-NA study. However, numerous small modifications were implemented to this system this past year to further improve the system robustness, reliability, and performance. Many of these modifications, which are too numerous to list here, focused on improving the optical-mechanical stability of the system. In addition, numerous software changes were also implemented for improved performance, reliability, and enhanced data quality assurance.

Community Instruments, Measurement, and Science Support

ACD supports several analytical instruments that are available by request from the community to support airborne field campaigns. These include instruments to measure carbon dioxide (CO_2), carbon monoxide (CO), ozone (O_3), and water vapor (H_2O). Teresa Campos (ACD/ATD) is responsible for the maintenance, deployment, data collection, and data reduction for these instruments. ACD also supports ongoing hydrocarbon calibration efforts by Eric Apel.

Chemistry Community Instruments

Teresa Campos and Sam Hall of the ARIM Group were responsible for instrument preparation and calibration, data acquisition software development, instrument deployment, and data analysis during several field campaigns. Preliminary results from the Gulf of Tehuantepec (GOTEX) airborne field experiment, conducted in the Eastern Pacific marine boundary layer near Salina Cruz, Mexico, indicate successful measurement of CO_2 air-sea exchange by the eddy covariance method. The sensitivity to aircraft acceleration was quantified and found to contribute to the flux signal only at frequencies less than 2 Hz. Even at these frequencies, however, the amplitude of the artifact is a factor of 50 smaller than equivalent power spectral content of ambient marine boundary layer data measured at the same altitudes, as shown in Figures 6 and 7.

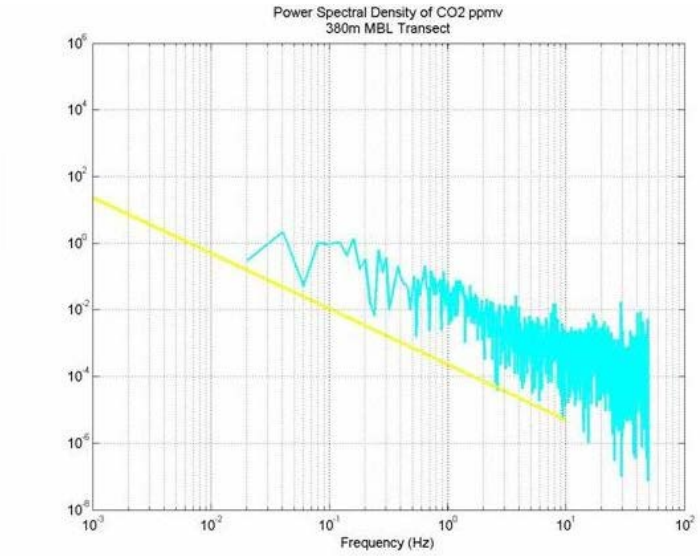


Figure 6: Power spectral distribution of two-minute ambient CO_2 measurements of marine boundary layer air during the 2004 Gulf of Tehuantepec Experiment. Observations were made at 380 msl off the coast of Salina Cruz, Mexico.

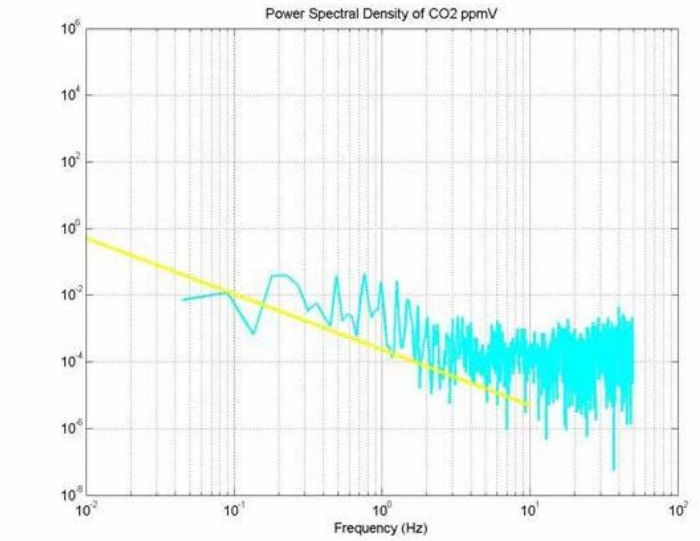


Figure 7: The power spectral distribution of a two-minute time series during which CO_2 calibration gas was sampled in-flight at 380 msl in the marine boundary layer. The measurement represents a quantification of the spectral dependence of the air motion sensitivity of the CO_2 sensor.

A collaboration between the Atmospheric Technology Division, the Atmospheric Chemistry Division, and the Biogeosciences Initiative has been in place for several years to fund development and field support of airborne facility in situ trace gas instruments. Supported developments include water vapor and fast-response ozone measurements in addition to carbon dioxide and carbon monoxide. The activities have been successful on several fronts in maintaining and improving the quality of requestable instrumentation and data sets.

The airborne CO_2 instrument was modified to enable flux measurements by the eddy covariance method. Assessment of measurement capabilities was assessed by using the instrumentation on the GOTEX experiment (Kenneth Melville [Scripps Institution of Oceanography], Carl Friehe [University of California, Irvine]) and the Airborne Carbon in the Mountains (ACME) experiment (Russell Monson [CU], David Schimel, Jielun Sun, and Britton Stephens, [NCAR's Climate and Global Dynamics [CGD] Division). Spectral analysis of GOTEX marine boundary layer data imply an instrument frequency response of 4-Hz, and time series analysis implied a mixing ratio measurement precision of 0.2 - 0.3 ppmv (1-s for a 1-second average). The flux artifact of this sensor due to air motion sensitivity was quantified in both marine and terrestrial boundary layer environments during

both missions by introduction of calibration gas into the sample cell during a portion of a boundary layer transect. A small artifact due to correlated air motion sensitivity was observed in GOTEX data at frequencies lower than 2 Hz. However, the amplitude of these fluctuations is a factor of 50 smaller than the equivalent power spectral content of ambient data obtained in the marine boundary layer at the same altitude. Preliminary ACME results from intercomparison to analyses of flask samples by Heather Graham and Ralph Keeling (Scripps Institute of Oceanography), imply an accuracy of ± 0.2 ppmv. This result has been reproduced by intercomparison to CME ground network working standards provided and analyzed by the CO_2 calibration facility by Britton Stephens (UCAR/RAF).

The commercial NCAR open-path diode laser absorption hygrometer was modified to improve accuracy of lower tropospheric water vapor mixing ratio observations and to increase the time response of the instrument from an 8-Hz sampling rate to 18-Hz. The modified laser hygrometer performed well as an experimental measurement on the second Alliance Icing Research Study (AIRS-II) and GOTEX experiments. Results from the AIRS-II mission established confidence in the accuracy of clear sky water vapor measurements to be +/- 5%, relative to chilled mirror sensors on the same platform. Preliminary results from the GOTEX data have confirmed the capability of this sensor to measure vertical fluxes by the eddy covariance method. Spectral analysis of 18-Hz data from boundary layer transects agree well with lyman alpha hygrometer data.

To increase confidence in the absolute accuracy of all NCAR facility water vapor measurements, an accurate, large dynamic-range water vapor calibration system was purchased. This commercial system includes a humidity generation system and a certified reference sensor with traceability to both the U.S. and U.K. standards organizations. Both cover a dew point range of -80º to +20º C, and the reference sensor accuracy is ± 0.1º C in the -60º to +20º C range and ± 0.2º C in the -80º to -60º C region. This facility is a crucial component of ensuring accuracy of water vapor measurements both in the troposphere and UTLS regions.

MSI Group Measurement Support

For the past decade Eric Apel of the Measurements, Standards, and Intercomparisons (MSI) Group has played a leadership role in community measurement support activities. These include supplying the community with primary calibration standards, conducting informal intercalibration exercises, and organizing and conducting formal intercomparisons of research instrumentation.

As part of the MSI Group's continuing effort in community measurement support activities this year, Apel prepared and provided a primary standard which was used by all research groups involved with the measurement of volatile organic compounds during the ICARTT campaign. The standard contained the following compounds: *Methane, CO, ethane, acetylene, ethane, propene, propane, butane, 134A, benzene, toluene, acetone, acetonitrile, carbon tetrachloride, chlorofluorocarbon (CFC) 113, and iso-propyl nitrate.* The MSI Group received assistance from Steve Montzka and Paul Novelli at NOAA's Climate Monitoring and Diagnostics Laboratory (CMDL) and Elliot Atlas of the University of Miami in the calibration of specific compounds in the standard.

In addition, Eric Apel, along with Alan Fried of ACD/ATD, organized and will convene a special session on "Tropospheric Photochemistry" at the annual AGU meeting in December.

This year the MSI Group also contributed to an ACD document outlining plans for a community facility to be housed in the new ACD building. This community facility would focus on chemical instrument calibration and validation, which are clearly-perceived needs in the community and a natural outgrowth of this Group's past and ongoing community support activities. It is necessary to quantify measurement uncertainties for instrumentation involved in key atmospheric experiments in which results have implications for local and national policy decisions. Kuster et al., 2004, documents an intercomparison study that the MSI Group participated in during Texas Air Quality Study (TEXAQS) 2000, a study that clearly has policy implications.

Managing the National Science Foundation

Atmospheric Chemistry Program

Chris Cantrell accepted a temporary assignment with the National Science Foundation to help manage the Atmospheric Chemistry Program. This was implemented under the Intergovernmental Personnel Act (IPA), in which persons "rotate" from their home institution for a period of time (usually one to three years) to perform services needed by the Federal government. The Atmospheric Chemistry Program at NSF considers ad hoc proposals from the community to investigate problems related to atmospheric composition (gas phase and condensed phase), transport and transformation, interaction between ecosystems and the atmosphere, and connections between chemistry and climate through theoretical, observation, and laboratory investigations. The program considers 150-200 proposals per year, which are each reviewed by four to six experts in the particular field of study, and the most meritorious are awarded funding. Many projects are at the boundaries of atmospheric chemistry and other disciplines (e.g., climate, meteorology, Arctic or Antarctic science, oceanography, international), and as such are reviewed by two or more programs. The assignment allowed a unique look at the federal process of funding scientific research, in particular the NSF process, and enabled Cantrell to become more familiar with the persons and activities in the atmospheric chemistry field. The goal of the IPA program is for rotators to bring back to their home institution the information gained in order to improve the relationship with the agency.

There were also many opportunities to interact with representatives of other domestic and foreign agencies. These processes can lead to enhanced interactions, and leveraging of limited funds that could enhance the outcomes of our investment in scientific research.

NSF also places a considerable emphasis on the "broader impacts" of scientific research. Thus, given a project with high priority scientific goals, and reasonable chances of success, the principal investigator would be expected to contribute to the wider aspects of science including education and training activities that are integrated with the research, broader participation of underrepresented groups, enhance infrastructure, wide dissemination, and provide benefits to society. Program officers at NSF examine the balance between the intellectual merit of quality, high priority scientific projects, and their contribution to these broader issues.

Field Campaigns Complementary to MIRAGE

ACD scientists from the ARIM, APOL, AON (Atmospheric Odd Nitrogen), and STM (Stratospheric/Tropospheric Measurement) Groups participated in two field campaigns in the summer of 2004, which were under the auspices of the ICARTT field campaign. These campaigns were clearly complementary to the objectives of MIRAGE (see Strategic Initiatives-MIRAGE section below) and the results will provide an improved understanding of pollution transport across the U.S. and the northern Atlantic to Europe.

International Consortium for Atmospheric Research on Transport and Transformation (ICARTT)

Several groups in North America and Europe independently developed plans for field experiments in the summer of 2004, designed to provide improved understanding of the factors that shape air quality in their respective countries and the remote regions of the North Atlantic. NASA and NOAA conducted experiments under the INTEX-NA and the NEAQS - ITCT (Intercontinental Transport and Chemical Transformation) 2004 programs respectively. The Europeans (U.K., Germany, and France) organized coordinated studies under Intercontinental Transport of Pollution (ITOP). While each of these programs has regionally focused goals and deployments they share many of the same goals and objectives and the proposed study areas overlap significantly. ICARTT was formed to take advantage of this synergy by planning and executing a series of coordinated experiments to study the emissions of aerosol and ozone precursors their chemical transformations and removal during transport to and over the North Atlantic. The capabilities represented by the consortium will allow an unprecedented characterization of the key atmospheric processes. Several ACD groups participated in INTEX-NA and NEAQS-ITCT 2004 as described below.

NASA Intercontinental Chemical Transport Experiment (INTEX-NA)

INTEX-NA was a major NASA science campaign to understand the transport and transformation of gases and aerosols on transcontinental and intercontinental scales and their impact on air quality and climate. A particular focus of INTEX-NA was to characterize and quantify the inflow and outflow of pollution over North America. Measurements from INTEX-NA will also provide important validation of satellite observations with ongoing satellite measurement programs, such as Terra, Aura, and the European Space Agency's (ESA) Envisat (Environmental Satellite). The experiment was conducted over the continental United States during the summer of 2004 using a variety of science aircraft.

The ARIM Group deployed two SAFS systems on the NASA DC-8 aircraft to measure the in situ total spectral actinic flux as a function of wavelength and calculate the in situ photolysis frequencies of 23 important photochemical reactions. Results are discussed in the Photochemistry/Radiation section below.

The APOL Group deployed the modified TDLAS system on the NASA DC-8 to measure formaldehyde (CH_2O). The instrument improvements worked extremely well in all respects, and this allowed the Group to successfully acquire ambient CH_2O measurements on 19 out of the 20 mission flights. Preliminary results are discussed in the Photochemistry/Formaldehyde section below.

NOAA New England Air Quality Study – Intercontinental Transport and Chemical Transformation (NEAQS-ITCT 2004) (formerly Northeast-North Atlantic [NENA] 2004)

NOAA's Health of the Atmosphere research is focused on the atmospheric science that underlies regional and continental air quality, with the goal of enhancing the ability to predict and monitor future changes. Under this program NOAA organized the NEAQS-ITCT 2004 campaign with the P-3B aircraft and NOAA research vessel *Ron Brown* operating out of New Hampshire. The study focused on air quality along the Eastern Seaboard and transport of North American emissions into the North Atlantic.

The AON Group deployed the PAN-CIGAR to measure PAN and related compounds. These measurements are a crucial part of evaluating photochemical processing and the influence of natural and anthropogenic hydrocarbons. Initial results are discussed in the Photochemistry/PAN section below.

Also, as a contribution to the NEAQS program, a sensitive NO instrument that the AON Group had previously flown on aircraft was modified and lab-tested to loan to Alex Pzenny (University of New Hampshire) and Eric Williams (NOAA Aeronomy Laboratory) for use at one of the ground sites.

The STM Group deployed a Whole Air Sampler on the P-3B to collect air samples for analysis of hydrocarbons, halocarbons, alkyl nitrates, and CO. These measurements are required to adequately assess photochemistry and transport. Sample analysis was recently completed and data quality control and analysis is currently underway.

Measurement of Pollution In The Troposphere (MOPITT)

The MOPITT experiment has provided atmospheric scientists with the first multi-year, global view of carbon monoxide (CO) profile concentrations in the troposphere. The experiment is approaching the five-year anniversary of its launch on the Terra satellite in December, 1999. With this, the project at NCAR will pass a milestone, with the completion of the initial phase that began more than 10 years ago. During this period the data processing software was developed and the first years of orbital data processed, validated, archived, and provided to the atmospheric chemistry community, as well as being used for scientific research. The mission is a joint Canadian-U.S. effort, and ACD is responsible to NASA for the continued development of the data reduction algorithms and for operational data processing at every stage from instrument counts to calibrated radiances, through to globally retrieved CO vertical profiles and total columns. MOPITT Version 3 validated tropospheric CO profiles are currently being processed and delivered to NASA for use by the international community. This is the first dataset of its kind, and represents a significant

advance in satellite remote sensing of the troposphere. The next phase of the core effort will concentrate on some additional improvements to the retrieval algorithms, as well as continuing with the scientific applications of the data.

The MOPITT Group has been active in 3 main areas this year: (1) continued improvement of the data reduction algorithms in preparation for Version Four, data processing, and delivery of the final products to NASA for later distribution to the community; (2) support of aircraft field campaigns; and (3) use of the MOPITT data in tropospheric chemistry and transport studies. More information about the MOPITT project can be found at http://www.eos.ucar.edu/mopitt/ and http://www.atmosp.physics.utoronto.ca/MOPITT/home.html.

MOPITT Accomplishments

Operational Data Production

The NCAR MOPITT team, led by John Gille, has been engaged in the ongoing data reduction process to produce geophysical quantities for scientific use by the community from the instrument count data. The elements of this processing capability and the people responsible, are the data handling interfaces and protocols between NCAR and the NASA centers which receive and archive the satellite data and the ancillary meteorological data (Daniel Ziskin, Jarmei Chen); the Level 0-1 processor which calibrates the instrument counts to produce geolocated radiances (Ziskin, Debbie Mao, Chen); and the Level 1-2 processor which comprises a forward model which provides a full simulation of the MOPITT measurement, a cloud detection algorithm, and a retrieval algorithm (David Edwards, Gene Francis, Merritt Deeter, Ben Ho, and Gille). The retrieval combines information from the measurements, the forward model, and previous measurements which define the current understanding of the atmosphere, to obtain the most likely CO profile consistent with the measured MOPITT signal. The Moderate-resolution Imaging Spectroradiometer (MODIS) cloud mask is also used operationally in the current data processing to provide added information about cloud contamination in the MOPITT field of view.

The algorithms continue to be developed. The data for the mission Phase 1, before the instrument cooler failure in April 2001, have been designated as a validated product. The data for the post-April 2001 period, Phase Two, are currently provisionally validated and will be upgraded to fully validated in the near future. Work has continued to characterize the instrument performance in the Phase Two period, and to develop the retrieval algorithms to ensure maximum utilization of the instrument signal to retrieve CO vertical structure.

The algorithms are now being prepared for the next data Version Four. Enhancements will include: (1) a new forward model with improved description of the MOPITT gas correlation cells; (2) an new description of the retrieval a priori surface emissivity; and (3) a variable CO retrieval a priori. The validation of MOPITT retrieved surface skin temperature using collocated MODIS measurements has been a major effort led by Ho. Surface skin temperature information retrieved from MODIS measurements has been used to generate a more accurate global monthly surface a priori emissivity (mean and variance) for use in the MOPITT retrieval algorithm to improve retrievals of surface temperature and CO profile. Monthly 1 degree grid mean 4.7 micron surface emissivity maps have been generated using an iterative algorithm taking as inputs MODIS skin temperature and surface characterization index in combination with MOPITT A-signals, which are most sensitive to the background scene. Analysis of the impact of the new a priori emissivity on the retrievals of tropospheric CO profiles indicates that more vertical information can be obtained, especially at night. This has the effect of reducing the apparent diurnal change in the MOPITT CO retrieval. A manuscript detailing this work is now in preparation, and this will be used in the new Version Four algorithm. The adoption of a new seasonally- and latitudinally-variable CO retrieval a priori (based on both in situ data and current operational MOPITT retrievals) is also planned for version 4. This will hopefully reduce retrieval biases that have been characterized by validation studies. This work is being led by Deeter.

MOPITT Data Validation

The on-going activity of validation of the MOPITT CO retrievals (Louisa Emmons) shows the continued accuracy of the data. In situ measurements from small aircraft, provided by Paul Novelli (NOAA CMDL), continue to form the basis for the validation comparisons. Figure 8 shows the high correlation between MOPITT retrievals and the in situ data (transformed with the MOPITT averaging kernels) for the Phase Two data through 2003.

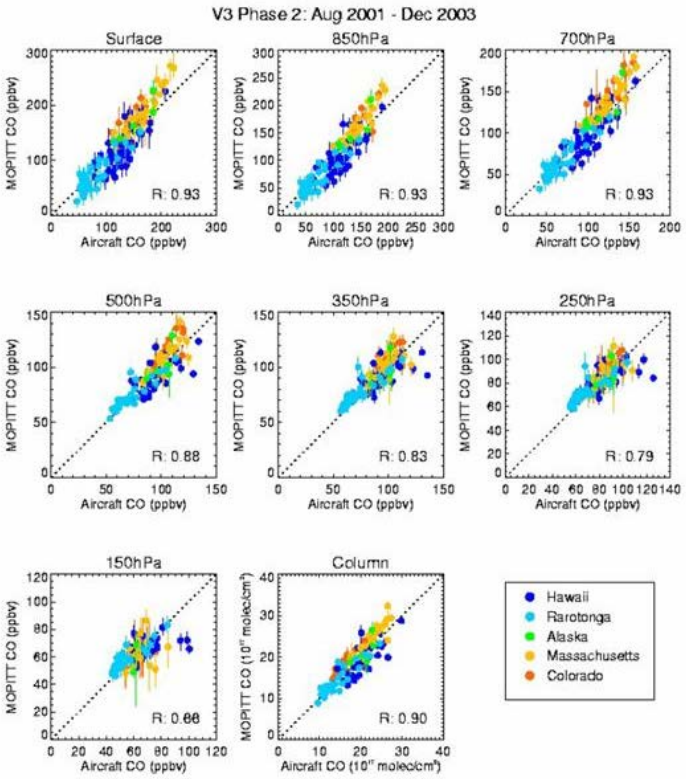


Figure 8: Validation of MOPITT CO retrievals for August 2001 to December 2003. Correlations of MOPITT CO with aircraft in situ data are shown for each retrieval level and the total column. Aircraft CO profiles, provided by Paul Novelli (NOAA CMDL) for five sites, have been transformed with the MOPITT averaging kernels.

The vertical resolution of the MOPITT CO retrievals is a key indicator of retrieval performance and is of interest to many end users. However, vertical resolution is highly variable, and depends on retrieval configuration, surface temperature and emissivity, atmospheric temperature profile, etc. One index for quantifying vertical resolution is termed Degrees of Freedom for Signal (DFS). DFS approximately represents the number of layers in the retrieved profile which are retrieved independently. Analysis of the MOPITT averaging kernels indicates that current MOPITT retrievals contain up to two pieces of information corresponding to the mid- and upper-troposphere. Figure 9 shows the latitude dependence of the zonal-mean DFS for both daytime and nighttime retrievals, and for both Phase One and Phase 2 periods. Most importantly, the figure shows that retrieval information content decreased only marginally as a result of the loss of half of the MOPITT channels in 2001. This work was recently published in Geophysical Research Letters.

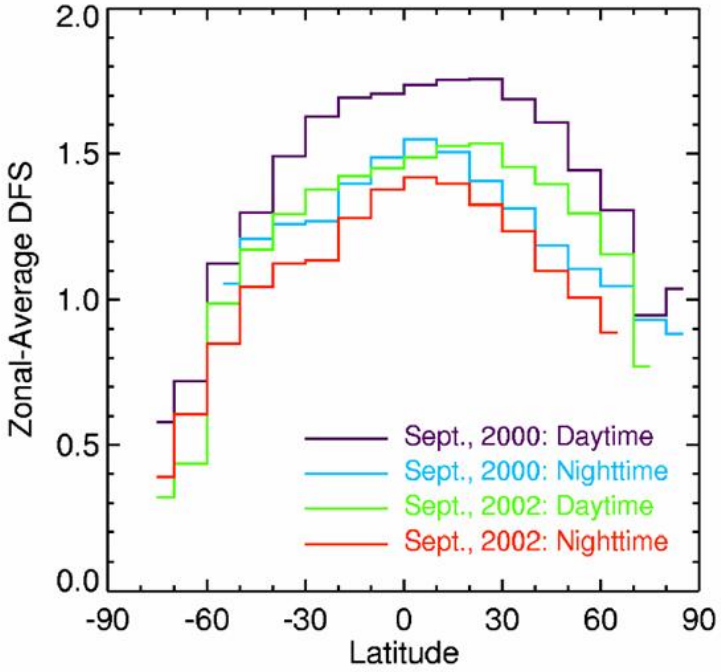


Figure 9: Latitude dependence of the zonal-mean DFS for both daytime and nighttime retrievals, and for both Phase One and Phase 2 periods.

Studies were completed using the 2001 flight data taken by the MOPITT Algorithm Test Radiometer (MATR) aircraft instrument (Alan Hills, Janguo Nui, Deeter) for (1) during April and May over the Oklahoma Cloud and Radiation Testbed (CART) site, and (2) during November over three western U.S. cities (Los Angeles, Las Vegas, and Denver). These flights were supported with in situ measurements by Paul Novelli (NOAA CMDL). MATR measurements over the western cities show plumes of CO, the direction and distribution of which appear to agree well with the prevailing meteorology. This work has recently been published in Applied Optics.

MOPITT Education and Outreach

The MOPITT website continues to be developed. This is regarded as an important means of community outreach and education. The website currently includes details of how to obtain the data and how to use it correctly, along with other MOPITT references.

The MOPITT team makes regular story contributions to the NASA Earth Observatory website. These often highlight intense burning events around the world that are of general interest. The team was also involved in the production of an animation of MOPITT data with accompanying story that was produced by the American Museum of Natural History for distribution as an educational tool.

MOPITT Science Studies

MOPITT Participation in INTEX-A

Remote sensing of CO directly addresses many of the scientific questions motivating aircraft field campaigns, and measurement of this gas is usually rated as being mission critical. CO is an important trace gas in tropospheric chemistry due to its role in determining the atmospheric oxidizing capacity, as an ozone precursor, and as an indicator and tracer of both natural and anthropogenic pollution arising from incomplete combustion. The satellite perspective provides the more general temporal and spatial context to the aircraft and ground-based measurements. During the summer 2004 NASA ICARTT/INTEX campaign, MOPITT CO retrievals were provided in near-real-time using an expedited data processing stream (managed by Ziskin, Chen, and Mao) for use in field analysis and flight planning (Edwards, Emmons and Gabrielle Pfister). Maps of the data were created and posted on the MOPITT website, and Emmons and Pfister were in the field to present and

discuss the MOPITT data during daily planning meetings. The large wildfires in Alaska during the summer of 2004 had a strong impact on the CO concentrations in the Midwest and eastern U.S. at times, and the MOPITT data were valuable for tracking the high CO values. This is shown in Figure 10.

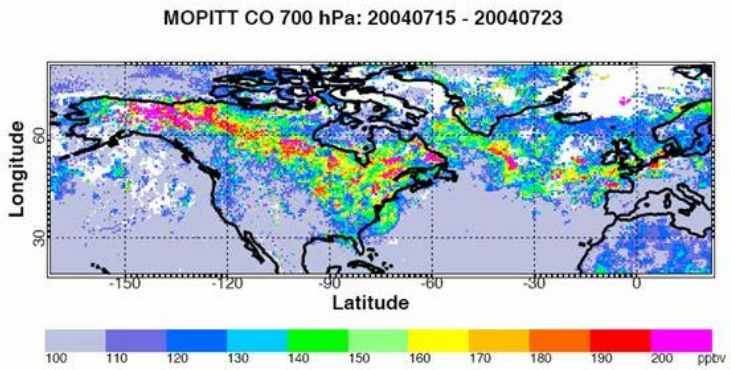


Figure 10: MOPITT 700 hPa CO mixing ratio for the period 15-23 July, 2004, showing the plumes produced by fires in Alaska. The emissions from these fires can be traced across North America and The Atlantic Ocean.

INTEX-A also provided MOPITT validation opportunities with in situ CO measurements on the DC-8 from G. Sachse, NASA Langley. Edwards was also Co-Investigator on the French component (ITOP) of the overall ICARTT mission, and on-going collaboration with Jean-Luc Attie at the Laboratoire d'Aerologie in Toulouse, France, resulted in a near-real time assimilation of the MOPITT data into the MOCAGE model for forecasting air quality in the area of flight operations. Measurements taken during the ICARTT campaign are now the subject of several scientific investigations into North American air quality modeling and inverse modeling to improve source emission estimates.

Long-range Transport of CO Emissions from Russian Fires

Studying satellite data on global air pollution levels, Edwards and other MOPITT team members at NCAR and other institutions noticed an unusual spike in CO levels in late 2002 and early 2003 that affected the entire Northern Hemisphere. Analysis pointed to Russian source: massive peat fires smoldered near Moscow in the late summer and fall of 2002, and unusually intense Siberian wildfires broke out in the spring and summer of 2003. During the peat fires, Russian colleagues working with spectrometer data from the Obukhov Institute of Atmospheric Physics in Moscow (Leonid Yurganov and Evgeny I. Grechko) took air quality measurements from Moscow and a nearby site at Zvenigorod. The research combined the ground-based measurements with observations of atmospheric pollutants from two instruments on the Terra satellite: CO levels from MOPITT, and aerosol optical depth from MODIS. The results showed that smoke and pollutants from the fires had been carried over much of the Northern Hemisphere, affecting CO levels as far away as North America.

Edwards and colleagues also looked at the impact of emissions from Siberia and other parts of eastern Russia. Massive fires in the giant boreal forests and on the tundra, often started by farmers, typically rage throughout the spring and summer. The 2003 fire season was particularly intense. Satellite data showed plumes from Asia following the jet stream, with high levels of CO crossing the Pacific Ocean, reaching western Canada, and traveling down to the U.S. East Coast—evidence of the global impacts of large-scale fires (Figure 11). The research will be published in the JGR.

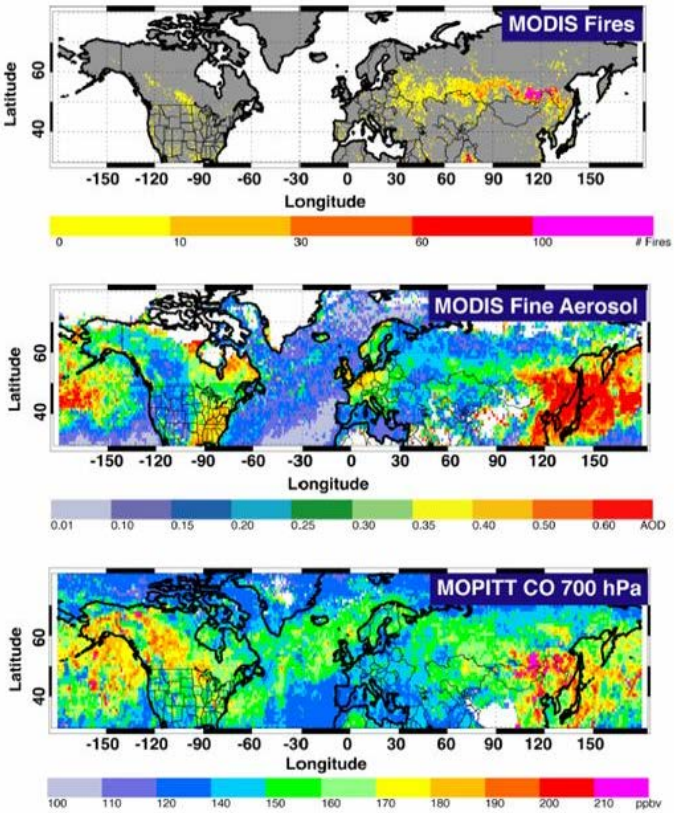


Figure 11: In the spring of 2003, the MODIS instrument on the Terra satellite instrument detected a large number of fires in Siberia, especially in the Baikal region (top). These fires produced large amounts of fine carbon aerosol, also detected by MODIS, that spread over the Pacific Ocean but lasted only a few days (center). They also produced CO, which was detected by the MOPITT (bottom). CO can last over a month, which allowed it to cross the Pacific Ocean and reduce air quality over North America before continuing on around the globe.

The CO Budget over Europe

Pfister completed a study on the CO budget for Europe. For this work, CO retrieved from MOPITT was used in conjunction with ground-based data provided by the Austrian Federal Environment Agency and CMDL and aircraft instruments (data provided by the German Aerospace Center [DLR] and National Center for Scientific Research, Paris [CNRS]), and compared to simulations from the MOZART CTM. The model simulations were provided by Gabrielle Petron (NCAR's Advanced Study Program [ASP]). The results showed that, on average, the largest contribution to the anthropogenic CO load over Europe at the surface comes from regional sources. Further significant impact is evident from sources in North America and Asia. With increasing altitude the influence of European sources weakens, and the impact of CO from other continents gains in importance with Asian emission showing the highest contributions during most months and at most heights. Studies where the CO was tagged in the model according to the time of emission showed that the transport time needed for pollution from North America to reach Europe might be as short as one week. Asian emissions can be seen in Europe less than two weeks after being emitted when transported towards the northwest. The results of these studies have been published in JGR.

Pollution from Mega-Cities

Work has begun to see if the MOPITT instrument could be used to track CO pollution originating from cities (Cathy Clerbaux). Though MOPITT was not optimized to detect pollution plumes from cities due to poor measurement sensitivity in the boundary layer, initial results look promising. By averaging the data over four years to reduce noise from transient plumes, signatures from cities have been distinguished from transported emissions. This pollution from distant sources, clouds and the instrument's low boundary layer sensitivity bias the results. This initial investigation focused on cities such as Mexico

City, Kuala Lampur, Singapore, Jakarta and Surabaya, Indonesia. MOPITT shows how El Niño-related wildfires in Kalimantan on Borneo Island in Indonesia, contaminated the air in 2002 above Jakarta and Surabaya. The instrument also shows how pollution gets dispersed from cities. Mexico City and Jakarta are both surrounded by mountains. Due to topography, the satellite reveals that pollution can only escape upward or through openings---to the north for Mexico City and east for Jakarta. This work will provide the basis for future efforts in support of the MIRAGE field campaign in Mexico City.

Involvement with Other Satellite Missions

Collaborations are underway with Larrabee Strow and Wallace McMillan (University of Maryland, Baltimore County [UMBC]) who are investigating the potential for retrieving CO from the Aqua/AIRS (Atmospheric Infrared Sounder) instrument. Data are also being made available to the National Institute for Space Research in The Netherlands (Ilse Aben) for use in CO validation studies for the Envisat/SCIAMACHY (SCanning Imaging Absorption SpectroMeter for Atmospheric CHartographY) instrument. MOPITT data will also provide key validation of the CO retrievals from the recently launched NASA Aura satellite, carrying the TES (Tropospheric Emission Spectrometer) instrument, and Edwards is the Aura Validation Team Liaison for MOPITT.

Seasonal and Inter-Annual CO Variability

Now that there is an almost five-year record of MOPITT data, the seasonal and inter-annual CO variability may be examined. Edwards has led a project to investigate the extent to which seasonal variability is explained by the CO photochemical sink in conjunction with sporadic perturbations caused by wildfires. Gille and Yudin have also studied interannual variations by using MODIS Fire counts to identify fire sources and have compared with year-to-year CO variations. Using inverse modeling tools in conjunction with the MOZART CTM and surface network measurements, they estimated the potential inter-annual variations of the biomass burning over North Asia. This work is being prepared for submission to GRL.

Data Assimilation and Inverse Modeling

Work continues on the assimilation of MOPITT retrievals in chemistry transport models and on inverse modeling of CO surface emissions using different schemes and techniques. Two articles on the inverse modeling of CO surface fluxes (Petron et al., 2004) and assimilation of MOPITT CO retrievals with optimized fluxes (Yudin et al., 2004) will be published in the next issues of GRL. Jean-Francoise Lamarque is leading an effort to evaluate biomass burning emission inventories using the assimilation of MOPITT data.

Comparison of CO and Aerosol Emissions from Biomass Burning

Edwards is leading a study to investigate emissions from biomass burning in Africa and South America. This is a major source of pollution in the tropical troposphere and a major forcing of tropospheric chemistry. The outflow of both aerosol and CO from the widespread fires in southern Africa and South America during September-November 2000, is being studied using observation from the Terra satellite, CO profiles from MOPITT and aerosol optical depth from MODIS. Recent developments in aerosol retrieval allow the distinction to be made between fine and coarse mode particles. The fine mode particles are produced by the same anthropogenic combustion processes that emit CO, and comparison of the fine mode aerosol and CO distributions provide information about biomass plume aging and the associated advection and convection of the emissions. The long range transport of these pollutants and the impact on atmospheric air quality in remote oceanic regions is also being studied, along with the seasonal changes in the pollutant distributions by comparing with the observations of CO and fine mode aerosol made during the December 2000-February 2001 period. A paper describing this work will soon be submitted to JGR.

Photochemistry

Urban areas are strong sources of pollutant gases and aerosols that can influence both regional and global environments. These pollutants include primary pollutants released into the urban atmosphere (primary pollutants, e.g., hydrocarbons and NO_x), as well as secondary pollutants produced in the atmosphere by photochemical processing (secondary pollutants, e.g., ozone, inorganic and organic nitrates, acids, peroxides, carbonyls, and other partly oxidized organics). Many of these secondary pollutants play an important role in the atmosphere far from source regions, for example as sources of HO_x and NO_x in the remote atmosphere. Understanding the details of this photochemical processing is a primary focus of ACD.

Peroxy Radical Studies

Chris Cantrell of the ARS Group investigates the behavior of odd hydrogen and organic radical species in the troposphere through observations using state of the art instrumentation. Over the last few years, the ARS Group has developed a chemical ionization mass spectrometric-based method for the quantification of hydroperoxy and organic peroxy radicals, which has been deployed in several aircraft- and ground-based campaigns. Work this year involved publication of results from recent studies and further laboratory work to improve the performance of the instrument during field deployments. Progress was slowed by the fact that Cantrell took a temporary assignment as Associate Program Director for Atmospheric Chemistry at the National Science Foundation in Arlington, Virginia, from August 2003 to August 2004.

In 2001, observations of peroxy radicals were made from the NASA P-3B aircraft during the Transport and Atmospheric Chemistry near the Equator – Pacific (TRACE-P) campaign. This experiment examined the emissions and evolution of trace gases from eastern Asia. Funding for participation in the campaign, analysis of the observations, and preparation of a manuscript (Cantrell et al., 2003) were provided by the NASA Tropospheric Chemistry Program. The paper presents methods for approximating the concentration of free radical species and ratios of species. A steady state model was employed that satisfactorily reproduces the observed concentrations except during encounters with clouds or air masses with high aerosol surface area densities, and when the NO concentrations were very high (> 0.5 ppbv) or very low (<5 pptv). The observations provided indirect evidence of the heterogeneous uptake of radicals by cloud droplets and aerosols. The failure of the model and low and high NO concentrations implies missing or misrepresented processes that will be investigated further. Cantrell contributed to several other papers related to the TRACE-P campaign.

The TRACE-P campaign involved significant collaboration with scientists from universities and national laboratories. The members of the Science Team are shown in Table 1.

ARS Table 1: Science Team members for TRACE-P mission.

Bruce E. Anderson	NASA Langley
Eric C. Apel	NCAR
Elliot L. Atlas	NCAR
Melody A. Avery and Stephanie A. Vay	NASA Langley
Alan R. Bandy	Drexel University
Donald R. Blake	University of California – Irvine
Edward V. Browell	NASA Langley
William H. Brune	Pennsylvania State University
Christopher A. Cantrell	NCAR
Gregory R. Carmichael	University of Iowa
Antony D. Clarke	University of Hawaii
James H. Crawford	NASA Langley
Douglas D. Davis	Georgia Institute of Technology
Fred L. Eisele	Georgia Institute of Technology
Johann Feichter	Max-Planke-Institut fur Meteorologie
Frank Flocke	NCAR
Alan Fried	NCAR
Henry E. Fuelberg	Florida State University
Brian G. Heikes	University of Rhode Island
Daniel J. Jacob	Harvard University
Makoto Koike	Nagoya University
Yutaka Kondo	Nagoya University
Reginald E. Newell	MIT
Samuel J. Oltmans	NOAA

Michael J. Prather	University of California – Irvine
Daniel D. Riemer	University of Miami
Glen W. Sachse	NASA Langley
Scott T. Sandholm	Georgia Institute of Technology
Richard E. Shetter	NCAR
Hanwant B. Singh	NASA Ames
Robert W. Talbot	University of New Hampshire
Anne M. Thompson	NASA Goddard
Charles R. Trepte	NASA Langley
Rodney J. Weber	Georgia Institute of Technology

In May and June of 2002, a ground-based comparison of the NCAR peroxy radical CIMS instrument (PeRCIMS) and Bill Brune's (Pennsylvania State University) Ground-based Tropospheric Hydrogen Oxides Sensor (GTHOS) was carried out. It involved comparing ambient concentrations of HO_2 and HO_2+RO_2 radicals and comparing signals from two synthetic radical sources. The results were very good and indicated the ability to independently generate known peroxy radical levels (see Figure 12), and the ability to quantify ambient radical levels. The results were published this report year (Ren et al., 2003). The outcomes were encouraging enough that a second comparison may take place in the spring or summer of 2005. This project involved collaboration with NCAR and Pennsylvania State University faculty and staff (see Ren et al. [2003] author list) that led to collection of valuable data and publication of two papers (Ren et al., 2003; Ren et al., 2004).

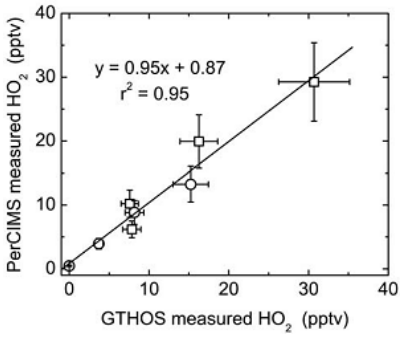


Figure 12: Comparison of GTHOS measured HO_2 with that generated by the NCAR calibrator (top panel), comparison of PeRCIMS measured HO_2 with that generated by the Penn State calibrator (middle panel) and comparison of PeRCIMS and GTHOS measurements on the same calibrator, either NCAR (squares) or Penn State (circle) (bottom panel).

Two final papers were published this year on the ACD-led TOPSE (Tropospheric Ozone Production about the Spring Equinox) campaign that involved measurements of a number of species aboard the NCAR/NSF C-130 aircraft during the winter to spring seasonal transition in 2000. These deal with the behavior of reactive nitrogen species (Murphy et al., 2004) (in collaboration with Ronald Cohen and students at the University of California, Berkeley) and photochemical ozone production (Stroud et al., 2004) (in collaboration with internal and external TOPSE participants) and help to complete the interpretation of the TOPSE observations.

One final paper on the ACD-led International Photolysis frequency Measurement and Modeling Intercomparison (IPMMI) exercise was published this year related to the observations and radiative transfer modeling of the UV-B photolysis of ozone, j($O(^1D)$) (Hofzumahaus et al., 2004). The IPMMI campaign and subsequent analysis involved collaboration with a number of scientists from the U.S. and Europe, and summarized the ozone photolysis results that solidifies the current understanding of the ozone molecular parameters and ability of the community to accurately measure and model this quantity.

Additional laboratory work on peroxy radicals was done by members of the Laboratory Kinetics Group, Geoff Tyndall and John Orlando, who, in collaboration with Alam Hasson (California State University, Fresno), conducted detailed modeling studies of previously reported laboratory experiments which revealed substantial yields of hydroxyl radicals in the reactions of HO_2 with both acetyl peroxy and acetonyl peroxy radicals. In the former

reaction, an OH yield of 40% was found, while in the latter case a yield of 67% was obtained. Prior to the beginning of this work, no evidence had been reported for the direct production of OH. Modeling studies indicated that the effects on tropospheric ozone and OH would probably be small (<5%); however, the implications for the stable oxygenated products would be greater. The reaction of HO_2 with acetyl peroxy has previously been thought to produce only acetic and peracetic acids. The yields of these compounds (and hence their source from this reaction) will now have to be reduced by almost a factor of 2. If other peroxy radicals from oxygenated species also undergo a similar reaction, the predicted yields of hydroperoxides will be substantially reduced. (Hasson et al., *J. Phys. Chem. A.,* 2004).

Peroxyacyl Nitrates (PANS)

As mentioned above, Flocke and Swanson flew a new instrument, the PAN-CIGAR (PAN-CIMS Instrument by GIT and NCAR), for fast (1-2 sec), continuous measurements of peroxy acetyl nitrate (PAN) and related species on the NOAA P-3B aircraft as part of the NOAA-led ICARTT and NEAQS programs.

The instrument was flown during ICARTT missions without an on-board operator and produced better than 85% data coverage for the entire mission. PAN, PPN, MPAN, APAN, PiBN, PBzN and MethoxyPAN were measured simultaneously. The performance is demonstrated in Figure 13, which shows some results from the July 20 flight while near 1 km altitude and while crossing the polluted outflow from New York City at a downwind distance of about 120 km.

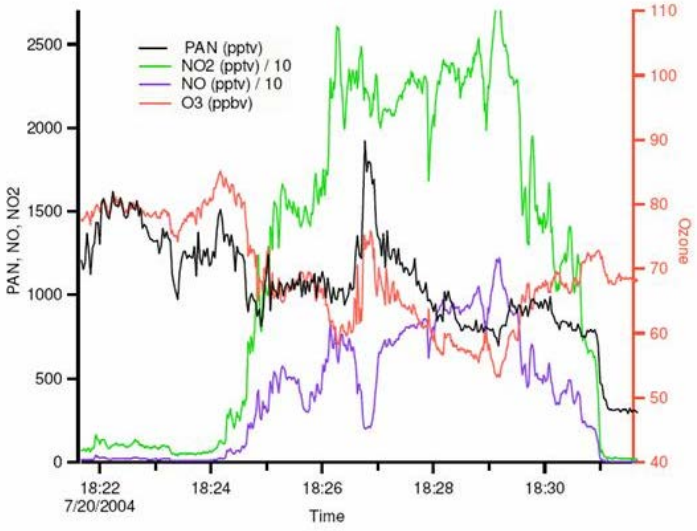


Figure 13: Preliminary data from the 7/20/2004 flight through the NY City Plume, ~120 km downwind, ~1 km altitude, during the ICARTT program.

While this outflow event shows a large amount of structure, probably caused by air masses of different photochemical age and different initial pollution levels, an excellent correlation down to the fine time scale of seconds is observed between ozone and PAN as a result of photochemical activity. These PAN data are the first reliable high-time resolution (2 sec) continuous measurements made from an aircraft. Similar transects of biomass burning plumes encountered during ICARTT will allow unprecedented analysis of the partitioning of reactive nitrogen species in aged plumes. The accuracy of the instrument could be verified through comparison with other measurements of reactive nitrogen and the sum of all reactive nitrogen on board the NOAA P-3 aircraft, and comparisons with instruments on-board the NASA DC-8, that also flew in conjunction with some of the ICARTT missions. Two abstracts analyzing results from the flights have been submitted for the AGU Fall Meeting.

ICARTT/NEAQS was an international multi-aircraft, ship and ground-based program including instrumented aircraft from England and Germany. Principal collaborators with the PAN Group were James Roberts, Andy Neuman, John Nowak, and Fred Fehsenfeld, all of

the NOAA Aeronomy Laboratory.

Formaldehyde (CH_2O)

The APOL Group (Alan Fried, Jim Walega, and Dirk Richter) has been actively involved in efforts to advance understanding of tropospheric photochemistry based upon high quality ambient CH_2O measurements acquired during various field campaigns. Last year's ASR describes one aspect of this activity involving the APOL Group's TRACE-P data. The Group is continuing with this endeavor this year with INTEX-NA data. Although it is far too early to formulate a comprehensive story, a preliminary first look at this data reveals a very important finding: namely, the persistence of elevated CH_2O mixing ratios at high altitudes during the summer time over the continental United States. Persistent continental thunderstorm activity during the summer months vertically convects polluted boundary layer air to high altitudes where it eventually mixes with cleaner background air in the outflow of clouds. Although this process has been well established, vertical convection of soluble and reactive gases, like CH_2O, has not been well characterized during such events. The flight tracks during the INTEX-NA study, which passed over natural and anthropogenic source regions of the south and mid-west United States, provided an excellent opportunity to study cloud outflow and cloud processing events.

The histogram plot of Figure 14 displays the APOL Group's one-minute CH_2O measurement distributions acquired during four early flights in July on NASA's DC-8 aircraft during the INTEX-NA campaign. These measurements were all acquired at pressure altitudes > 30,000 feet where one typically expects to observe CH_2O mixing ratios around 50 to 100 pptv. Although the observed spread is fairly large, the median value of 192 pptv is more than a factor of 2 higher than typical expected background levels. Such elevated CH_2O levels in the upper troposphere can play a significant role in the HO_x radical budget since the primary source of these radicals, $O^1(D) + H_2O$, decreases as the available H_2O vapor decreases with altitude. Despite the fact that this observation is based on very limited data, the Group observed a similar persistence of elevated CH_2O at high altitudes during many other flights.

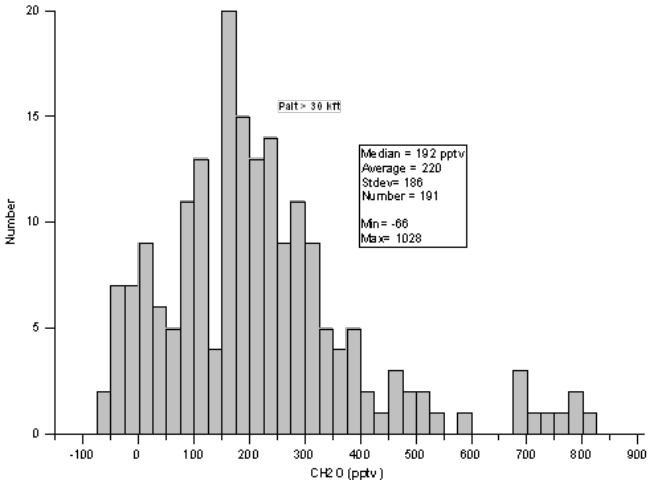


Figure 14: Histogram of the CH_2O distribution observed Palt > 30 kft during four selected INTEX-NA flights in early July 2004.

Radiation

Photochemical reactions provide the driving force for much of the chemistry in the atmosphere. The in situ rates of these photolysis reactions are important in understanding production and loss terms for the key atmospheric species odd hydrogen radicals and ozone. The objective of this research by the ARIM Group (Rick Shetter, Barry Lefer, and Sam Hall) was to deploy two SAFS systems on the NASA DC-8 aircraft platform during the INTEX-A mission in the summer of 2004 to measure the in situ total spectral actinic flux as a function of wavelength and calculate the in situ photolysis frequencies of 23 important photochemical reactions. Photolysis frequencies for photodissociation reactions involving

O_3, NO_2, CH_2O, HONO, HNO_3, N_2O_5, HO_2NO_2, PAN, H_2O_2, CH_3OOH, CH_3ONO_2, $CH_3CH_2ONO_2$, CH_3COCH_3 , CH_3CHO, CH_3CH_2CHO, CHOCHO, CH_3COCHO, $CH_3CH_2CH_2CHO$, and $CH_3COCH_2CH_3$ will be calculated from the measured UV-VIS spectral actinic flux. The instrumentation, which has flown on the NASA DC-8 during the Pacific Exploratory Measurements (PEM)-Tropics A , Subsonic Assessment, Ozone and Nitrogen Oxide Experiment (SONEX), PEM-Tropics B, Stratospheric Ozone Loss Validation Experiment (SOLVE), and the TRACE P missions, had an approximated detection limit of less than 0.01 W/m2/nm dependent on wavelength resulting in photolysis frequency detection limits of 2 X 10^{-7} sec^{-1} for $jO(^1D)$ and 1 X 10^{-7} sec^{-1} for jNO_2, all with a time response of 10 seconds.

In addition, the ARIM Group deployed a newly developed actinic flux system equipped with a monolithic monochromator with a cooled back thinned windowless CCD detector and a PC014+ based data acquisition and control system. This new system will have a time response of 0.1 to 10 HZ.

The instruments performed quite well on all of the aircraft flights with 100% data return. Final calibrations are currently being performed and data will be submitted to the INTEX/ICARTT archive in the next few months for use by the INTEX and ICARTT science team members.

Regional and Global Chemical Transport Models and Air Pollution Studies

Many of the chemical and physical processes that occur in the atmosphere are non-linear, so it is not possible to apply simple scaling relationships (e.g., simple dilution) to estimate the impacts on chemistry and climate of current emissions and future urban growth. Therefore, detailed numerical model representations of the primary chemical and physical processes are required.

Weather Research Forecasting with Chemistry (WRF-Chem)

ACD scientists are playing a major role in the development and testing of a new, state-of-the-art regional chemistry transport model, the Weather Research Forecasting with Chemistry (WRF-Chem) model. Xuexi Tie, Sasha Madronich, and visiting graduate students, Zhuming Ying (York University) and GuoHui Li (Texas A&M University [TAMU]), are collaborating with George Grell of NOAA's Forecast Systems Laboratory (FSL) to implement chemical models developed at NCAR into WRF-Chem and to apply the model to the planning of a major international field campaign, MIRAGE-Mex, planned for early 2006.

The WRF-Chem model was successfully ported over the central Mexico region, with emissions data for Mexico City and the surrounding region and was used to perform simulations at various resolutions (4 km, 6 km, and 12 km). Mexico City emissions were implemented through a collaboration with Aron Jazcilievich of the Universidad Nacional Autonoma de Mexico (UNAM). Preliminary results show that the modeled temperatures and winds reproduce well the observed diurnal cycles, but with a cold bias indicating that the "heat island" of the city is not yet well represented by the model. The diurnal cycles and magnitudes of surface concentrations of CO, NO_x ($NO + NO_2$), and O_3 within Mexico City compare well with observations, and show that the model is able to capture high pollution events. In anticipation of the MIRAGE-Mex field campaign, the interaction of urban outflow plume with the surrounding region was studied. For this study, Alex Guenther and Christine Wiedinmyer provided current estimates of regional biogenic (vegetative) emissions, and Jean-Francois Lamarque provided biomass burning emissions. Preliminary results show (Figure 15) that this interaction leads to more regional O_3 production than would be expected from the three sources (urban, biogenic, and biomass burning) taken in isolation. These preliminary results have been presented at conferences (Tie, and Madronich, Modeling of Mexico City Air Pollution and Outflow with WRF-Chem, 5th WRF/14th MM5 User's Workshop, June 22-25, 2004, Boulder, CO; Tie, Madronich, Effect of mobile, biomass burning, and biogenic emission on Mexico City's Air

Pollution and Outflow, 13th International Scientific Symposium of Transport and Air Pollution, Boulder, September 13-15, 2004, Boulder, CO.)

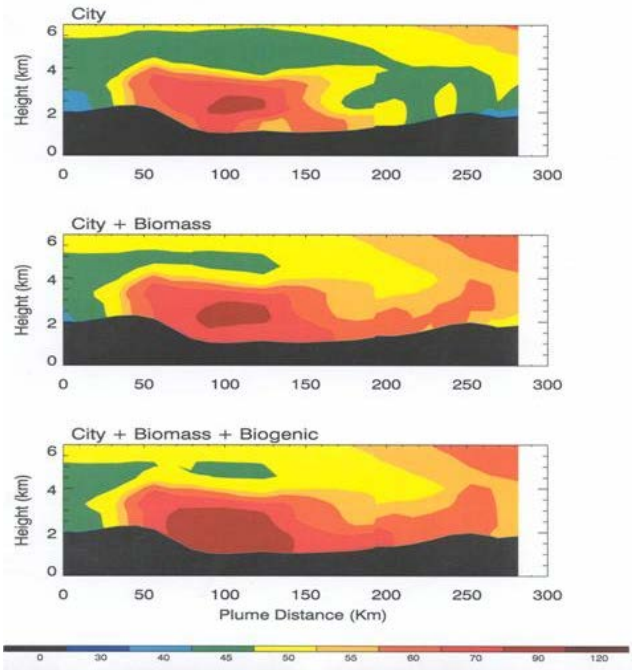
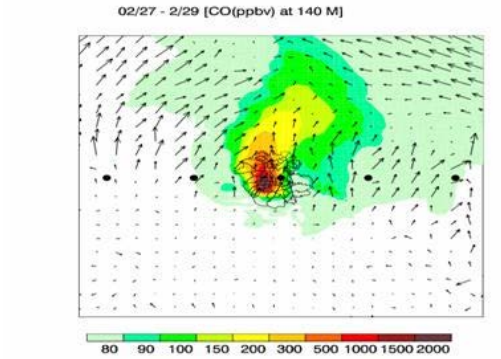


Figure 15: Ozone (O_3) concentrations simulated with the WRF-Chem model, showing the interaction between the Mexico City pollution plume with regional biomass burning and biogenic emissions. Upper panel shows the O_3 resulting from urban emission only. Middle panel includes effects adding biomass burning emissions, which contribute NO_X in the NO_X-limited regime (far-field, ca. 200-300 km). Lower panel adds biogenic emissions, which contribute hydrocarbons in the hydrocarbons-limited regime (near-field, 50-150 km).

The WRF-Chem model is also being used to determine the most favorable location for ground-based measurements during MIRAGE-Mex. This heavily instrumented "supersite" will be a link between the urban measurements and the mostly aircraft-based, regional-scale measurements, and therefore should be located outside the city in the direction of prevailing outflow. Initial WRF-Chem simulations for late February 2004 indicate that the outflow was predominantly towards the north-east (Figure 16), but additional simulations are underway to better establish the frequency distributions. This information, together with logistic considerations, will be used to select the location of the measurement site.



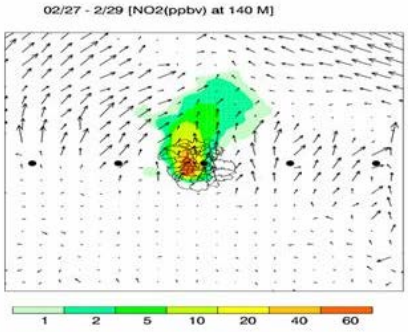


Figure 16: Surface concentrations of CO and NO_2 near Mexico City during 27-29 Feb 2004. Note prevailing outflow towards the North-East.

HANK Regional Transport Model

As the development and testing of the WRF-Chem model continues, some regional studies have been carried out with ACD's more mature HANK model. HANK is an off-line regional model based on MM5 meteorology and is in use by the broader community. A collaborative study by Peter Hess, Tie, and Wenfang Lei (TAMU) examined the air quality in the Houston-Galveston area, and, in particular, the role of industrial emissions, with two publications describing the results (Lei et al., *J. Geophys. Res.*, 2004; Zhang et al., *Proc. Natl. Acad. Sci.,* 2004). The HANK model was also used by Hess and collaborators, Moti L. Mital (Ohio Supercomputing Center) and C. Sharman, (National Physical Laboratory, New Delhi, India) on first-ever regional air quality simulations in India, where pollutant concentrations are exceptionally high and therefore of regional and even global interest.

Global Chemical Transport Models and Air Pollution Studies

The MOZART-2 model, developed by ACD scientists in collaboration with researchers from universities and other institutions, has been used to elucidate a variety of global-scale issues. Hess, in collaboration with David Parrish (NOAA/Aeronomy Laboratory) used MOZART-2 to examine decadal trends of pollutants on the west coast of the U.S. between 1985 (measurements made at Punta Arenas) and 2002 (measurements made during the ITCT-2K2 experiment). The model results suggest that much of the measured differences during these two time periods are due to the sampling of different meteorological regimes, rather than pollution trends. A paper describing this work has been accepted.

Hess and post-doctoral fellow, Kazuyo Murazaki, used MOZART-2 to examine for the first time the effect of climate change on U.S. air quality, by comparing simulations for 1990-2000 and 2090-2100. The main conclusion is that while climate change increases the local ozone production over the eastern U.S, it decreases the import of ozone from Asia. Significant changes were also found in photolysis rates over the U.S. as well as in chemical inflow, outflow, and transport. Overall, these results suggest that climate change and air quality will be fundamentally linked over the next century.

Tie, Madronich, and collaborators, Daniel Lack, Neville Bofinger, Aaron Wiegand (Queensland University of Technology) and Bernard Aumont (University of Paris) implemented a parameterization for the formation of secondary organic aerosols (SOA) in MOZART-2, and carried out simulations to assess the effect of the SOA on global atmospheric oxidants. These results (Lack et al., 2004.) are part of a wider assessment of the role of aerosols in global tropospheric chemistry (Tie et al., in preparation).

The MOZART-2 model was also used by Tie, Guenther, and Wiedinmyer to examine how regional and global tropospheric chemistry might be affected by changes in biogenic volatile organic emissions that occur as a result of land cover change. Tie, with collaborators Renyi Zhang and David Bond (TAMU) examined the relative impacts of anthropogenic and natural NO_x sources over the U.S., and with collaborators Sushil Chandra and Jerrold R. Ziemke (NASA) found evidence for elevated tropospheric O_3 over the oceans in the Northern Hemisphere. (Zhang et al., *Proceedings of National Academic*

Science, 2003; Wiedinmyer et al., submitted 2004; and Chandra et al., submitted 2004.)

Louisa Emmons, Hess, and Lamarque, in collaboration with John Mak (State University of New York [SUNY], Stony Brook), have been studying the signatures of ^{13}C in CO using observations and model simulations (Figure 17). Since different sources of CO have different isotope ratios, ^{13}CO will vary depending on the relative contributions of the sources. Tracers of the ^{13}C isotopes of all of the carbon compounds have been added to the MOZART mechanism. Using the biomass burning emissions developed by James Randerson (University of California, Irvine), that include the C3/C4 plant type fraction, they have been able to include the appropriate ^{13}C emissions for forest versus savanna burning. The model simulation of ^{13}CO has helped explain the observed seasonal and interannual variations in the time series at several stations. The differences between modeled and measured amounts of both CO and the isotope fraction are being used to estimate improvements to the CO emission inventories.

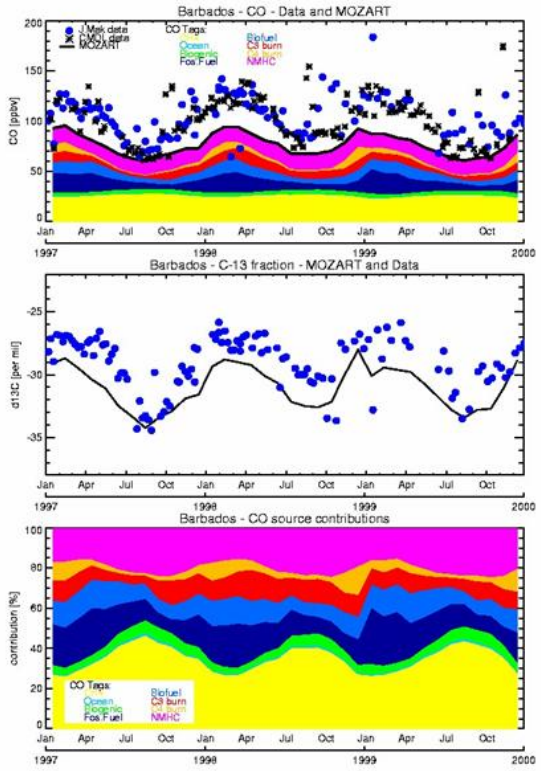


Figure 17: Comparison of measurements and MOZART results for CO and $d^{13}CO$ at Barbados (13N, 59W) for 1997 through 1999. The top panel shows CO measurements from J. Mak, SUNY Stony Brook (blue dots) and the NOAA/CMDL network (black stars), along with the simulated CO. The various source contributions to CO (CH_4 and NMHC oxidation, and fossil fuel, biofuel, biomass burning, biogenic and ocean emissions) are also shown. The second panel shows measured and modeled $d^{13}CO$. The third panel shows the CO source contributions as fraction of the total CO (in %).

Research Groups

Analytical Photonics and Optoelectronics Laboratory (APOL)

Atmospheric Odd Nitrogen (AON)

Atmospheric Radiation Investigation and Measurement (ARIM)

Biosphere-Atmosphere Interactions (BAI)

Laboratory Kinetics (LK)

Measurement of Pollution in the Troposphere (MOPITT)

Measurements, Standards, and Intercomparisons (MSI)

Regional and Process Studies (RPS)

Stratospheric/Tropospheric Measurements (STM)

Reactive Carbon Research

One of the major challenges in tropospheric chemistry over the next decade will be to understand and predict the fate of reactive carbon. Achieving this goal requires the study of the many complex chemical, physical, and biological processes that control the surface emissions of these species, their chemical transformations in the atmosphere (in both gas and condensed phases), and their eventual removal from the atmosphere via deposition. A number of activities in ACD, including field and laboratory observations, focused on the study of reactive carbon over the past year.

Emissions of Primary Organic Compounds

This year the Eric Apel of the MSI Group collaborated with university and government researchers on a number of important data interpretation projects resulting in two publications.

In Grossenbacher et al., 2004, two data sets are compared in which isoprene nitrate concentrations are measured along with (among others) isoprene, NO_x, and first generation reaction products with isoprene: methacrolein and methyl vinyl ketone. A conclusion of the study is that it is important that isoprene nitrates be quantified as part of future atmospheric field studies, along with other biogenic nitrates, to assess biogenic organic nitrates' relative role in sequestering atmospheric NO_x, and the extent to which the biogenic organic nitrates represent a significant fraction of the alkyl nitrates detected in previous studies. This is particularly important in light of suggestions that atmospheric deposition of nitrogen may be an important source of nitrogen to nitrogen-limited forests, and that gas-phase nitrogen compounds can undergo direct uptake by leaves, thus potentially impacting the carbon cycle.

Jobson et al., in press, discusses that Houston, Texas, has one of the worst air pollution problems in the country. The 2000 TEXAQS was initiated to help ascertain the causes of the poor air quality. The MSI Group's instrument was one of four in situ instruments making measurements of C_1-C_{10} hydrocarbons at the La Porte supersite during the TEXAQS Experiment. This paper explores the sources of VOCs in the Houston area and finds that industrial emissions have a strong impact on the atmospheric mixing ratios of light alkanes and light alkenes; the light alkenes at times dominated the airmass reactivity. These species react very quickly and in the presence of NO_x can rapidly form ozone, one of the major components of poor air quality.

Reactive Carbon Species as Sources and Reservoirs of Radical Species

Eric Apel of the MSI Group has also collaborated with university and government researchers on studies of hydrocarbons as sources of radical species.

Measurements of the Penn State Total OH Loss Measurement (TOHLM) instrument (DiCarlo et al., 2004) with OH losses calculated from the sum of the measurements of individual species thought to be the largest contributors to OH loss in the forested environment. A major discrepancy was found which leads to the conclusion that there are unmeasured (unknown) reactive species in the forested environment that are the cause. Potential candidate reactive species are the C_{15} sesquiterpenes. It is suggested that significant work remains in order to understand the chemical environment in the forest.

Oxygenated Volatile Organic Carbon (OVOC) contribution to the HO_x cycle

There is much uncertainty in our understanding of regional and global distributions of oxygenated VOCs (OVOCs), their contribution to the HO_x cycle and to secondary organic aerosol formation (Apel et al., in preparation). If recent measurements are accurate, there is a suggestion that the OVOCs may in fact be more abundant than non-methane

hydrocarbons (NMHCs) (Singh et al., 2004). Recent experiments have begun to show a convergence between formaldehyde measurements and model results (Fried et al., 2003). However, this is not the case with higher molecular weight carbonyl compounds (Singh et al., 2004); most measurements in the free troposphere for the higher aldehydes (C_2 and up) show significantly higher mixing ratios than models predict. This paper in progress explores the distribution of acetone, methanol, acetaldehyde and methyl ethyl ketone in the Pacific during springtime. Relationships to tracer species such as CO, acetonitrile and methyl chloride are investigated with respect to source relationships. The Model for Ozone and Related chemical Tracers (MOZART) model is used to calculate expected mixing ratios and arithmetic ratios of species of interest in the TRACE-P regime and these are compared with measurements.

Gas-aerosol Partitioning of Organic Species

Jim Smith and Fred Eisele of the Photochemical Oxidation and Products Group (POP) have developed an instrument, the Thermal Desorption Chemical Ionization Mass Spectrometer (TDCIMS), for characterizing organic compounds in ultrafine aerosol. Historically, the identification of organic compounds has been one of the most difficult challenges in aerosol measurement, as organic compounds in aerosol (1) have very low vapor pressures and are not easily detected, (2) are usually large compounds and easily decompose during analysis, and (3) often have many structural isomers, and are thus difficult to identify. The TDCIMS technique, which has undergone several improvements over the past year, is well suited for overcoming many of these challenges. Since it relies on chemical ionization mass spectrometry to ionize and detect compounds in the aerosol, it is both sensitive and imparts less fragmentation to the parent ion compared to techniques that rely on electron impact ionization or laser ablation and ionization. An additional feature is its use of a triple quadrupole mass spectrometer, which allows for the identification of complex ions and structural isomers by collision-induced dissociation of ions of a pre-selected mass. In addition to these inherent advantages, a number of additional improvements have been incorporated in the TDCIMS instrument specifically targeted at organics. New data acquisition and control software now allows for rapid mass spectrum acquisition of up to 50 amu s^{-1}, thus allowing large mass ranges to be scanned in the time that the aerosol is undergoing thermal desorption. Temperature programming has also been added to the thermal desorption procedure allowing this to be ramped from room temperature to ~300 °C. An octopole ion guide has also been installed in the ion beam path, resulting in improvements in sensitivity of up to an order in magnitude. Evaluation and calibration of the instrument is on-going, as are measurements of ambient aerosol performed outside the POP laboratory and at the Marshall Test Site. This work is being carried out by a second graduate student, also supported by the ASP graduate fellowship program and co-advised by J. Smith (ACD) and Jose Jimenez (CU).

Laboratory Kinetics

The Laboratory Kinetics (LK) Group (Geoffrey Tyndall, John Orlando, and David Hanson) has continued its studies of tropospheric oxidation processes, maintaining an emphasis on the chemistry of volatile organic compounds.

Oxidation Pathways for Alkyl Iodides

Alkyl iodides (e.g., ethyl iodide, CH_3CH_2I) are emitted from the oceans to the atmosphere. Once in the marine boundary layer these compounds are rapidly oxidized by photolysis and by reaction with OH and chlorine atoms, leading to the release of free iodine atoms. The subsequent chemistry of these iodine atoms is believed to result in the destruction of ozone and the formation of new particles in the boundary layer. The LK Group, along with colleagues from the GIT and Auburn University, has been collaborating on a study of the mechanism of the oxidation of these alkyl iodides. The reactions of ethyl iodide and 2-propyl iodide with chlorine atoms have been shown by both experimental and theoretical means to proceed in part via the formation of a bound complex and in part via more conventional hydrogen abstraction pathways. Figure 18 shows product yields from the

oxidation of 2-propyl iodide. The propene and chloroacetone are formed following elimination of iodine from the initially formed primary alkyl radical, while acetone comes from the secondary oxy radical. The 2-chloropropane is produced from an exchange reaction via the adduct. Product yield data are in qualitative disagreement with a previous study, but are in keeping with expectations based on this Group's previous studies of the analogous bromine compounds and with general halocarbon oxidation structure/reactivity rules.

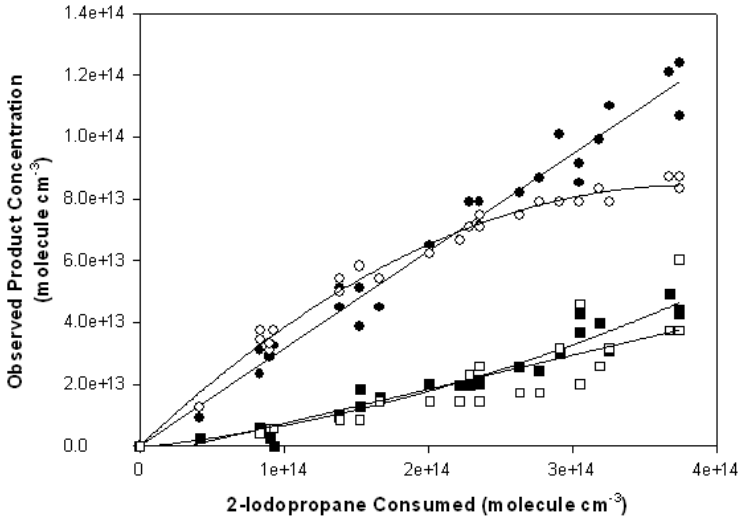


Figure 18: Products observed in the Cl-atom initiated oxidation of 2-iodopropane, for $[CH_3CHICH_3]_o$ = 14 x 10^{14} molecule cm^{-3}, in 720 Torr air diluent: Acetone, solid circles and solid line (upper); propene, open circles and solid curve (upper); 2-chloropropane, open squares and solid line (lower); chloroacetone, solid squares and solid line (lower).

Nitrate Production from Toluene Oxidation

The rate-limiting step in the tropospheric production of ozone is the reaction of peroxy radicals (HO_2 and organic peroxy radicals, designated RO_2) with NO:

$RO_2 + NO \rightarrow RO + NO_2$

In competition with this radical cycling pathway is the formation of organic nitrates,

$RO_2 + NO + M \rightarrow RONO_2 + M$

a process that removes reactive radicals from the atmosphere and limits the extent of ozone production. There is currently a great deal of activity centered on achieving a quantitative understanding of organic nitrate production over the range of temperature and pressure conditions encountered in the troposphere. Working with scientists at NCAR and at the Ford Motor Company, Cherelle Blazer (SOARS) has been examining the extent of nitrate production from the oxidation of toluene, a major anthropogenic emission. Chlorine atoms are reacted with toluene in an environmental chamber to provide a clean source of benzyl peroxy radicals in the presence of NO, and the yield of benzyl nitrate is then quantified as a function of temperature and pressure. The data indicate a strong positive dependence of the yield of benzyl nitrate on pressure as expected. However, preliminary indications suggest that the nitrate yield does not increase significantly with decreasing temperature. This latter result conflicts with current understanding, and may lead to substantial changes in predicted nitrate formation rates in the troposphere.

Oxidation Mechanisms of Methyl Formate and Methyl Acetate

Methyl formate and methyl acetate are important members of the ester family, oxygenated organic molecules that are present in the atmosphere. While both may be emitted from vegetation, their major sources are thought to be from their use as solvents and flavoring agents in the food industry. They can also be produced directly in the atmosphere from the oxidation of ethers. While esters are undoubtedly present in urban atmospheres, their measurement has proven difficult. ACD scientists and post-doc Andre Pimentel (NASA

Goddard) have studied the oxidation of both these esters by OH radicals, their primary mode of destruction in the atmosphere.

$OH + CH_3C(O)OCH_3 \rightarrow H_2O + CH_3C(O)OCH_2$ (1a)

$OH + CH_3C(O)OCH_3 \rightarrow H_2O + CH_2C(O)OCH_3$ (1b)

$k_1 = 3.5 \times 10^{-13}$ cm^3 molecule^{-1} s^{-1}

$OH + HC(O)OCH_3 \rightarrow HC(O)OCH_2$ (2a)

$OH + HC(O)OCH_3 \rightarrow C(O)OCH_3$ (2b)

$k_2 = 1.8 \times 10^{-13}$ cm^3 molecule^{-1} s^{-1}

Both reactions are very slow, which makes quantification of the product yields difficult. However, theoretical prediction of the branching ratios is also difficult for slow reactions, making measurement essential. Detailed studies of both molecules revealed evidence for OH attack at both carbon atoms in each molecule. Pathways (1a) and (2a) both lead to the formation of organic acids and anhydrides (which will probably be taken up by droplets and hydrolyzed to the corresponding acids). Pathways (1b) and (2b), on the other hand, produce simpler products such as CO and CO_2. Figure 19 shows formation of acetic acid, acetic formic anhydride, and CO_2 from the oxidation of methyl acetate by OH radicals. The CO_2 yield is curved upwards, indicating that it is formed from the rapid decomposition of another product.

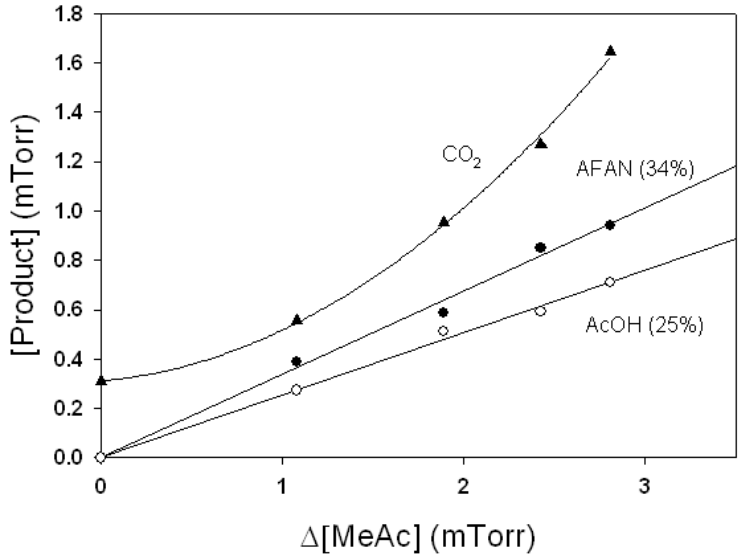


Figure 19: Product yields from the reaction of OH with methyl acetate (MeAc) at 700 Torr total pressure in the presence of 300 Torr O_2. The data for CO_2 have been offset vertically by 0.3 mTorr, and the line through the CO_2 data is a quadratic fit, for visual purposes. The data clearly indicate OH attack at both possible sites in the molecule.

In a separate set of experiments, chlorine atoms were used to oxidize methyl acetate at a variety of temperatures. The resulting oxy radical, $CH_3C(O)CH_2O\cdot$ can either react with O_2, forming formic acetic anhydride (AFAN), or decompose by the so-called alpha-ester rearrangement to give acetic acid and the formyl radical.

$CH_3C(O)OCH_2O \rightarrow CH_3C(O)OH + HCO$

The latter step is temperature dependent, and so a strong variation of the product yields with both oxygen and temperature is anticipated. Figure 20 shows the yields of AFAN and acetic acid from the combined set of experiments. The lines represent a global fit to all the data using an activation energy of 10.1±1.5 kcal/mole. The ester rearrangement is a

reaction unique to oxy radicals derived from esters, involving a five-membered Hydrogen atom transfer to the carbonyl group, and this is the first measurement of its activation energy.

The results of both sets of experiments were combined with experiments of the reaction mechanisms initiated using atomic chlorine (Cl) to provide a complete picture of the oxidation of methyl acetate and methyl formate under atmospheric conditions (Tyndall et al., *J. Phys. Chem. A.*, 2004).

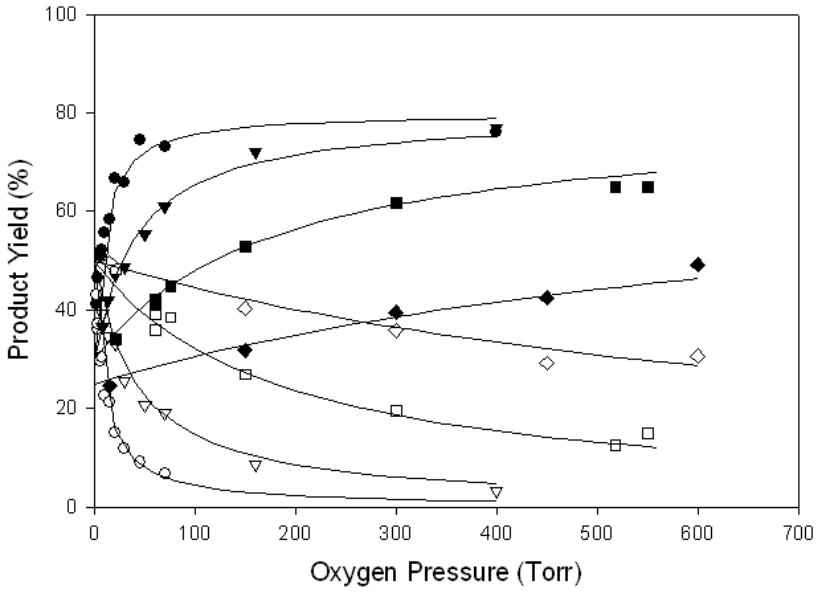


Figure 20: Plot of product yields from the oxidation of methyl acetate by chlorine atoms as a function of oxygen pressure at different temperatures. Circles, 253 K; Triangles, 273 K; Squares, 296 K; Diamonds, 324 K. Acetic formic anhydride is given by closed symbols, acetic acid by open ones. The lines are a simultaneous fit to all the data using an activation energy of 10.1 kcal/mole for the alpha-ester rearrangement.

Research Groups

Photochemical Oxidation and Products (POP)

Atmospheric Radical Studies (ARS)

Analytical Photonics and Optoelectronics Laboratory (APOL)

Laboratory Kinetics (LK)

Measurement, Standards, and Intercomparisons (MSI)

Multiphase Processes in the Troposphere

Multiphase processes are an important part of atmospheric chemical processes and additional studies are required to quantify the chemical and physical gas- and condensed-phase processes that control the number density, size distribution, chemical composition, and physical and optical properties of aerosols. ACD scientists are addressing these needs through instrument development and field campaigns.

Interactions of clouds, aerosols, and chemistry are complex and varied. Cloud effects on chemical species include modification of the radiative properties, which directly influence photochemistry and emissions of biogenic organic compounds. Cloud chemistry, which includes aqueous and/or ice chemistry and modified gas chemistry, affects photochemistry and aerosol composition.

ACD scientists are using cloud-chemistry modeling to evaluate the impact of boundary layer processes and convective transport on chemical species distributions and interactions.

Recent advances in atmospheric chemistry research have focused on the central role of photochemical processing within snow pack. ACD scientists participated in several field

campaigns to evaluate these photochemical processes in mid latitudes and Polar regions.

Aerosols

Jim Smith, Lee Mauldin, Ed Kosciuch, and Fred Eisele of the POP Group conducted field measurements of atmospheric ion clusters and testing of a linear ion trap. If ion inducted nucleation is to play a role in the formation of new atmospheric particles, certain ion clusters such as $(H_2SO_4)_n$ would be expected to be present in the atmosphere at concentrations on the order of 10^1 to 10^2 ions cm^{-3}. Measurements of these clusters is difficult because of their low concentrations, but by using techniques developed in the early 1980s along with some recent improvements, these ions were observed and studied this past summer at the NCAR Marshall field site. The results are still being analyzed but appear to be supportive of an ion-inducted nucleation model recently developed by the NOAA Aeronomy Laboratory.

Linear ion traps offer several advantages over conventional mass spectrometers for the rapid measurement of large numbers of organics. As is the case for conventional ion traps, linear traps provide near simultaneous measurements of multiple compounds by acquiring spectra in a quasi-parallel manner by trapping and storing a wide range of ion masses and then analyzing them in a time short compared to their collection. The overall trapping and analysis efficiency of a standard ion trap, however, is quite low while linear traps offers both high ion throughput and high trapping efficiency. Last year a quadrupole mass spectrometer was converted into a linear ion trap mass spectrometer and tested in the laboratory. This year the linear ion trap was interfaced with an ion source capable of atmospheric sampling and taken into the field. The instrument is presently beginning some preliminary measurements at the NCAR Marshall field site.

The POP Group has also designed and built new aerosol instruments and improvements have also been made to the TDCIMS. The first new instrument is a Hygroscopicity Tandem Differential Mobility Analyzer (HTDMA). The HTDMA exposes size-selected particles to high humidity to characterize their ability to take in water vapor (their hygroscopicity). The motivation of this research is to understand the relationship between aerosol composition, hygroscopicity and cloud condensation nucleus potential of carbonaceous aerosol. It is often assumed that based on the hygroscopic growth of an aerosol one can extrapolate and determine the Cloud Condensation Nuclei (CCN) activity of the aerosol. This may not always be possible, particularly for ambient multi-component aerosols. An organic species may have a very low hygroscopicity (which would yield low hygroscopic growth at sub-saturated conditions), but still act efficiently as a CCN. The POP Group's research will investigate the conditions for which hygroscopicity can be correlated with CCN activity. With these results, scientists may then be able to formulate an analytic relationship between hygroscopic growth and CCN activation for use in climate models. This work is carried out in collaboration with Jim Smith and Athanasios Nenes (GIT). A graduate student from GIT, advised by J. Smith and Nenes, is carrying out this work in the POP laboratory with support from the Advanced Study Program's Graduate Research Fellowship program.

Another set of instruments, called Radial Scanning Mobility Particle Sizers (RSMPS), were built to perform field measurements of particle size distributions in the diameter range from 3-100 nm. This work was performed, in part, by Damian Mattis (SOARS). These instruments are compact and rugged, allowing them to be deployed to remote locations to perform continuous measurements of particle size. Such surveys will provide a better understanding of the location, meteorology, and chemical environment in which new particle formation and subsequent growth take place. In some cases these measurements will provide crucial information to allow TDCIMS measurements at a later time.

David Hanson of the Laboratory Kinetics Group (LK) measured the uptake of methane sulfonic acid by dilute sulfuric acid droplets in the laboratory using an aerosol laminar flow reactor (ALFR). This is important for understanding the growth rates of atmospheric aerosols when significant levels of methane sulfonic acid are present. Results indicate that uptake of methane sulfonic acid is very efficient. The results and this conclusion were presented as an invited talk at the 2004 fall meeting of the American Chemical Society. These results are not in agreement with those from a different technique: the droplet train

apparatus (DTA) that is in use in several laboratories. Application of these laboratory results to the atmosphere lead to vastly different predictions of particle growth rates which can affect climate processes. Thus it is important to understand the reasons for this descrepancy. Hanson and colleagues seek to understand all the kinetic processes in both the DTA and the ALFR to provide a physically based accounting of them. In this vein, two papers were published in the past year, and another is in preparation, on the physical basis of the emperical relationships that currently support the analysis of the DTA results. These publications are the result of collaborations with Akihiro Morita, Inst. of Molecular Science, Okazaki, Japan, and Masakazu Sugiyama, Dept. of Elect. Eng., Univ. of Tokoy, Japan.

Clouds - Cloud Chemistry Modeling

Effect of Boundary Layer Processes on Chemical Species' Distributions - Segregation of Chemical Reactants in a Shallow Cumulus Boundary Layer

Shallow cumulus clouds provide locations for aqueous chemical reactions in addition to enhancing transport and mixing and scattering radiation. Mary Barth (ACD's Regional and Process Studies [RPS] Group, joint appointment with NCAR's Mesoscale and Microscale Meteorology [MMM] Division), Si-Wan Kim (MMM visitor, Seoul National University), and Chin-Hoh Moeng (MMM) used the NCAR large-eddy simulation (LES) coupled with gas and aqueous chemistry (over 50 species) to investigate the segregation between hydroxyl radical (OH) and isoprene, species which react to eventually produce ozone. Knowing the degree of segregation between reactants will help improve regional and global-scale chemistry simulations that assume the reactants are well-mixed; it will also improve interpretation of chemical species measurements in the atmospheric boundary layer. Results of a simulation with only gas-phase chemistry show that segregation of OH and isoprene reaches 30% in the cloud layer (Figure 21). Inside the cloud layer, the turbulent flux of isoprene is positive and the vertical gradient of the mean OH concentration is also positive. This leads to a major sink of the covariance between these species, and hence a larger segregation. When aqueous-phase chemistry is also included, the segregation between the two species reaches 40% in the cloud layer, further indicating the importance of cloud chemistry on the distribution of OH and isoprene. These LES results will continue to be analyzed to determine which chemical reactions are contributing to the covariance of isoprene and OH.

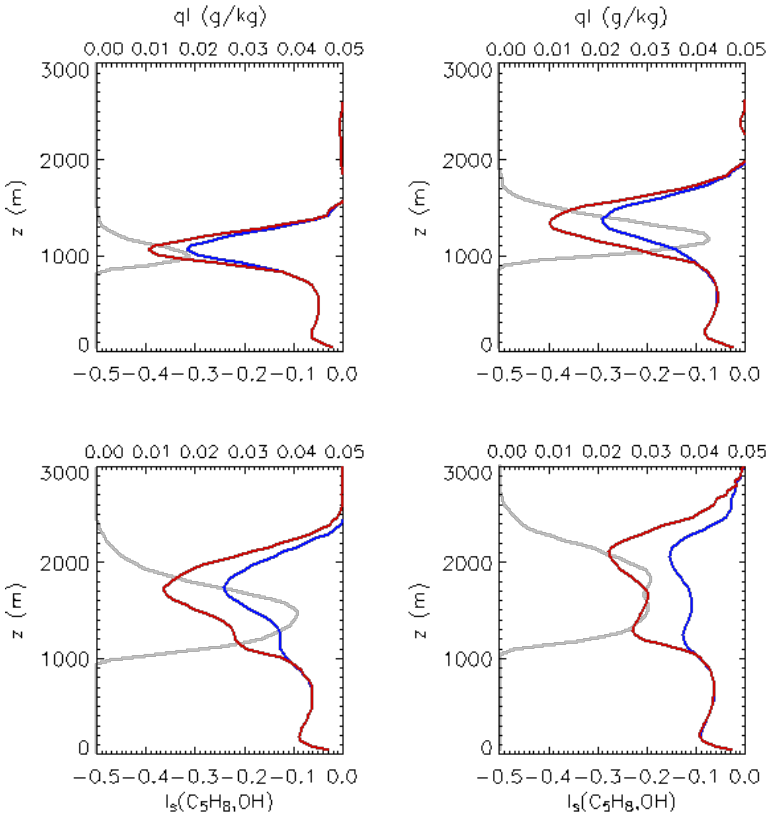


Figure 21: Intensity of segregation between isoprene and OH at (a) 1200 LT, (b) 1300 LT, (c) 1400 LT and (d) 1500 LT. Red lines with aqueous chemistry, blue lines with only gas chemistry. Gray lines are liquid water

content (scaled at top of figure).

WRF-AqChem: A Coupled Meteorology and Multi-Phase Chemistry Model - Development and Initial Results of Model

Barth, William Skamarock (MMM), and Kim implemented a simple gas and aqueous-phase chemistry mechanism into the WRF model to begin investigations on the effect of convection on the chemical environment. Convection plays an important role in transporting pollutants from the surface to the upper troposphere, scavenging soluble species and depositing much of the soluble species to the surface, and converting species chemically in the cloud drops. Simulations of the 10 July 1996 STERAO storm were performed to provide a way to evaluate the modeled chemistry results with observations (Figure 22). Sensitivities of the chemical species distributions to the cloud microphysics representation are currently being investigated. This WRF-AqChem model will continue to be developed by incorporating the aqueous chemistry modules into the community WRF-Chem model, by incorporating lightning production of NO_x and interactions between gas and ice phase species. Barth and Skamarock also plan to continue collaborations with John Worden and Kevin Bowman (NASA Jet Propulsion Laboratory) to examine the feasibility of using convective-scale cloud chemistry modeling with satellite data retrieval of ozone and carbon monoxide.

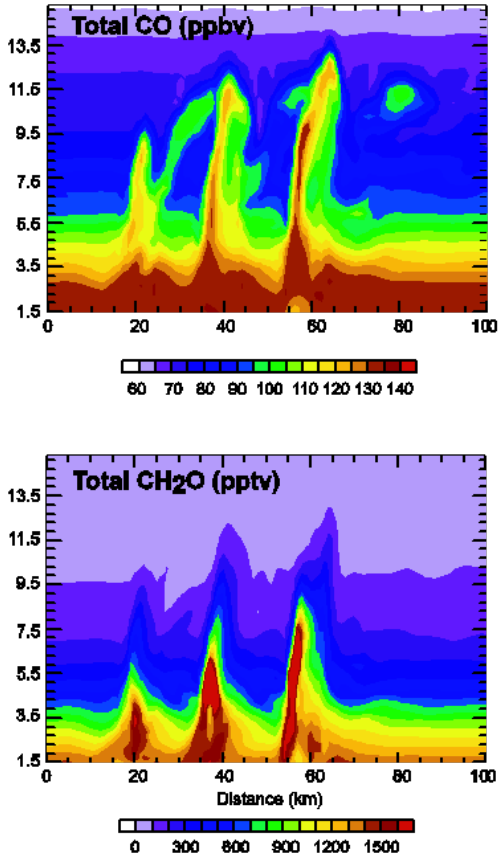


Figure 22: Cross-section of the total (gas + cloud water + rain + ice + snow + hail) mixing ratio of carbon monoxide (CO) and of formaldehyde (CH_2O). Both species are found in high concentration near the surface and lower concentration above the boundary layer. Carbon monoxide, an insoluble species, is primarily transported to the upper troposphere, while CH_2O, a soluble and reactive species, has a fraction reacted or precipitated to the ground.

Intercomparison of Convective Cloud Chemistry Models

Barth designed and led an intercomparison study for convective cloud chemistry models as part of the 6th International Cloud Modeling Workshop, Cloud Chemistry Case (http://box.mmm.ucar.edu/individual/barth/TracerTransportDeepConvection.html). An intercomparison of these models will show how well-reputed models perform when simulating the same storm, giving a range of results that agree reasonably with

observations. The intercomparison case focused on the 10 July 1996 STERAO storm for which observations of carbon monoxide, ozone, and nitrogen oxides (NO_x) are available.

Barth and Kim contributed results from the WRF-AqChem model. These results are being compared to those from Chien Wang (Massachusetts Institute of Technology), Jean-Pierre Pinty and Celine Mari (Laboratoire d'Aerologie, Toulouse, France), Ann Fridlind (NASA, Ames Research Center), Vlado Spiridonov (Hydrometeorological Institute, Skopje, Macedonia), Maud Leriche and Sylvie Cautenet (Laboratoire de Météorologie Physique, Clermont-Ferrand, France), and Ken Pickering, Lesley Ott (University of Maryland) and Georgiy Stenchikov (Rutgers University). Passive tracer transport show similar results among the models and agree fairly well with observations. The intercomparison of NO_x produced from lightning and of the soluble species, nitric acid, hydrogen peroxide and formaldehyde, is currently being pursued.

Cloud Chemistry Process Studies - The Importance of the Cloud Drop Representation on Cloud Chemistry

Previous studies have shown that the representation of cloud drop microphysics affects the amount of sulfate produced by aqueous chemistry because aqueous sulfur chemistry depends on pH, and pH varies with drop size. Because other aqueous chemical reactions (e.g., those involving hydroperoxy radical and formic acid) also depend on pH, Barth is using a cloud parcel model coupled with gas and aqueous chemistry to investigate the importance of the model's cloud drop representation on cloud photochemistry. Barth's study focused on ozone, hydrogen peroxide, formaldehyde and formic acid under remote and moderately-polluted chemical and aerosol conditions. Results of the study showed that formaldehyde and formic acid are sensitive to the cloud drop representation, while ozone and hydrogen peroxide are not.

Snow/Ice

Mid-latitude Snow Chemistry Experiment

The MSI Group (Eric Apel) was selected to receive funds from the NCAR Director’s Opportunity Fund for a project entitled: “Investigation of snow-mediated photochemical processes at mid-latitudes”. This is a two-year project that is being conducted at the CU Alpine Research station at Niwot Ridge. Eric Apel, Elliot Atlas (now at University of Miami), Aaron Swanson, and Barry Lefer (now at University of Houston) are collaborating on this project with Russell Monson and Mark Williams (CU) and a number of colleagues from other universities. Two students, from the Louis Pasteur Institute in France, played an active role, under the direction of Apel, in the set-up of the experiment last winter and the initial data analysis.

Objectives of the study included increasing our understanding of key aspects of photochemical processes in snow that may be occurring at mid-latitudes. The combination of biological and photochemical processes within a snow covered terrain could have significant impacts on the seasonal budgets of many trace gas species, along with important effects on the chemistry of the boundary layer atmosphere. Figure 23 shows the students, Maxime Jaeger and Vincent Schell, participating in the hard work required to set up the experiment. Figure 24 shows a view of the sampler that was constructed and placed in the snow. The sampler was designed to obtain depth profiles of targeted VOCs in the interstitial air throughout the snow pack and above the snow pack. Figure 25 shows Swanson obtaining snow samples to be analyzed for physical and chemical makeup in a recently excavated snow pit.

Figure 23: Students transporting equipment to the site.

Figure 24: Sampler constructed and placed at the site for sampling the interstitial air in the snow pack.

Figure 25: After digging a snowpit, Swanson takes snow samples.

A significant fraction of the trace-gas emissions are thought to be products of biomass growth in microbial and fungal communities brought on by thermal insulation of the soil by the snow (Swanson et al., 2004, and references therein). The MSI Group is investigating whether the emissions from wintertime activity are an important source of VOCs to the atmospheric background mixing ratios and on what scales, local or global. Figure 26 shows some results that were obtained during one of the experiments conducted in spring 2004.

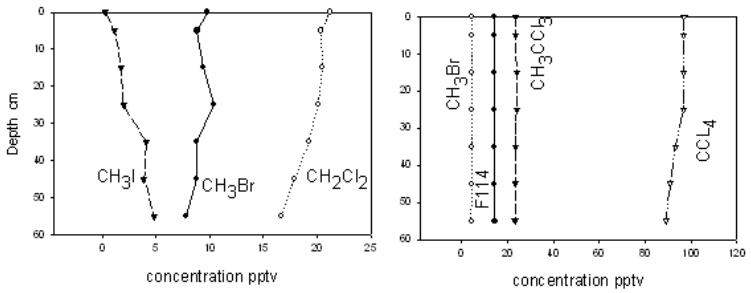


Figure 26: Depth profiles of select VOC species during spring 2004 experiment.

The Group is continuing to work up the data collected throughout spring 2004, in anticipation of next year's experiment. From Figure 26, it is clear that the terpenes show large concentration gradients and high relative concentrations near the soil surface. There are some clear differences in depth profile shapes for a number of species. With the data, species that increase significantly with depth and those which show losses to the soil surface can begin to be categorized to help us understand consumption and production processes for a variety of species. This data will be compared to data previously collected at this site by Swanson and co-workers, as well as data collected at other sites.

Deployment of a Snow Pack UV Radiation Profiler to Summit, Greenland

Sunlit snow has been shown to be one of the most photochemically active, and strongly oxidizing, regions of the entire troposphere, rather than simply a passive sink for the products of tropospheric chemical processing. Photolysis of nitrate initiates very active chemistry that leads to the release of a number of important trace gases. Initial measurements suggest that just above sunlit snow the production of HO_x from photolysis of HCHO, HOOH, CH_3CHO and HONO are all significant, and collectively dominate over photolysis of O_3. The net result is a large enhancement of OH and HO_2 in air just above the snow. Oxidation by OH is the main sink for a number of gases important for climate change and stratospheric O_3 depletion, so this enhancement may perturb chemistry in much of the free troposphere and also modify the chemical records of atmospheric composition ultimately preserved in glacial ice. While recent work has shown that photochemical and physical processes in the snow pack can impact the chemistry and composition of both the atmosphere and snow pack, these processes are, in general, poorly understood. This is especially true for the processes that produce and consume OH and HO_2.

In an effort to better understand this photochemical environment, Barry Lefer and Rick Shetter of the ARIM Group deployed a custom-profiling spectroradiometer to determine the intensity of solar UV radiation at five different depths in the surface snow pack. This instrument serially samples the radiation field from 290 to 560 nm from five different fiber optic cables inserted into the snow pack at different depths between 1 and 150 cm. These snow pack profiles of solar irradiance were used to determine the attenuation rate of UV in the snow pack and how this varied with changes in environmental variables such as snow pack density, soot content, solar zenith angle (SZA) and overhead ozone column. Given the isotropic nature of the radiation field in the snow pack, the measured irradiance spectra were converted to actinic flux spectra and the photolysis frequencies of several important snow pack photochemical reactions were calculated for the different sampling depths. This data has helped determine that the photic zone (or photochemically active region) of the snow pack is only the top 15 cm of the Greenland snow pack. This instrument was deployed for the months of March, April and May 2004 at the Greenland Summit Ice Camp (Figure 27) as part of the NSF-funded Collaborative Research Grant titled: "Impact of snow photochemistry on atmospheric radical concentrations at Summit, Greenland."

Instrument Description

The NCAR Snow Profiling spectroradiometer (NSPS) instrument consists of a small cosine-corrected irradiance probe (Ocean Optics), 5m fiber-optic with high UV throughput (Ocean Optics), a precision computer controlled dovetail slide (Velmex), a double monochromator (CVI Digikrom CM 112), a photomultiplier tube with a bialkali photocathode (Electron Tubes, LTD), a custom four-stage current-to-voltage amplifier and a PC computer for fully automated data acquisition and system control. Spectra from 280 to 560 nm are scanned every 30 seconds. The spectral band pass full width at half maximum (FWHM) for this optical system is 1.0 nm. Absolute spectral calibrations are performed with a National Institute of Standards and Technology (NIST) traceable 1000 Watt QTH irradiance standard in the NCAR laboratory before and after instrument field deployment. Field calibrations are performed with 250 W secondary QTH lamps every four-to-five days to assess the relative stability of the instrument sensitivity. Wavelength calibrations of the monochromator are performed in conjunction with each sensitivity calibration using the

emission lines from a mercury lamp to track any drift in the monochromator wavelength assignment.

Figure 27: Summit, Greenland snow photochemistry camp.

A Scanning Actinic Flux Spectroradiometer was also deployed to Greenland to measure the UV radiation incident to the snow pack surface. The quartz optical collector for this system was mounted on the roof of the mobile sampling laboratory and had a 30 cm artificial horizon to limit the field of view to 2pi steradians to minimize the influence of reflected light from the other sampling inlets.

It is quite difficult to measure snow pack radiation levels due to issues of self-shading by the optical sampling inlet. To this end, the ARIM lab has selected miniaturized Teflon sampling inlets (approximately 1 cm in diameter and less than 2.5 cm long), which attach directly to the end of a fiber optic using an SMA connector. These miniature-sampling inlets were inserted into the snow pack at a location near the gas sampling activities at five different depths between the surface and one and a half meters. Each sampling inlet was attached to a 5m fiber optic cable that was connected to the same spectroradiometer. The snow spectroradiometer serially samples each of these five depths, thus collecting a complete snow profile every two and a half minutes. The above-snow spectroradiometer continuously measured the actinic flux reaching the snow surface, which can account for any changes in the light environment (e.g., due to clouds) while a specific snow profile is being collected.

Antarctic Polar Plateau

One of the more fascinating recent advances in atmospheric research has been the recognition of the central role of photochemical processing within the snow pack on the chemistry of polar plateau boundary layer air. The most dramatic effects of the snow pack emissions appear to exist in Antarctica where, as part of the Antarctic Tropospheric Chemistry Investigation (ANTCI) field experiments, Fred Eisele, Lee Mauldin, Bruce Henry, and Edward Kosciuch (all members of the ACD Photochemical Oxidation and Products [POP] Group), in collaboration with colleagues from GIT and several other universities, have gained major new insights into the vertical and horizontal distribution of NO and NO_y. Very high levels of NO have been previously reported at the South Pole ground site with concentrations in the hundreds of pptv (parts per trillion by volume). These concentrations were shown in recent Twin Otter flights to be maintained well beyond the near vicinity of the South Pole. These high levels persisted in near surface air samples for ~ 300 km both upwind and downwind of the pole. It now seems likely that somewhat similar levels will be found over much of the plateau region. The influence of these snow surface emissions of NO_x was also observed to extend into the free troposphere. NO concentrations on the order of tens of pptv were still observed up to a half a km above the snow surface, suggesting that OH concentrations, and, hence, oxidation rates are very likely to be enhanced above those previously expected for this region. This observation is quite significant because it now demonstrates that a much larger fraction of the troposphere has an enhanced oxidation capacity and it is through this region that sulfur and other reactive compounds must be transported in order to reach the Pole and other plateau locations. Thus, reactive compounds such as DMS and SO_2 can be oxidized during transport far more quickly than previously calculated in model simulations. This decreased DMS lifetime is consistent with past and present observations showing very low concentrations

of DMS, SO_2, and gas phase H_2SO_4, and MSA at the South Pole. Additional Twin Otter flights near the coast addressed another previous mystery: Why have past observations of NO concentrations at the coast been so much lower than those observed at the Pole? Several flights along the Trans-Antarctic Mountains, particularly across the base of large glacial flows such as Byrd Glacier, at times revealed very high concentrations of NO and NO_y (hundreds of pptv). These enhanced concentrations are presumably the result of NO-rich boundary layer air, which, due to the katabatic flow, is transported from the plateau down these glacial valleys resulting in the transport of this NO_x enriched air to a few select outflow regions at the coast. The potential importance of these results for understanding ice core MS/sulfate ratios is the suggestion that the ratios of these compounds deposited to the snow surface may well depend on the distance from the coastal source of sulfur and the proximity of glacial outflow relative to sulfur inflow.

Some preliminary results arising from the in situ ground-based South Pole measurements have also been obtained. For example, PAN should have an atmospheric lifetime of months over Antarctica, and therefore could provide a mechanism for transporting reactive nitrogen from mid latitudes to the polar region. The results of PAN measurements at the Atmospheric Research Observatory (ARO) building at the South Pole, however, suggest that there are insufficient PAN concentrations to significantly affect the nitrogen chemistry over the plateau.

Early in the study, several instruments were operated during a nearly complete solar (~85% occlusion) eclipse. Since the sun height normally changes little during our study period, this eclipse was a rather unique opportunity to observe changes in photochemically-generated compounds with nearly an order of magnitude change in UV light as shown in Figure 28. Several interesting relations are demonstrated by this figure.

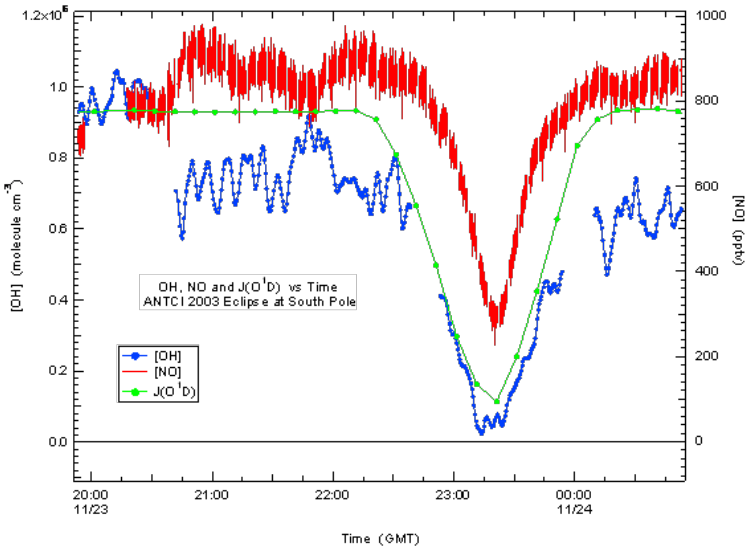


Figure 28: Some interesting South Pole boundary layer photochemistry observed during the near total solar eclipse that occurred on November 23, 2003. Since the sun only sets and rises once a year at the South Pole, this unique and rapid photochemical transient will be the basis for a modeling case study.

Prior to the eclipse, the anti-correlation between NO and OH can be seen.

- Above ~175 pptv of NO, NO_x levels are large enough that the reaction of OH with NO_2 becomes a significant sink for OH, thus a decrease in NO (and hence NO_x), causes an increase in OH.

During the eclipse, the percentage change in OH is larger than the percentage change in UV radiation ($J(O^1D)$).

- This observation reflects the fact that primary production of OH, via O(1D) production, has been decreased, while at the same time the steady state partitioning between NO and NO_2 is shifted to primarily NO_2, an OH sink. Thus during the eclipse, the production of OH is decreased while the sinks for OH are increased, causing the larger observed percentage change.

There is a time delay between UV and the response of NO.

- The time delay in the response of NO to the decrease in UV reflects the lifetime of NO in the atmosphere. The delay in response to the increase in UV reflects the photolysis lifetime of ambient NO_2 and nitrate in the snow pack (the source of much of the NO_x in the South Pole boundary layer).

Also note the small OH concentrations (~$4x10^4$ molecule cm^{-3}, or ~2 parts per quadrillion by volume) that the instrument is capable of measuring.

A new, compact mass spectrometer instrument has been designed and built this past year in order to allow OH to be measured on a Twin Otter aircraft during the upcoming ANTCI 2005 study. This instrument, when complete, should be four to five times smaller and lighter than the existing four channel system but still provide similar sensitivity for measuring OH, H_2SO_4 and MSA. The new system makes use of advances in mass spectrometer and octopole lens design and will serve as a prototype for a future HIAPER OH instrument.

Research Groups

Atmospheric Radiation Investigation and Measurement (ARIM)

Laboratory Kinetics Group (LK)

Measurement, Standards, and Intercomparisons (MSI)

Photochemical Oxidation and Products (POP)

Regional and Process Studies (RPS)

Chemistry in the Climate System

The global climate system is a composite of local, regional, hemispheric, and interhemispheric processes that occur from the surface to the upper atmosphere on time scales of minutes to decades. The role of chemistry in this complex system involves multiple interconnected components with a range of temporal and spatial scales.

A primary focus of the chemistry-climate modeling studies in ACD is to evaluate direct anthropogenic and biogenic emissions both spatially and temporally, to determine the influence of transport processes on the distribution of those emissions, and to examine the impacts of the emissions on atmospheric chemistry. In addition, the modeling studies also examine aerosol distributions, formation processes, influence on chemical species, and radiative properties and impacts including indirect aerosol and cloud effects. These studies, based on the current climate system, additionally provide a foundation for model simulations designed to study the influence and feedbacks of climate and global change on chemistry of past and, most importantly, future climate regimes.

Focused studies of biogenic emissions are a key aspect of ACD research on biogeochemical cycles. These studies include measurements of emissions and vertical flux of many species, including VOCs, NO_y, O_3, and CO. These measurements have been collected on a broad range of spatial scales from leaf, plant, and canopy scales, through to regional scales. The implications of these flux determinations on the local, regional, and global atmosphere are evaluated through the incorporation of empirically-based flux parameterizations in numerical model simulations.

The upper troposphere/lower stratosphere region of the atmosphere plays a crucial role in the climate system because of the radiative impacts of water vapor, ozone, and aerosols in that region. ACD research in the UTLS region is focused on understanding the distributions of ozone and water vapor and how photochemistry, multiphase chemistry, convection, and stratosphere-troposphere exchange influence those distributions.

The role of the middle atmosphere (the region between the lower stratosphere and the lower thermosphere) in the climate system is not well characterized. ACD research in this area is focused on understanding the broad interactions between chemistry, radiation, and transport using a combination of models and measurements/calculations of chemical

constituents and energy budgets.

Climate Simulations

The distribution and abundance of radiatively active gases and aerosols are important determinants in the Earth's radiation budget and the state of the climate system. Atmospheric chemistry and transport are key factors in determining the abundance and distribution of these trace gases and aerosols. Changes in the chemistry-climate-biogeochemistry system are expected to be strongly coupled with important, but as yet not well quantified, feedbacks. ACD scientists are evaluating this system through model development and simulations of various climate states.

Present-Day Climate

Tropospheric Ozone Interannual Variability

Using the available ozonesondes data, Lamarque has studied the interannual variability of tropospheric ozone focusing on the Northern Hemisphere poleward of 40°N. This analysis shows that the spring ozone interannual variability is strongly related to the phase of the NAO (Lamarque et al., 2004). Lamarque, Hess, and Mahowald are in the process of extending this analysis for a further understanding of the ozone budget in the troposphere.

Studies of the Arctic Oscillation

The study of the Arctic oscillation in tropospheric ozone by Hess and Lamarque was one of the first to show the influence of the Arctic oscillation on tropospheric ozone. It is shown in both a data analysis of ozonesondes and in model simulations. The NAO explains a significant amount of the interannual variability of springtime ozone over North America (Lamarque and Hess, 2004).

Role of Convective Versus Synoptic Transport

Hess examined the relative importance of convective versus synoptic transport and the seasonal variation and the atmospheric regions affected by these modes of transport. This study is important for understanding the different processes which influence the UTLS (and was summarized during the UTLS workshop). These modes of transport affect the chemistry in different ways (Hess, submitted).

Santa Fe Project

As an outcome of the Chemistry-Climate Interactions workshop organized by Lamarque and Jeffrey Kiehl (CGD), a project for the study of nitrogen deposition on the biosphere and its impact on the carbon cycle was designed. Lamarque, in collaboration with various groups (GISS, UKMO, Lawrence Livermore, UCI, Max-Planck Mainz, Max-Planck Hamburg, IPSL Paris) has combined and analyzed the results of nitrogen deposition. These results have been presented as a poster at the International Global Atmospheric Chemistry (IGAC) meeting. In addition, this model intercomparison will also be used for a paper on the ozone radiative forcing in the 21st century.

Past and Future Climates

Intergovernmental Panel on Climate Change (IPCC) Simulations

Lamarque, in collaboration with Hess, Emmons, Lawrence Buja (CGD), Warren Washington (CGD), and Claire Granier (NOAA/IPSL), has performed MOZART simulations from 1890 to 1990 in 20-year increments. The simulated ozone field has been used by the CCSM group in their simulations of the 20th century climate for the next IPCC Assessment.

Model Development

Off-line Community Atmosphere Model (CAM)

Phil Rasch (CGD), Hess, Stacy Walters, and Francis Vitt have successfully created an off-line-transport version of CAM, the transport model embedded within the CCSM framework. This model imports meteorological fields from other sources (e.g., NCEP, ECMWF) into the CAM model instead of using internally generated fields. This provides the opportunity to simulate the transport and chemistry of trace constituents (reactive and passive species and aerosols) using meteorological analysis. These distributions can then be compared with measurements on an episodic basis and used in process studies. This model introduces a new capability into the CCSM framework and reduces the software engineering effort required for maintaining multiple chemical transport models within the same institution. It also allows improvements to the consistency of representations of physical processes within the model and allows all components of the climate system to influence the chemical simulations. We anticipate that this model will replace the MATCH and MOZART CTMs.

Simple trace constituents have been successfully simulated in the off-line model using meteorological fields from NCEP, ECMWF and CAM. These tracers include an ozone-like tracer and other diagnostic species. The trace constituent distributions have been compared against those produced in MOZART, online CAM and MATCH with good results. This model is now coded to the computational standards of the CCSM. Chemistry is currently being implemented into the off-line-CAM model.

Interactive Community Atmosphere Model (CAM3)

Lamarque has completed the implementation of interactive chemistry (including aerosols) from the MOZART model into CAM3, using the WACCM (Whole Atmosphere Community Climate Model) framework. The radiative coupling is done through the ozone distribution and the aerosol distributions. This work has been presented at the CCSM workshop in July and will be the basis for the released version of CAM3 with interactive chemistry. This work is in collaboration with CGD (Rasch and Mahowald) and Walters (WACCM).

Lamarque has expanded the aerosols package developed by Tie to have a better representation of the formation of ammonium nitrate. This package is now running in the newest version of MOZART and in CAM3. In addition, several modifications were made to the modeling of dry deposition in MOZART in order to accommodate aerosols. Finally, interactive biogenic emissions of isoprene and soil NO_x emissions are now part of MOZART.

Model for Ozone and Related Chemical Tracers (MOZART)-4

MOZART-4 is an update to the MOZART model published by Horowitz et al. in 2003. This update has been necessary to transform MOZART into a state-of-the-art chemical transport model and to make it available to the community at large. The updates to MOZART will be included in the online and off-line CAM with chemistry. Numerous updates have been implemented by Lamarque, Emmons, John Orlando, Geoff Tyndall, Tie, Walters, and Hess. The improved chemical mechanism now considers three classes of large anthropogenic hydrocarbons: a large alkane (butanes and larger), a large alkene (butenes and larger) and an aromatic species (toluene). Reaction rates have been updated. Updated emissions have been constructed consistent with the new chemical mechanism. The ability to input multi-year emission datasets has been added. Lower boundary conditions can now be fixed for long-lived species (e.g., H_2 and CH_4). Interactive emissions are implemented, e.g., for isoprene and soil NO_x, as these depend respectively on the model temperature and photosynethic radiation and on the calculated soil wetness. The aerosol parameterizations have been updated. Photolysis frequencies are calculated with the fast TUV code, allowing online calculations consistent with model clouds and aerosols. Dry deposition is interactive for all species and with an additional parameterization of the effect of microbes on the dry deposition of CO and H_2. The lightning parameterization has been updated. New output fields have been enabled. A synthetic ozone field can be used in the stratosphere so as to constrain the stratospheric-

tropospheric flux of ozone to reasonable values when running MOZART with analyzed wind fields. Interactive water fields, instead of diagnosed water, have been implemented. Finally, a new website documenting the model, related publications, and ongoing research in global tropospheric modeling has been developed which allows downloading of the source code.

Tracer Version of MOZART-4

A tracer version of MOZART-4 has been developed by Hess, Vitt, and Gabrielle Pfister. This tracer version allows reading a number of chemical species into the model and specifying their chemical sources. For example, it allows the input of an OH field and the source of CO from the oxidation of hydrocarbons. The tracer version of MOZART-4 will be used for inverse modeling studies at considerably less expense than running the full version.

Adjoint Version of MOZART

Hess, Gabrielle Petron, and Baker developed most of the components for an adjoint version of the MOZART code during this year. The basic framework for the MOZART adjoint (i.e., running the model backwards) and the appropriate check pointing has been implemented. An adjoint of the diffusion code and convective code has been developed. In addition, an optimization code to solve for emissions has been developed.

Research Group

Global Modeling

Biogeochemical Cycles

The mission of the Biosphere-Atmosphere Interactions (BAI) Group is to advance understanding of the role of biosphere-atmosphere interactions in the Earth system and predict its response to human perturbations. This is being accomplished through multidisciplinary field, laboratory and modeling studies of the processes controlling these interactions on various scales (e.g., leaf to canopy to regional/global). BAI members during FY04 included Alex Guenther, Jim Greenberg, Peter Harley, Thomas Karl, Ryan Schnell, Andrew Turnipseed, and Christine Wiedinmyer.

Laboratory Studies

BAI scientists (Guenther, Greenberg, Harley, and Karl) are using laboratory facilities to characterize the processes that control biomass burning and biogenic emissions. Biomass burning studies were conducted in the ACD laboratory roasting/burning chamber facility in collaboration with Hans Friedli (ASP) and in the United States Department of Agriculture Missoula fire laboratory burn facility in collaboration with Robert Yokelson and Theodore Christian (both of University of Montana). Biogenic emission studies were conducted in the ACD phytotron and growth chamber facilities in collaboration with Emiliano Pegoraro (Edinburgh University, U.K.), Allison Steiner (University of California, Berkeley) and Teresa Nunes (University of Aviero, Portugal).

The laboratory biomass burning studies demonstrated that oxygenated volatile organic compounds (VOCs) and nitrogen compound emissions from fires are higher than most previous estimates and likely have an important role in fire dynamics (i.e., fuel ignitability) and regional air quality. This research also suggests that emissions of some compounds from smoldering fires (including charcoal production and post flaming phase pyrolysis) are underestimated in existing fire emission inventories. Three manuscripts (Karl et al., Greenberg et al., Christian et al.) describing these results are in preparation for submission to peer-reviewed journals.

The laboratory biogenic emission studies have shown that isoprene emission is more resistant and recovers more quickly from drought than does photosynthesis and stomatal

conductance. Isoprene emission rates show a strong correlation with leaf water potential, providing a useful parameterization for including the effects of drought stress in isoprene emission models. Other experiments have demonstrated that sesquiterpene emission rates from some important tree species are comparable to monoterpene emission rates and exhibit similar temperature dependence. Biogenic methanol emission rates were observed to vary across and within plant species by at least an order of magnitude. Leaf age was identified as the major source of within species variation in methanol emission. Observed light dependent monoterpene emissions varied as a function of growth temperature and certain monoterpenes (e.g., ocimene) were released at elevated levels in response to temperature stress. This work is described by Pegoraro et al., Harley et al., and Nunes et al., which are in preparation for submission to peer-reviewed journals in late 2004.

U.S. Field Studies

BAI scientists investigated biosphere-atmosphere interactions with six U.S. field studies during FY04 and analyzed data from an additional three U.S. field studies. The six FY04 field studies supported the research of investigators from five universities. A study of the contribution of biogenic isoprene emission to regional aerosol and oxidants was conducted at a poplar plantation in northern Oregon and was conducted in collaboration with Brian Lamb, Halvor Westberg and Adam Hill (Washington State University). The potential allelopathic role of biogenic VOC emissions from invasive Artemesia shrubs in New York was conducted in collaboration with Jed Sparks and Jacob Barney (Cornell University). An aircraft investigation of cicada outbreaks in Indiana was conducted in collaboration with Paul Shepson (Purdue University) and showed that the emissions from decaying cicadas did not have a significant impact on atmospheric chemical composition. Trace gas fluxes over a Colorado grassland were measured in collaboration with Matt Dunn (ASP/CU) and James Smith (ACD). The observations show that the grassland was a significant source of methanol and a sink for acetic acid and methyl acetate. Ozone deposition was measured at the Niwot Ridge, Colorado AMERIFLUX site in collaboration with Russell Monson (CU). The negative impact of high O_3 events on the subalpine forests downwind of Denver, Colorado are minimized by their occurrence during late afternoon-early evening periods when plant activity is low due to both water stress and low light levels. Studies of ammonia fluxes from soybean fields in North Carolina were conducted in collaboration with John Walker (North Carolina State University and United States Environmental Protection Agency [USEPA]). Significant fluxes were observed and the results demonstrated the utility of the ammonia CIMS system designed and built by ACD.

FY04 efforts also included a workshop, database development, data analysis and manuscript preparation associated with the Chemical Emissions, Losses, Transformations and Interactions with Canopies (CELTIC) study in Duke Forest, North Carolina led by BAI in collaboration with Chris Geron, Bob Arnts (USEPA) , Walker, Jose Jimenez, Darin Toohey, Alice Delia (CU), Sparks (Cornell), Mark Potosnak (Desert Research Institute), Greg Huey, David Tanner, Darlene Slusher and Robert Stickel (GIT), Kolby Jardine and Bradly Baker (South Dakota Institute of Mining and Technology), Jose Fuentes (University of Virginia) Will Vizuete (University of Texas), Fred Mowry and Jeff Herrick (Duke University), Francesca Rapparini (Istituto di Biometeorologia, Italy), Rei Rasmussen (Oregon Graduate Institute). The CELTIC results indicate that isoprene emission increases with elevated ozone and, on a canopy scale, with elevated CO_2.

Future changes in ozone and CO_2 could thus change regional isoprene emission rates leading to feedbacks. The pine plantation forest floor (soil and leaf litter) was a significant sink of methanol, acetone, acetaldehyde and isoprene. This is not well represented in existing models and could lead to overestimated ambient concentrations. Substantial sesquiterpene emissions observed from pine trees could be the dominant source of biogenic secondary organic aerosol mass under certain environmental conditions. PAN (and PAN-like compounds) were deposited at a much faster rate than is predicted by current models by a factor of 3-5. This has significant implications for the lifetime of PAN in the atmosphere and its role as a transporter of reactive nitrogen in the atmosphere. Simultaneous observations of biogenic VOC and total organic aerosol during CELTIC

allowed new constraints on aerosol yields and OH formation due to ozonolysis. The average aerosol yield for alpha-pinene, beta-pinene and d-carene are higher than calculated, supporting recent laboratory studies showing that polymerization reactions could enhance aerosol partitioning (Figure 29). Based on observed isoprene decay within the canopy, the upper limit of nighttime OH mixing ratios is less than reported measurements for other forests. Estimates of biogenic contributions to secondary organic aerosol mass at Duke Forest suggest that biogenic sources dominate which is somewhat surprising for this moderately polluted site.

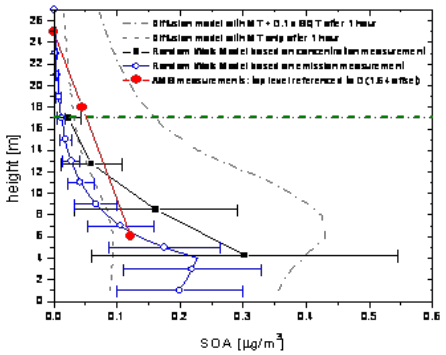


Figure 29: Comparison of SOA growth between different modeling approaches compared to measured gradients (red circles).

Analysis and publication of two other previous U.S. studies were completed in FY04. A tower flux study of isoprene and oxygenated VOC emissions from a northern Michigan deciduous forest was conducted in collaboration with Raymond Fall (CU) and Armin Hansel (University Innsbruck, Austria). The differences can be explained by the different physiological and phenological processes controlling these emissions. The multiscale (enclosures, tower, tethered balloon, aircraft) Ozarks Isoprene Experiment (OZIE) study was conducted in collaboration with Brian Lamb and Halvor Westberg (Washington State University), Jay Turner (Washington University), Paul Palmer (Harvard University), Geron and Thomas Pierce (USEPA) and demonstrated that central U.S. oak forests and woodlands have very high isoprene emission rates resulting in elevated regional formaldehyde concentrations. This formaldehyde is often transported northward and eastward towards urban centers such as St. Louis and Chicago, and participates in the production of ozone (Figure 30). Current photochemical models underpredict the magnitude of formaldehyde produced by isoprene oxidation which leads to incorrect chemistry simulations within the urban centers.

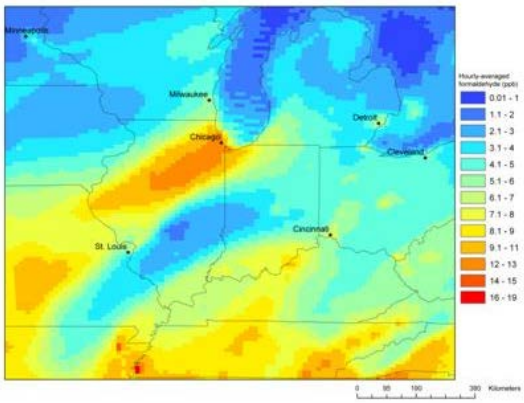


Figure 30: Hourly-averaged formaldehyde concentrations for 06:00 CDT on July 21, 1998, as modeled by CAMx. Winds on this day were predominantly from the south-southwest. A plume of elevated formaldehyde can be seen being transported from the forests of the Ozarks towards the northeast and into the Chicago urban area. The majority of this formaldehyde has been formed from the photooxidation of isoprene emitted from the Oak forests of the Ozarks on the July 20.

International Field Studies

BAI scientists participated in international investigations of biosphere-atmosphere

interactions in Brazil, Ireland, and Japan during FY04 and analyzed results from previous studies in China, Costa Rica, Brazil, and Finland. The FY04 Chemistry And Production Of Smoke (CAPOS) study in the Brazilian Amazon used airborne and ground measurements to characterize the primary emission composition of VOCs and other gases from tropical fires and within aging plumes in collaboration with Robert Yokelson and Theodore Christian (University of Montana), Don Blake (University of California, Irvine), Paulo Artaxo (University Sao Paulo, Brazil), and Joao Caravalho (Center for Weather Forecasts and Climate Studies [CPTEC] of the National Institute for Space Research [INPE], Brazil). Additional background measurements were made at a primary tropical forest flux tower near Manaus, Brazil in collaboration with Potosnak, Artaxo, Julio Tota and Antonio Manzi (Brazilian National Institute of Amazon Research [INPA], Brazil). Significant flux of monoterpenes was estimated from the vertical profile shown in Figure 31. The aircraft observations generally confirmed the emission profiles measured in the laboratory studies described above (Figure 32). The contribution of semi-volatile organic gases to secondary organic aerosol mass was studied in Japan in collaboration with Yoshizumi Kajii (Tokyo Metropolitan University).

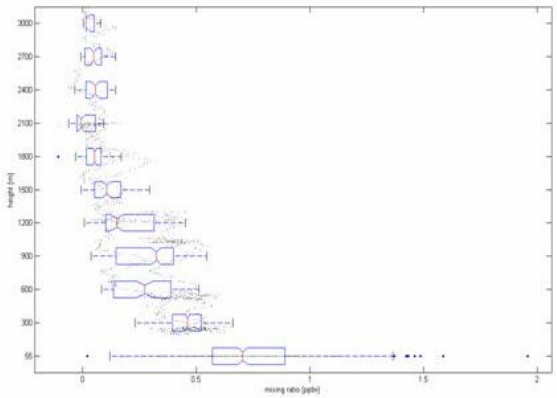


Figure 31: Altitude profile of monoterpenes above the Z34 tower close to Manaus.

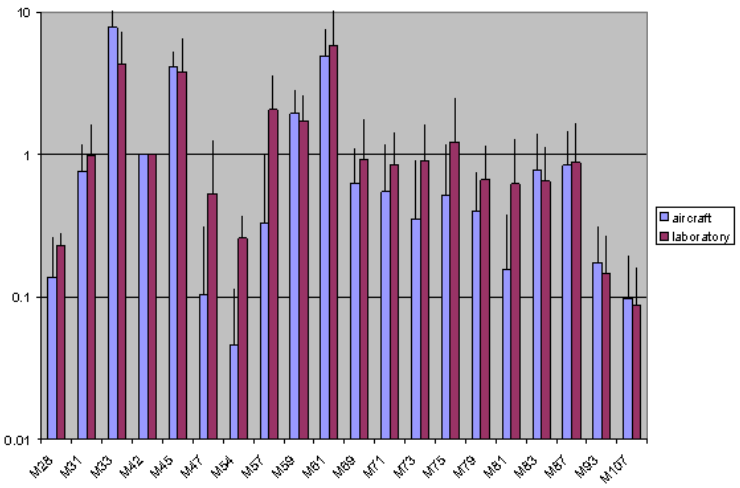


Figure 32: Comparison of emission profiles of identified compounds obtained by the PTRMS instrument between laboratory experiments (average of 30 experiments) conducted at the USFS fire lab in October 2003 and airborne measurements (35 samples from 10 fires) in 2004. All data are normalized to the biomass burning marker acetonitrile.

The results indicate that humidity plays a significant role in determining the uptake of some semi-volatile compounds. BAI scientists participating in the BIOFLUX field study on the Irish coast investigated biogenic fluxes of organic iodide compounds in collaboration with Colin O'Dowd (National University of Ireland), Liisa Pirjola (University of Helsinki, Finland) and Thorsten Hoffman (Institute of Spectrochemistry and Applied Spectroscopy [ISAS], Dortmund, Germany). A tethered balloon system was used to characterize vertical gradients of several alkyl halides including di-iodomethane, ethyl bromide and ethyl iodide. Concentrations decreased with height indicating a surface source of these compounds which are believed to be involved in new particle formation.

Two manuscripts were published in FY04 (Spirig et al., and Boy et al.) describing BAI results from the Origins of Secondary Organic Aerosol (OSOA) study that was conducted at a boreal forest site in Finland in collaboration with Christoph Spirig (Swiss Federal Institute of Technology [ETH] Zurich, Switzerland), Michael Boy and Markku Kulmala (University Helsinki, Finland). Total monoterpene oxidation rates during the OSOA study were not correlated with particle production events, but there was a strong correlation with ozone indicating that more ozone reactive biogenic compounds, such as sesquiterpenes, may make an important contribution. Vertical gradients of particles above the forest suggest that particle growth occurs throughout the boundary layer.

Tropical forest biogenic emissions were studied in the eastern Amazon (Brazil) in collaboration with Luciana Vanni Gatti and Carla Trostdorf (Energy and Nuclear Research Institute [IPEN], Brazil) and in Costa Rica in collaboration with Deborah Clark (University of Missouri), Sparks, and Potosnak. Seasonal isoprene variations in the Amazon were much higher than expected (more than a factor of 3 higher in the dry season). Tropical forest ecosystems in both Brazil and Costa Rica were both a significant source (daytime) and sink (nighttime) of methanol, acetone, and acetaldehyde. Dry deposition velocities of these and other (e.g., methyl vinyl ketone, methacrolein, and acetonitrile) compounds were a factor of 10-20 higher than estimated from existing deposition models which has important implications for regional and global chemistry and transport models. This work is described in Greenberg et al., 2004; Harley et al., 2004, Trostdorf et al., 2004, and Karl et al., 2004.

Baker et al., 2004, and two manuscripts in preparation describe studies of the impact of land cover change on biogenic emissions from Chinese landscapes that were conducted in collaboration with Baker, Rassmussen, Bai Jianhui (Institute of Atmospheric Physics [IAP] Chinese Academy of Sciences), Susan Owen (Lancaster University), and Geron. Chinese rubber tree and oil palm plantations have much higher terpenoid emissions than native tropical forests. This suggests that there has been and continues to be significant increases in biogenic VOC emissions in some tropical regions of China. Severe drought results in a dramatic reduction in these emissions demonstrating the equally important role of climate change.

Regional Modeling Studies: U.S.

Wiedinmyer and Guenther investigated biosphere-atmosphere interactions in the U.S. using regional chemistry and transport models. FY04 studies included an investigation of the impact of future climate and land cover on regional air quality in the Pacific Northwest and north central U.S. in collaboration with Brian Lamb (Washington State University), Cliff Mass (University of Washington) and Susan Fergusen (U.S. Forest Service) and a study of the contribution of sesquiterpenes and other biogenic VOC emissions to secondary organic aerosols in the eastern U.S. in collaboration with Jana Milford (CU). Both of these projects were initiated in FY04, and efforts were directed at setting up the regional air quality modeling system and developing the emission scenarios.

Regional Modeling Studies: International

Wiedinmyer, Sreela Nandi (ASP/ACD Postdoctoral Fellow), and Guenther investigated biosphere-atmosphere interactions in China, Brazil, and Mexico using regional chemistry and transport models in FY04. The contribution of biogenic VOC emissions to oxidant and particle production in China was studied in collaboration with Xiaoping Wang and Denise Mauzerall (Princeton University). The results indicate that future growth in China's fossil fuel emissions will lead to costly decreases in public health and crop productivity. Much of this region is VOC-limited so changes in biogenic VOC emissions will have important consequences for air quality. The BAI Group, along with Hsiao-ming Hsu (MMM and NCAR's Research Applications Program [RAP]), investigated the influence of biomass burning on regional air quality in the Brazilian Amazon along with a detailed sensitivity study of emission inputs which demonstrated that there are large difference in the fire emissions predicted using different methods recommended in the literature. The BAI Group also supported regional simulations of air quality in Mexico in preparation for the ACD Megacity Impacts on Regional and Global Environments [MIRAGE] study (Xuexie

Tie, ACD).

Global Modeling Studies

Wiedinmyer and Guenther investigated global scale biosphere-atmosphere interactions in FY04 using global chemistry and transport models. The contribution of biogenic VOC emissions to global organic aerosol was examined in collaboration with Joyce Penner (University of Michigan). The study showed that uncertainties in biogenic VOC emissions are a significant contributor to the total uncertainty associated with estimates of global radiative forcing of aerosols. A biogenic VOC model was integrated into the NCAR Community Climate System Model [CCSM] Land Surface Model [LSM] and used to investigate the sensitivity of emissions to climate and land cover in collaboration with Sam Levis and Gordon Bonan (CGD). Biogenic VOC emissions were sensitive to climate, and the estimated interannual variability exceeded 10% of the estimated annual anthropogenic emission estimates used for the IPCC emission scenarios. Finally, a study examining interactions among global change (climate and land cover), biogenic isoprene emissions, and the chemical composition of the atmosphere was completed in collaboration with Tie, Ronald Neilson (U.S. Forest Service), and Claire Granier (CNRS). Climate and land cover-driven changes in biogenic VOC emissions impacted simulated regional surface ozone concentrations by as much as -30% to 50% under certain emission and climate scenarios. The ozone production chemistry was shown to change under different emission scenarios (i.e., NO_x versus VOC) and has implications for unhealthy ozone concentrations and future ozone abatement strategies (see Figure 33).

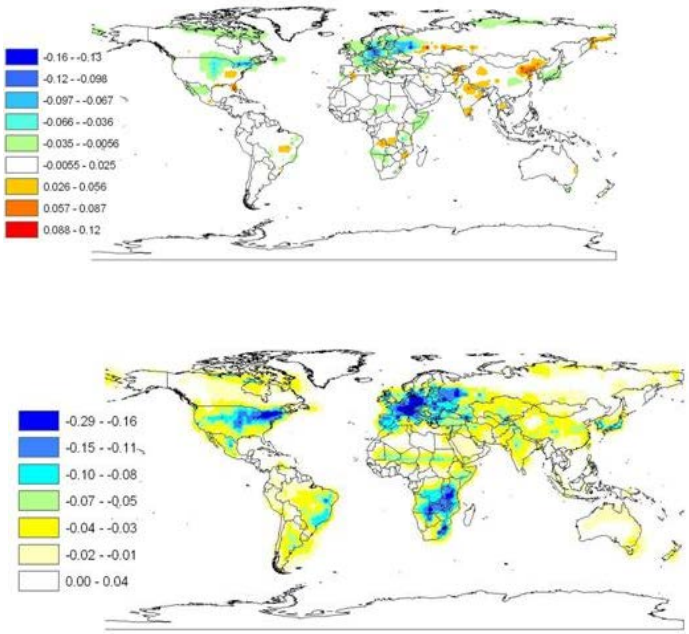


Figure 33: Change in L_N/Q for the month of July for [(FUTVEG-CURCLIM) – (CURVEG-CURCLIM)] (top) and [(FUTVEG-FUTCLIM) – (CURVEG-CURCLIM)] (bottom).

Model and Database Development

Guenther and Wiedinmyer also developed biogenic and fire emission models and databases for the scientific and air quality regulatory communities. FY04 accomplishments include the initial release (user's guide and files are available on the NCAR community data portal, https://cdp.ucar.edu/) of the Model of Emissions of Gases and Aerosols from Nature (MEGAN) which predicts biogenic emissions on a global scale at 1 km resolution (Figure 34). MEGAN was also integrated with the NCAR global models, MOZART and the Community Land Model (CLM), and an effort was initiated to integrate MEGAN with regional air quality models. In addition, a modeling framework was developed to predict daily emissions from fires for all of North America at a 1 km resolution for easy use in regional air quality model simulations. Fire emission inventories developed by this model will allow air quality modelers to include fire emissions with their model simulations and determine if fire emissions have a large impact on their air quality (Figure 35).

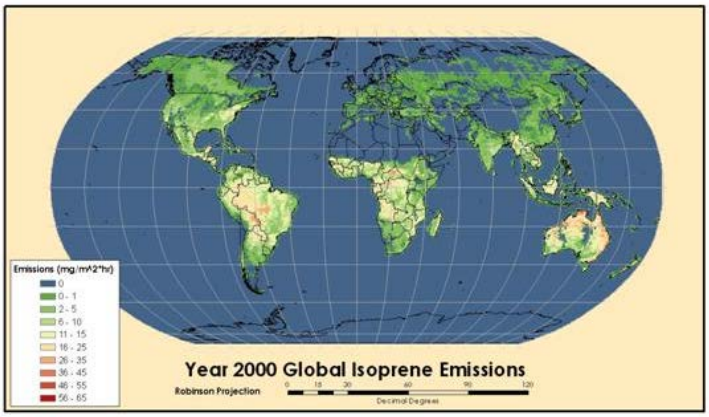


Figure 34: Global annual isoprene emission distribution for the year 2000 estimated by the MEGAN model.

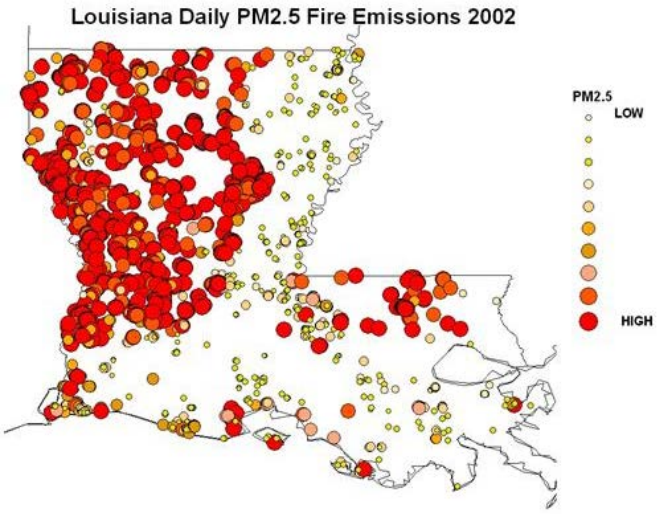


Figure 35: Estimates of fire emissions of PM 2.5 (particulate matter less than 2.5 mm) for Louisiana.

Instrument Development

Turnipseed, Guenther, Greenberg, and Karl developed instruments for investigating biosphere-atmosphere exchange in FY04. This included a Disjunct Eddy Accumulation (DEA) system that captures and stores air based on the vertical wind direction and speed. The concentrations in these stored samples (along with wind statistics) can then be used to determine fluxes of chemical trace species which are difficult to determine by other flux techniques which often need fast (< 1 s) measurement times. This project was in collaboration with Lamb and Mount, Shepson, and Steve Shertz (ATD). Two separate systems developed and evaluated in FY04 allow for DEA flux measurements of volatile organic compounds (VOCs) from both a tower and an aircraft platform.

Research Group

Biosphere-Atmosphere Interactions

Integrated Study of Dynamics, Chemistry, Clouds, and Radiation of the Upper Troposphere and Lower Stratosphere (UTLS)

The UTLS region is of critical importance for understanding long term global or climate change. The UTLS is a region where ozone is an effective greenhouse gas, and where water vapor, cirrus clouds, and aerosols each make a significant contribution to the radiation budget. The UTLS is also a region where transport processes that couple the

stratosphere and troposphere occur on a multitude of scales, which when combined with the strong vertical gradients in many chemical constituents, present a challenge to observational techniques and numerical models. Chemically, the UTLS region represents a transition in the nature of the mechanisms of ozone production and loss. ACD scientists are involved in studying various aspects of transport and chemistry in the UTLS as well as developing models and instruments to support these studies.

Satellite Data Analysis

The Satellite Data Analysis (SDA) Group (William Randel, Laura Pan, Bruce Henry, Steven Massie, and Fei Wu) focuses on studies of global scale chemical behavior using satellite measurements, meteorological data sets, and model simulations. Recent work has focused on chemical and dynamical behavior of the tropopause region, both in the tropics and extratropics, aiming to understand and quantify the processes which contribute to coupling in the UTLS.

The tropical tropopause layer (TTL, ~12-17 km) behaves as a transition between the convectively controlled troposphere and radiatively balanced stratosphere. Because air enters the stratosphere primarily in the tropics, the TTL serves as a boundary condition for the global stratosphere. Key science issues include understanding mechanisms of dehydration and cirrus cloud formation, and fast transport into and through the TTL (with relevance to short-lived chemical species). Many features of the TTL are poorly observed by conventional data sets, and there are important uncertainties in the relationships between temperatures, winds, clouds and water vapor on large and small scales. Current work in this Group is aimed at improved understanding of the TTL using new satellite observations, plus global model simulations.

William Randel has used high vertical resolution temperature profiles derived from Global Positioning System (GPS) radio occultation measurements to study temperature variability within the TTL, and links to large-scale tropical convection. Much of the TTL temperature variability is observed to occur in the form of eastward-propagating, planetary-scale Kelvin waves. These waves have typical vertical wavelengths of ~4-8 km, which are well-resolved by the GPS measurements (but not by other satellite measurements). The GPS results demonstrate that the global-scale Kelvin waves are directly forced by transient deep convection over Indonesia. Furthermore, the Kelvin waves show strong coupling to the background winds, in particular, showing enhanced amplitudes coincident with the descending westerly shear phase of the quasi-biennial oscillation (QBO).

Randel also leads a World Climate Research Program (WCRP) Stratospheric Processes and their Role in Climate (SPARC) initiative on detection, attribution and prediction of stratospheric changes. This is an international effort aimed at quantifying past changes in stratospheric climate, understanding the responsible processes through model studies, and predicting stratospheric changes in the future. As part of this work, Randel co-organized a SPARC workshop on Stratospheric Temperature Trends in Silver Springs, MD, in November 2003. Randel and Andrew Gettelman were co-authors on a joint SPARC-IGAC white paper describing Chemistry Climate Interactions, which will form the basis for joint scientific activities during the next decade. Randel is also involved as a lead author of an ongoing IPCC *Report on Safeguarding the Ozone Layer and the Global Climate System*, to be completed in 2005.

Gettelman and Randel are using tropical temperature and water vapor measurements from the AIRS instrument on the NASA Aqua satellite to characterize large- and small-scale variability. This work is in collaboration with William Irion and Annmarie Eldering (NASA Jet Propulsion Laboratory [JPL]). Gettelman has made detailed comparisons between AIRS data and aircraft measurements during pre-AVE (Atmospheric Variability Experiment), demonstrating high quality for the AIRS data. Ongoing work includes quantifying the relationships between temperatures, water vapor and clouds, and understanding the effects of large-scale (satellite) vs. small-scale (aircraft) sampling.

The extratropical UTLS is a dynamically active region characterized by large variability, strong constituent gradients, and significant mass fluxes between the troposphere and stratosphere. Pan has led several studies aimed at understanding constituent structure and variability in this region, using aircraft and satellite measurements together with model

simulations. One project focuses on using tracer correlations to quantify the mixing of stratosphere and troposphere air near the subtropical jet. Figure 36 shows an example of a stratospheric intrusion event observed during SONEX. The relationships between chemical tracers identifying stratospheric and tropospheric air (O_3 and CO, respectively) are used to understand mixing and exchange and to compare to model calculations.

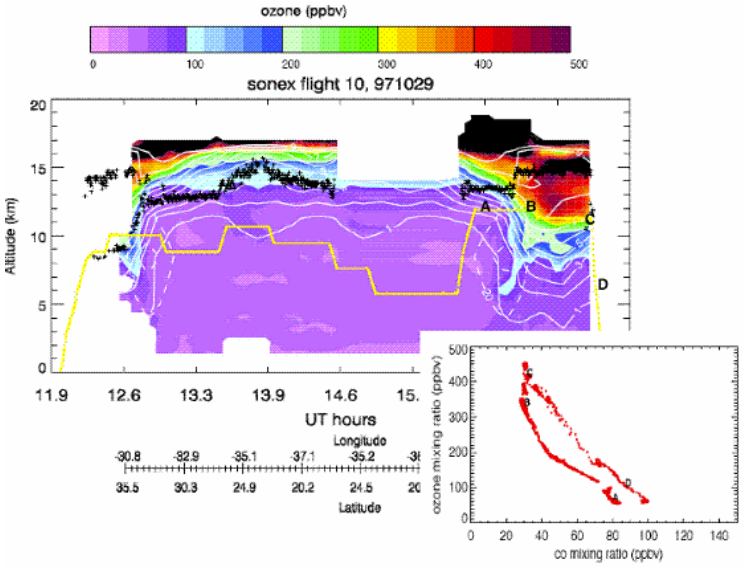


Figure 36: Color image shows the NASA Langley LIDAR (LIght Detecting And Ranging) measurements of ozone onboard NASA DC-8 research aircraft, October 29, 1997, during the SONEX campaign. The black dots are the thermal tropopause as measured by the Microwave Temperature Profiler. The ozone measurements show an intrusion of stratospheric air into the troposphere near the right edge of the image. The inset shows a scatter plot of CO-O_3 measurements near the intrusion, provided along the aircraft flight track. The letters A, B, C, and D indicate the measurement locations for the "mixing line."

Massie has focused on using satellite measurements to quantify tropospheric aerosols and pollution and their variability over time. An analysis of Total Ozone Mapping Spectrometer (TOMS) satellite data shows a significant increase in tropospheric aerosols over China and India during 1980-2000 (Figure 37). These increases are expected, due to large increases in population and SO_2 emissions (converted to sulfate aerosols) in China and India, but this is the first study to quantify the changes based on satellite observations. This analysis was in collaboration with Omar Torres (Joint Center for Earth Systems Technology, University of Maryland Baltimore County and the NASA Goddard Space Flight Center) and Steven Smith (Pacific Northwest National Laboratory, Joint Global Change Research Institute).

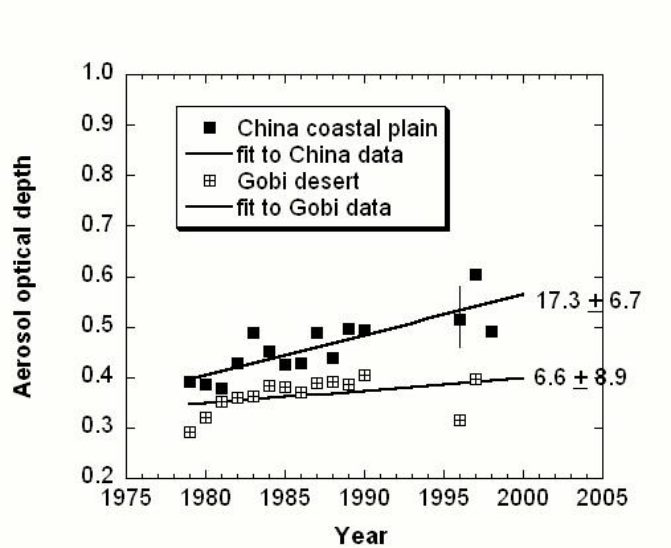


Figure 37: Winter averages of TOMS total aerosol optical depths, averaged for consecutive months from November through February for the China coastal plain and the Gobi desert. Aerosols over the Gobi desert are mainly due to desert dust, while aerosols over the coastal plain have a large contribution from sulfate. Linear

fits and decadal trends are indicated.

Mijeong Park (Seoul National University) is working with Randel and Rolando Garcia to study the structure and variability of the South Asian monsoon in the UTLS region, and its effect on trace constituent transport. She is using satellite measurements of UTLS ozone and water vapor from AIRS, along with output from the Whole Atmosphere Community Climate Model, second version (WACCM2), to understand stratosphere-troposphere coupling associated with the monsoon circulations. Results from WACCM2 and AIRS reveal consistent patterns of relatively high water vapor and low ozone within the monsoon anti-cyclone during summer. Variations in monsoon convective activity with 10-20 day periods are associated with fluctuations in anti-cyclone intensity and structure, and tracer variability. Analyses of observations and model results will be aimed at quantification of monsoon effects on stratosphere-troposphere exchange.

Additional UTLS related research is described in the Middle Atmosphere Studies section under WACCM results.

Model Development

Gettelman is leading a collaborative effort with Chris Webster (JPL), David Noone (CU), Andrew Dessler, Sun Wong (University of Maryland), and Natalie Mahowald (CGD), modeling isotopes of water in the atmosphere. Stable isotopes of water provide information about transport and budgets within the atmospheric hydrologic cycle. Heavier isotopes preferentially partition into condensed phases of water, and so the level of isotopes relative to a standard provides an integrated history of condensation. Thus heavy isotopes of water (chiefly HDO and H2-18O) can be used to understand the different pathways of transport in the upper troposphere. Specifically, air which contains significant quantities of evaporated ice will have a different set of isotopic ratios than air from which all the condensed phase has been removed.

Gettelman used an idealized model of the TTL to simulate the distribution of water isotopes, and compared against observations from in situ aircraft measurements. The model is able to reproduce the range of isotopic depletions observed in the data, and also reproduce individual episodes that mirror or depart from Rayleigh fractionation processes. The observations and the model simulation of HDO for a field campaign in the tropical upper troposphere are indicated in Figure 38, which also contains a theoretical curve of the isotopic ratio of a parcel lifted from the surface with all the condensate removed (a “Rayleigh distillation” curve).

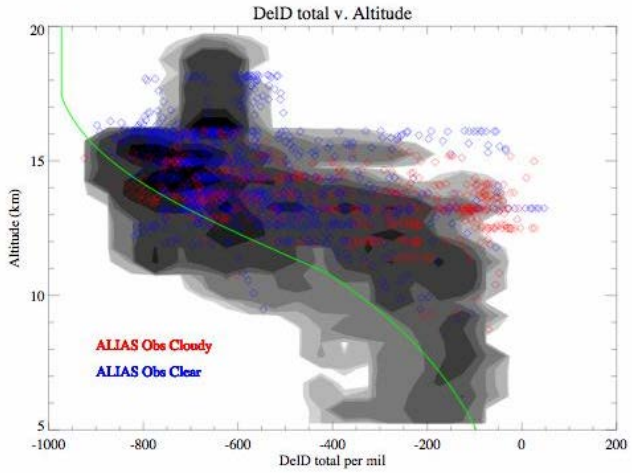


Figure 38: The observations and the model simulation of HDO for a field campaign in the tropical upper troposphere are indicated in Figure 38, which also contains a theoretical curve of the isotopic ratio of a parcel lifted from the surface with all the condensate removed (a “Rayleigh distillation” curve).

The observations clearly indicate that water substance in the upper troposphere does not follow a Rayleigh distillation model. The fact that this simple model reproduces the observed wide distribution of isotopic composition suggests the importance of detrained ice in the TTL, as hypothesized from previous work. The results of the model and the

observations also illustrate that stratospheric abundances of stable isotopes of water can be understood based on known isotopic physics, convective detrainment of ice and gradual dehydration.

Gettelman has also been working as part of a team with university collaborators to put isotopes in the NCAR Community Climate System Model. As part of this work, Gettelman and Mahowald coordinated a workshop on “Isotopes in the Earth System” held at NCAR in January 2004.

In collaboration with Paul Konopka of Research Center of Jülich, Germany, Pan has evaluated the application of the Chemical Lagrangian Model of the Stratosphere (CLaMS) model in the region of the extratropical tropopause. Using a simple initialization of O_3 and CO, they have demonstrated the importance of mixing in reproducing observed tracer variability. Figure 39 demonstrates the successful simulation of mixing for the event shown in Figure 36. This shows that the observed O_3-CO relationship is reproduced when mixing is included in the calculations, whereas under pure advection the tracer relationships cannot be obtained. A successful simulation of the observed “mixing line” will allow quantification of irreversible UTLS transport.

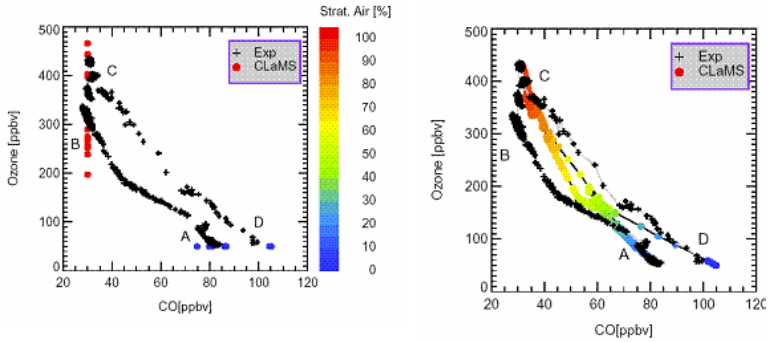


Figure 39: CLaMS simulation of mixing in the vicinity of the subtropical jet (color points), compared with observations (black points, from Figure 36). The colors denote the fraction of stratospheric air in each parcel. The left panel shows a simulation with mixing, and the right panel is a simulation with no mixing.

UTLS Chemistry and Aerosols

Brian Ridley and the AON Group have completed analyses covering two subjects relating to the NO and NO_y measurements (made in conjunction with a variety of other gaseous and particulate/ice constituents) obtained from flights of the high altitude NASA WB-57F aircraft during the Cirrus Regional Study of Tropical Anvils and Cirrus Layers-Florida Area Cirrus Experiment (CRYSTAL-FACE) project during July 2002.

The first subject considers the uptake of HNO_3 by sulfate aerosols (Figure 40). In situ measurements revealed near-zero mixing ratios of gas-phase HNO_3, in the absence of ice particles, at and just above the tropical tropopause for extended periods of one flight south from Key West, Florida. These data are unique within CRYSTAL-FACE for having depletion of gas-phase HNO_3 not in association with ice particles. In a collaboration with David Fahey, Ru-Shan Gao, Peter Popp, Tim Marcy (NOAA Aeronomy Lab), Robert Hermann (NASA JPL), Elliot Weinstock (Harvard University), and Darrel Baumgardner (UNAM), the AON Group has interpreted this removal as HNO_3 uptake on sulfate aerosols in an ice-supersaturated environment. Calculations for ternary (H_2O, H_2SO_4, HNO_3) liquid solutions can approximately account for the low HNO_3 mixing ratios by demonstrating that near complete removal from the gas phase is expected for the observed conditions. It is possible that a modest amount of NH_3 may contribute to the HNO_3 uptake. Nitric acid trihydrate (NAT) equilibrium calculations also yield significant uptake, but the nucleation barrier for NAT makes uptake by liquid solutions more likely, especially in the presence of the large aerosol volume for this case. This phenomenon may have significance for the subsequent evolution of the reactive nitrogen balance in the air mass, as well as for the potential role of these aerosols as sites for ice nucleation in subsequent cirrus cloud

formation. A manuscript is nearly complete.

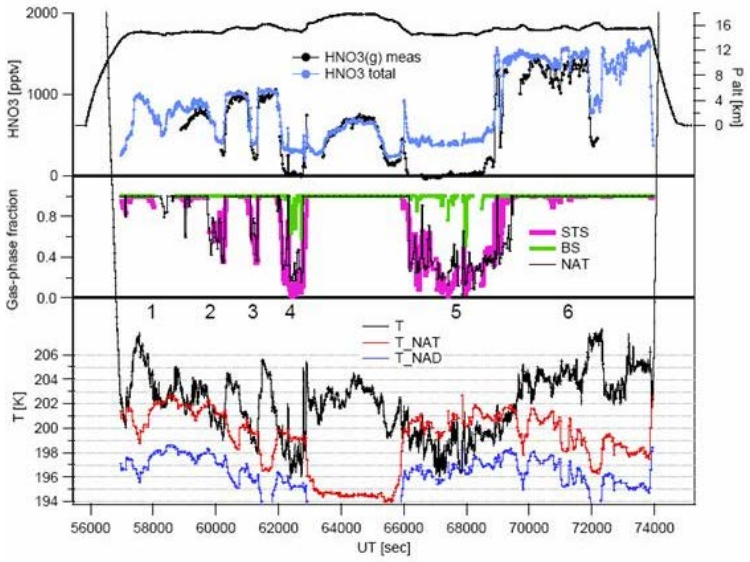


Figure 40: Plot of measured gas-phase HNO_3 (courtesy of David Fahey et al., NOAA Aeronomy Lab), with near-zero values in periods four and five, along with the calculated uptake of HNO_3 by ternary liquid solutions (STS), binary liquid solutions (BS, H_2O/HNO_3), and NAT. Ambient temperature is plotted (black), along with the equilibrium threshold temperatures for NAT (red) and NAD (blue). Although both the STS and NAT equilibrium calculations yield significant uptake, the nucleation barrier for NAT makes uptake by liquid solutions more likely, especially in the presence of the large aerosol volume for this case. Also, it is possible that a modest amount of NH_3 in solution may enhance the HNO_3 uptake beyond that calculated here.

The second subject considers the production of NO by lightning as investigated by the aircraft during penetration of the anvils of a large number of different thunderstorms that formed over Florida. A manuscript has just been published. Exceptionally high mixing ratios (6-10 ppbv) over large scales (20-50 km) were observed as a result of lightning production, which will have a substantial impact on the photochemical generation of ozone in the downwind outflow altitude range. Larger scale peak mixing ratios of NO were higher on average than found during an earlier study of thunderstorms over eastern Colorado. Injection of NO from the storms was overwhelmingly into the upper troposphere and very little, if any, into the stratosphere. The observations were also compared with the lightning parameterization scheme that is used in the MOZART global chemistry-transport model. Lesley Ott and Ken Pickering (University of Maryland), Lihua Li, Gerry Heymsfield, and Matt McGill (NASA Goddard), Paul Kucera (University of North Dakota), Louisa Emmons (ACD), and Martin Schultz and Guy Brasseur (Max Planck, Hamburg) contributed greatly to the storm analyses and model comparison.

Mike Coffey and Jim Hannigan of the Optical Techniques (OT) Group, as part of the international Network for the Detection of Stratospheric Change (NDSC), operate an infrared Fourier transform spectrometer (FTS) at Thule, Greenland (76.53°N). The NDSC is a network of high quality ground based observing stations for early measurement of changes in the composition and state of the stratosphere and determination of their causes. Operation of the spectrometer at Thule is automatic, with monitoring from Boulder, whenever the weather is suitable and the sun is above the horizon. Observations were made on 75 days of the possible 225 sunlit days of 2004. Missed days usually are due to stormy weather. Those data were analyzed for column amounts of gases, including both stratospheric gases important in ozone chemistry and tropospheric gases related to climate change.

In conjunction with other observations from the network, composed mostly of instruments from nations other than the U.S., the OT Thule measurements were used in the validation activities of recently launched satellite-borne instruments. Collaborations are ongoing with instruments aboard the Envisat (ESA) platform; plans and collaborations have been established for validation of the EOS-Aura (U.S., U.K., Netherlands, Finland, Launched July, 2004) satellite-borne instruments. During March 2004, observations were made in conjunction with measurements by the Atmospheric Chemistry Experiment (ACE) instrument aboard the Canadian SCISAT (Scientific Satellite)-1 satellite. This was the first opportunity for coincident observations by the ACE FTS and the NCAR FTS since the

launch of SCISAT-1 in August 2003. Coincident observations are critical to the validation of space-borne sensors. Other coordinated observations will be undertaken as the irregular orbit of SCISAT allows.

Results from observations by the airborne Fourier transform spectrometer (0.06 cm-1 resolution), that span more than 20 years, have been reprocessed to produce a unique archive of observations, from the base of the stratosphere, covering a wide range of latitude and season. This archive of infrared spectra has been used along with recent advances in least squares fitting in multiple wavelength regions to study the long-term trends in water and its isotopes, OCS and CO. Water transfer across the tropopause and redistribution in the lower stratosphere are important factors to the chemistry, radiation and dynamics of that important atmospheric transition region. Variations in the behavior of the water isotopes can provide insight into the sources and distribution of water.

Measurements of organic trace gases and other tracers, such as CO_2, N_2O, CH_4 and water vapor, are among those required to adequately characterize the chemistry of any given stratospheric region and to provide important information to diagnose stratospheric transport processes. Four complementary observational systems are currently employed to measure these trace gases in the stratosphere and each have their own unique set of advantages. The four include satellite observations, in situ measurements, remote soundings, and measurements from whole air samples. Elliot Atlas, Sue Schauffler, Verity Stroud, Rich Lueb, and Amy Lueb of the STM Group have collected and analyzed whole air samples from high altitude aircraft, the NASA ER-2 and WB-57, for a number of years. The maximum altitude for these aircraft is about 65,000 feet. Recently the STM Group designed and built a whole air sampler to be flown on a high altitude balloon up to 110,000 feet. Two test flights were flown, one in October, 2003 and the second in September, 2004, from Ft. Sumner, New Mexico. Figure 41 shows a vertical profile of methane and nitrous oxide (N_2O) from the 2004 flight. The structure of the profile above about 70,000 feet is similar to that seen in the 2003 flight and the STM Group is currently evaluating potential transport characteristics that my influence the distributions.

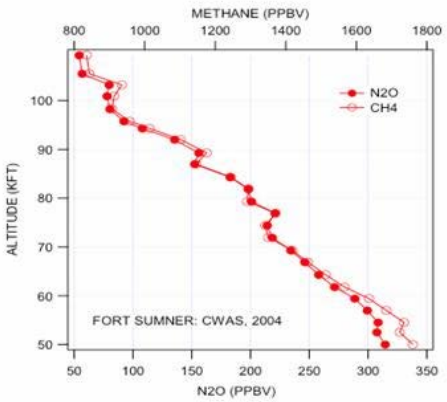


Figure 41: Vertical profiles of N_2O and CH_4 from samples collected by the Cryongenic WAS (CWAS) during the balloon flight from Ft. Sumner, NM in 2004.

An important use of whole air sampler trace gas measurements is to determine temporal trends of mixing ratios in the stratosphere to accurately assess the impact of changes in these gases on stratospheric ozone. Figure 42 shows a correlation between hydrofluorocarbon (HFC) 134a, which is a replacement for CFC-12, and N_2O from the balloon flight in 2004 and a series of ER-2 flights out of northern Sweden in 2000. The

higher 134a mixing ratios in 2004 are a result of increased emissions over time, which leads to increased mixing ratios over time. The STM Group is continuing analysis of these results for all the major halocarbons.

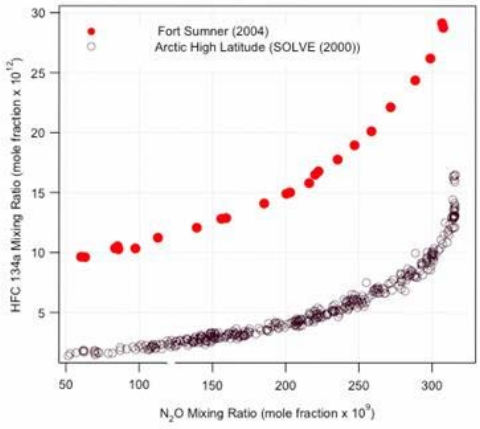


Figure 42: HFC 134a mixing ratios relative to N_2O mixing ratios from WAS samples collected on the NASA ER-2 during the SOLVE campaign in 2000 and from CWAS balloon samples collected from Fort Sumner, NM in 2004. The higher HFC 134a mixing ratios during 2004 relative to 2000 are a result of increasing tropospheric mixing ratios over time due to increasing emissions. HFC 134a is a replacement compound for CFC-12 in refrigerant applications.

Atlas and Schauffler of the STM Group also flew a Whole Air Sampler (WAS) on the WB-57 during the NASA Pre-AVE campaign conducted out of Houston and Costa Rica in January and February 2004. Pre-AVE was an initial test experiment leading to AVE, scheduled to begin in FY 2005. The Pre-AVE campaign was designed to test aircraft instruments to ensure their measurements are adequate for Aura validation and to test flight strategies for underflights of Aura during the AVE campaigns. The science goals of Pre-AVE were to characterize air in the extratropical and tropical upper troposphere and lower stratosphere and to examine water vapor, particles and other gases in the tropics to gain insight into their relationships to climate change.

There were three flights out of Houston, Texas, a transit flight to Costa Rica, three flights out of Costa Rica over the equator, and a transit flight back to Houston. Up to 50 samples were collected per flight and sent back to NCAR for analysis, by Verity Stroud and Amy Lueb, of halocarbons, hydrocarbons, organic nitrates, CO, and N_2O. These trace gases have different chemical lifetimes and either natural and/or anthropogenic emissions and are used to evaluate source regions, air mass transport, and chemical gradients in the upper troposphere and across the tropical tropopause region. Additionally, the measurements provide needed information on the role of short-lived halogen compounds to the chemistry of the UTLS, and on the transport of hydrochlorofluorocarbons (HCFCs) and HFCs into the lower stratosphere.

Though the data are not finalized, some interesting observations during the mission demonstrate the utility of tracer measurements from the whole air sampler in identifying air masses influenced by convection. The convective transport of tropical air is suggested by the data illustrated in Figure 43 that shows a vertical profile of bromoform and methyl iodide over Houston, Texas. Bromoform and methyl iodide have significant emissions from mainly biogenic sources in the surface ocean, with strong sources in the tropical ocean. The profile over Houston shows a clear maximum in bromoform and methyl iodide near 10 km, while dichloromethane (not shown) was closer to a “typical” profile of decreasing mixing ratios with altitude. The layer near 10 km was therefore associated with relatively recent convective outflow from tropical/marine convection. The relatively high levels of methyl iodide (a trace gas with a lifetime of only several days) also shows that the convection was recent or the levels would have decayed to near background levels.

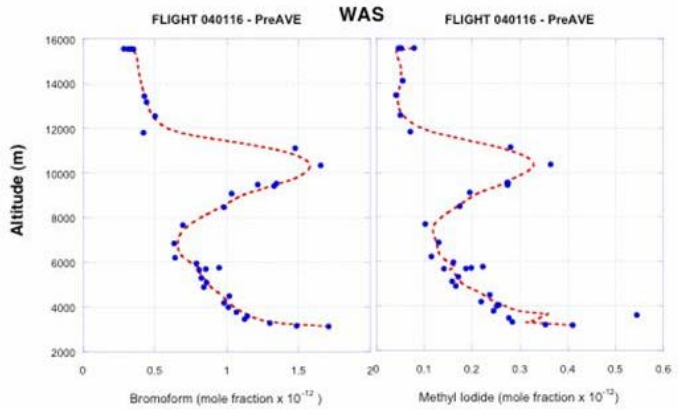


Figure 43: Vertical profiles of bromoform and methyl iodide near Houston, TX showing a maximum near 10 km that appears to be associated with relatively recent convective outflow from tropical/marine convection.

Instrument Development

ACD has been or will develop several instruments for use on the HIAPER GV aircraft. Four of these, the Trace Organic Gas Analyzer (TOGA), HIAPER Radiation Package (HARP), fast ozone, and CIMS were funded as part of the HIAPER MRE for community instrumentation.

Trace Organic Gas Analyzer (TOGA): Measurements, Standards, and Intercomparisons (MSI) Group

A main goal of the MSI Group's research activity is to participate in collaborative efforts to quantify the chemical composition of the atmosphere, characterize how it is changing in response to natural and anthropogenic forcings, and, ultimately, develop the capability to predict changes that may have important implications for the health of the Earth's ecosystem. An area of MSI expertise is in the development and deployment of instrumentation to measure a suite of volatile organic compounds (non-methane hydrocarbons, oxygenated volatile organic compounds, and CFCs and HCFCs) that directly impact the ozone chemistry of the troposphere/lower stratosphere. A special emphasis is placed on the interpretation of our measurements with respect to their impact on cycles of NO_x, HO_x and ClO_x.

The MSI Group was awarded funding to design and construct the HIAPER Trace Organic Gas Analyzer (TOGA). The HIAPER aircraft presents a unique opportunity for the MSI Group to study many atmospheric chemical and dynamical processes that occur in the upper troposphere, lower stratosphere (UTLS) region of the atmosphere, including the exchange between the lower troposphere and the UTLS (particularly convective and frontal transport of reactive organic compounds); the influence of oxygenated compounds on the UTLS HO_x budget; the participation of short-lived halogen compounds in ozone destruction cycles; the importance of the UTLS as a location of aerosol formation and modification; and the impact of the upper troposphere as a transport conduit for global anthropogenic pollution. A diagram for the sample flow and detection is shown in Figure 44.

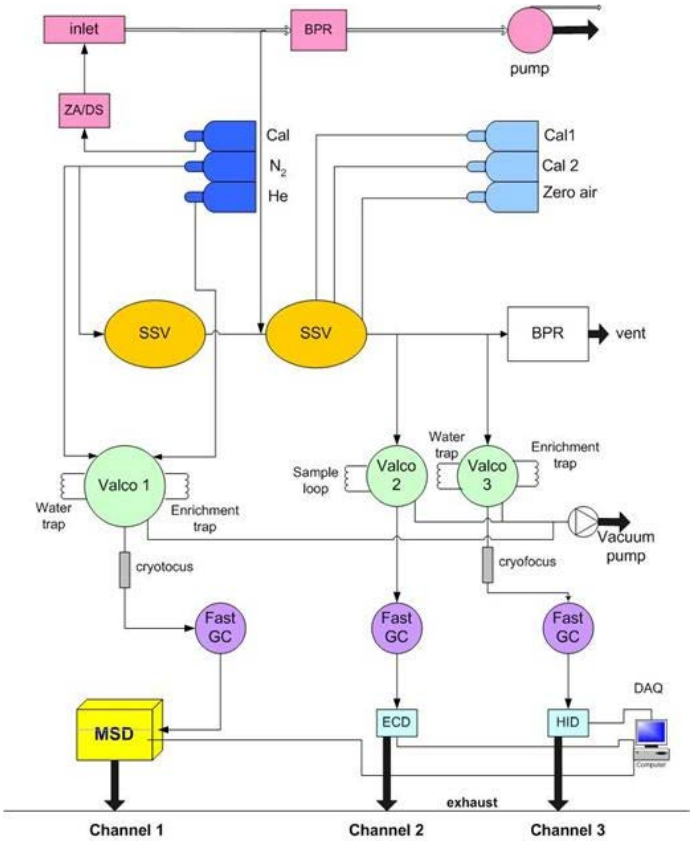


Figure 44: Simplified sample flow and detection for TOGA. SSV = stream selector valve. BPR = back pressure regulator, ZA/DS = zero air/dynamic dilution system, MSD = Agilent 5973 mass spectrometer, ECD = electron capture detector, HID = helium ionization detector.

The TOGA will have the unique capability of simultaneously measuring, with one instrument, a suite of organic compounds that play important functions in many areas of atmospheric chemistry. Several of the compounds are precursors or intermediates in atmospheric oxidation sequences. Others are indicators or tracers of different anthropogenic and biogenic processes. By utilizing a full suite of individual compounds, the Group will be able to investigate important processes that are occurring in the troposphere and the UTLS. The compounds that TOGA will measure consist of a series of hydrocarbons, oxygenated compounds, halocarbons (including HCFCs and CFCs), and a few nitrogen and sulfur containing compounds. These species are identified in the HIAPER Advisory Committee Report as high priority in the research air chemistry instrument needs, and these measurements are possible due to the very recent development of new fast gas chromatographs. A demonstration of the analysis of a series of oxygenated volatile organic compounds (VOCs) is shown in Figure 45. The trace in red shows the temperature program.

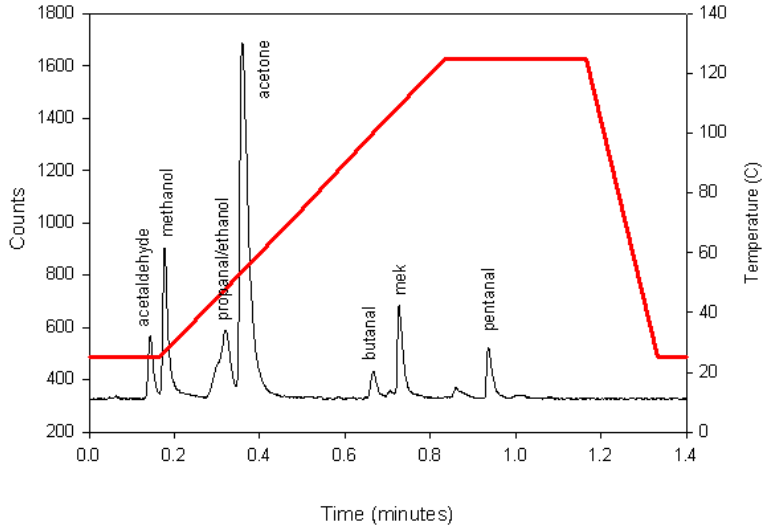


Figure 45: Demonstration of chromatography obtained in a recent analysis on the new chromatograph. Analysis to pentanal originally required 3.5 minutes.

The TOGA instrument will be an effective tool that can be used in conjunction with other research instruments to understand key processes occurring in the troposphere and UTLS.

NO/NO_y and O_3: AON Group

A major effort has continued with the design, fabrication, and laboratory testing of components for the NO_y/NO instrument to be deployed on HIAPER. The basic detector module, electronics, data system design and much of the machining have been completed. Assembly is ongoing and testing will start in December. The design of inlets and fabrication has yet to be completed.

The Group, plus Teresa Campos (ACD/EOL-RAF), was successful with a proposal to the HIAPER-MRE funding pool to construct a fast ozone (5 Hz response) instrument. Initial design, based on instruments we have flown on many other aircraft, has been started. Both the NO/NO_y and O_3 instruments will operate autonomously on HIAPER.

HIAPER Radiation Package (HARP): ARIM Group

Rick Shetter and three co-investigators, Barry Lefer (University of Houston after 1 September 2004), Manfred Wendisch (Leibniz Institute for Tropospheric Research, Germany), and Peter Pilewski (CU), collaborated on an NSF-MRE proposal to provide state-of-the-art radiation instrumentation for the HIAPER aircraft. The ARIM Group will design, fabricate, and deliver down and up-welling wavelength dependent actinic flux spectroradiometers and down and up-welling horizontally stabilized wavelength dependent irradiance spectroradiometers. The actinic flux spectroradiometers will provide actinic flux data from 280 to 680 nm with data frequencies ranging from 0.1 to 10 Hz. The irradiance instruments will provide flat plate irradiance from 300 to 2400 nm with data frequencies of 1 Hz. The irradiance optical collectors will be mounted on actively stabilized platforms to maintain horizontal stability to 0.1 degree up to aircraft pitch and roll angles of 6 degrees. This proposal was selected for funding and work will start in FY05.

Development of Autonomous Actinic Flux Instrumentation for High Altitude Aircraft – NASA WB-57

The ARIM Group completed the development and design of two CCD-based Actinic Flux Spectroradiometer (CAFS) instruments to measure the down- and up-welling UV and visible actinic flux as a function of wavelength for the NASA WB-57 aircraft. The instruments were fabricated and will be integrated on the NASA WB-57 aircraft platform for

an Aura validation mission in October and November of 2004. The UV actinic flux can be used in conjunction with radiative transfer calculations to obtain ozone column abundances above the aircraft, which will be extremely useful for Aura satellite instrument validation activities. A second part of the proposal is in collaboration with Dr. Irina Petropavlovskikh (CU; NOAA). She will develop algorithms to calculate the ozone column abundances from the UV actinic flux. This will be accomplished by applying radiative transfer calculations to obtain the direct fraction of the measured actinic as a function of wavelength and solving for the ozone absorption. The ozone column data will be extremely useful for the Aura satellite validation activities and for future deployment of actinic flux instrumentation on NSF aircraft.

Chemical Ionization Mass Spectrometer (CIMS): LK Group in Collaboration with Georgia Institute Of Technology

A CIMS capable of measurements in two basic configurations will be constructed for HIAPER in collaboration with Greg Huey (GIT). In one configuration the instrument will measure nitric acid, pernitric acid, and sulfur dioxide in real time. Other species such as chlorine nitrate and dinitrogen pentoxide may be available after post-flight data processing. The second configuration will allow measurements of organic compounds such as methanol, acetaldehyde, and acetone. Data will be reported from one to three second time intervals.

Development of a prototype HIAPER OH instrument

A new, compact mass spectrometer instrument has been designed and built by the POP Group (Fred Eisele, Lee Mauldin, and Ed Kosciuch) this past year in order to allow OH to be measured on a Twin Otter aircraft during the upcoming ANTCI 2005 study. This instrument, when complete, should be four to five times smaller and lighter than the existing four-channel system but still provide similar sensitivity for measuring OH, H2SO4 and MSA. The new system makes use of advances in mass spectrometer and octopole lens design and will serve as a prototype for a future HIAPER OH instrument.

Fourier-Transform Infrared (FTIR) Spectrometer for HIAPER

The OT Group (Mike Coffey and Jim Hannigan) has developed a compact (within the limits of long internal path length) high resolution (0.003 cm-1) Fourier transform spectrometer for use aboard the new NCAR research aircraft, HIAPER. The optics and mechanical components of that instrument were completed and tested in 2004; electronics are in production.

Research Groups

Atmospheric Odd Nitrogen (AON)

Atmospheric Radiation Investigation and Measurement (ARIM)

Measurement, Standards, and Intercomparisons (MSI)

Optical Techniques (OT)

Stratospheric/Tropospheric Measurements (ST/M)

The Satellite Data Analysis (SDA)

The High Resolution Dynamics Limb Sounder (HIRDLS)

Middle Atmosphere Science

WACCM was developed to study middle atmosphere physical and chemical processes. Members of the WACCM Group include Rolando Garcia, Doug Kinnison, Daniel Marsh, and Stacy Walters in collaboration with Byron Boville and Fabrizio Sassi (CGD), and Raymond Roble, Benjamin Foster, and Qian Wu (NCAR's High Altitude Observatory

[HAO]). WACCM is still under development; however, WACCM simulations have been used in a variety of middle atmosphere studies. Mesospheric processes have also been examined by ACD scientists using a combination of observations and modeling.

Whole Atmosphere Community Climate Model – Model Development and Results

Impacts of El Niño-Southern Oscillation (ENSO) on the Middle Atmosphere

(Fabrizio Sassi [CGD], Douglas Kinnison [ACD], Byron Boville [CGD], Rolando Garcia [ACD], and Raymond Roble [HAO])

WACCM was used to study the response of the middle atmosphere to ENSO. The model was forced with observed sea surface temperature (SST) for the period 1950–2000. Circulation and temperature anomalies associated with ENSO have the structure of vertically-propagating planetary waves that extend from the troposphere to the mesosphere. In addition, there are anomalies in the zonal mean winds accompanied by large temperature anomalies of opposite sign in the stratosphere and mesosphere; the former being warmer and the latter colder during El Niño events. Near the summer mesopause, changes in momentum deposition by parameterized gravity waves results in warming during El Niño. Detailed statistical analysis shows that the wavelike response to ENSO is significant throughout the middle atmosphere and even in the troposphere; zonal mean anomalies associated with ENSO are significant in early and late winter in the middle atmosphere (Figure 46). A chemical/transport simulation was carried out using output from this WACCM run. It shows that when the lower stratosphere is colder (as during La Niña events), some ozone depletion takes place in Northern Hemisphere winter. Conversely, when the lower stratosphere is warmer and more disturbed, as is the case during El Niño events, heterogeneous chemical processes are inhibited (Sassi et al., 2004).

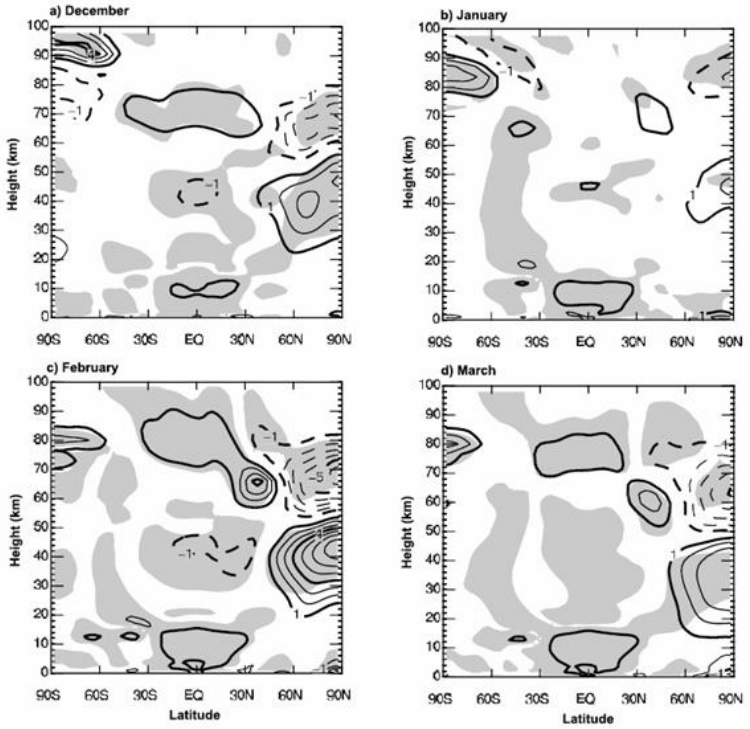


Figure 46: El Niño minus La Niña zonal mean temperature anomalies (K) during (a) December, (b) January, (c) February, and (d) March. Contour interval is 1 K. Shading indicates anomalies that are significant at least at a 95% level according to the Monte Carlo test.

Seasonal Variability of Trace Species in the UTLS Region

(Mijeong Park [Seoul National University], Douglas Kinnison [ACD], Byron Boville [ACD], Rolando Garcia [ACD], Wan Choi [Seoul National University])

Seasonal variations of several trace constituents (methane, water vapor, and nitrogen

oxides) derived from the Halogen Occultation Experiment (HALOE) satellite observations near the tropopause were analyzed and compared to output from the MOZART-3 chemistry-transport model driven by WACCM dynamics. These species have strong gradients near the tropopause, so that their seasonality is indicative of stratosphere/troposphere exchange (STE) and circulation in the near-tropopause region. Results show good agreement between observations and model simulations for methane and water vapor (Figure 47), whereas nitrogen oxides near the tropopause are much lower in the model than suggested by HALOE data. The latter difference is probably related to the lightning and convective parameterizations incorporated in MOZART-3, which produce NO_x maxima not near the tropopause, but in the upper troposphere. Constituent seasonal variations highlight the importance of the Northern Hemisphere (NH) summer monsoons as regions for transport into the lowermost stratosphere. In MOZART, there is clear evidence that air from the monsoon region is transported into the Tropics and entrained into the upward Brewer-Dobson circulation, bypassing the tropical tropopause (Park et al., J. Geophys. Res. 2004).

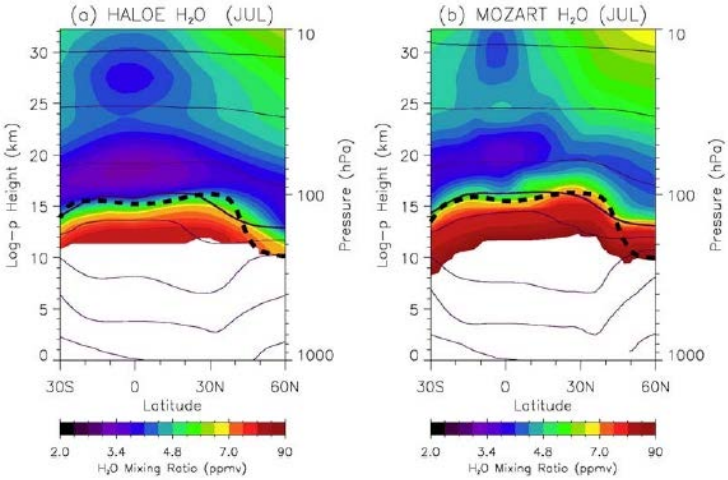


Figure 47: Meridional cross sections of water vapor mixing ratio in the South Asian monsoon region (60_–120_E) in July. Results are shown for (a) HALOE observations and (b) MOZART simulation. The heavy dashed lines indicate the tropopause appropriate for each data set.

Stratospheric Influence on Seasonal Cycles of Tropospheric Tracers

(Cynthia Nevison [ACD], Douglas Kinnison [ACD], Raymond Weiss [Scripps Institution of Oceanography])

The stratospheric influence on the tropospheric seasonal cycles of N_2O, CFC-11 (CCl_3F), CFC-12 (CCl_2F_2) and CFC-113 (CCl_2FCClF_2) was investigated using observations from NASA's Advanced Global Atmospheric Gases Experiment (AGAGE) global trace gas monitoring network and the results of WACCM simulations. WACCM provides the basis for a number of predictions about the relative amplitudes of N_2O and CFC seasonal cycles and about the relative magnitude and phasing of seasonal cycles in the Northern and Southern Hemispheres. These predictions are generally consistent with observations (Figure 48), suggesting that the stratosphere does exert a coherent influence on the tropospheric seasonal cycles of trace gases whose primary sinks are in the stratosphere. This stratospheric influence may complicate efforts to validate estimated source distributions of N_2O, an important greenhouse gas, in atmospheric transport model studies. (Nevison et al., in press).

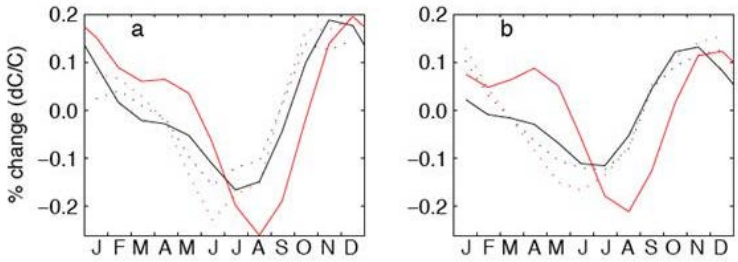


Figure 48: Comparison of modeled vs. observed seasonal cycles. Dotted lines are WACCM 700mb CFC-11 (red) and CFC-12 (black) seasonal cycles. Solid lines are AGAGE observations a) Mace Head, b) Trinidad Head.

Monsoon Impacts on Stratosphere/Troposphere Exchange (STE)

(Andrew Gettelman [ACD/CGD], Kinnison [ACD], Timothy J. Dunkerton [North West Research Associates], and Guy Brasseur [Max Planck Institute, Hamburg])

Using observations from aircraft and global chemical and climate models, the transport characteristics of the Asian monsoon complex on the upper troposphere and lower stratosphere have been examined in detail. A long-term WACCM climatology resembles the satellite climatology of water vapor and ozone in the monsoon regions (Figure 49). A simulation with observed winds is able to reproduce individual transport events observed from aircraft, and these events are used to infer that large scale motions and monsoon circulations can explain the global correlations of ozone and water vapor around the tropopause. A detailed analysis of model fluxes of water vapor and ozone indicates that the Asian Monsoon circulation may contribute 75% of the total net upward water vapor flux in the Tropics at tropopause levels from July to September. Some of this air may enter the tropical stratosphere and bypass the tropical tropopause altogether (Gettelman et al., in press).

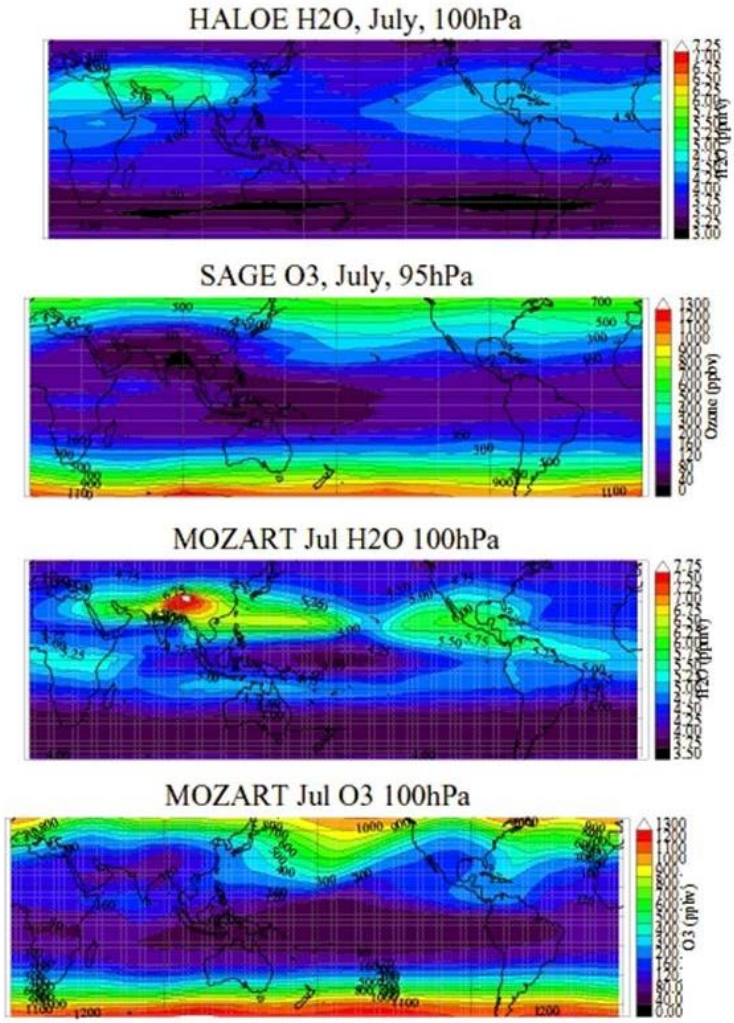


Figure 49: Top two panels: Climatology of water vapor from HALOE at 100hPa and ozone from SAGE at 95hPa. Bottom two panels: Climatology of water vapor and ozone from a 22-year MOZART-3 simulation driven with WACCM dynamics. The impact of the Indian monsoon circulation is evident in both data and model.

Parameterization of Gravity Wave Fluxes Due to Convective Excitation

(Jadwiga Beres [ASP], Boville [CGD], Garcia [ACD], Sassi [CGD])

A new method of specifying the gravity wave spectrum above convection has been implemented in WACCM. This parameterization is interactive with the underlying convection and introduces realistic spatial and temporal distributions of gravity wave activity as well as yielding gravity wave characteristics related to the underlying wave source. The new scheme improves the structure of the tropical stratospheric and mesospheric Semi-Annual Oscillations in WACCM (Figure 50) and provides insight into the wave motions that might be responsible for extratropical mesospheric forcing. The newly-implemented scheme also provides a new direction for gravity wave parameterizations as the gravity wave forcing is no longer fixed and will follow changes in tropospheric climate. This allows for more accurate studies of effects of changing climate on the middle atmosphere and on examining the feedbacks between the troposphere and the middle atmosphere. (Beres et al., submitted).

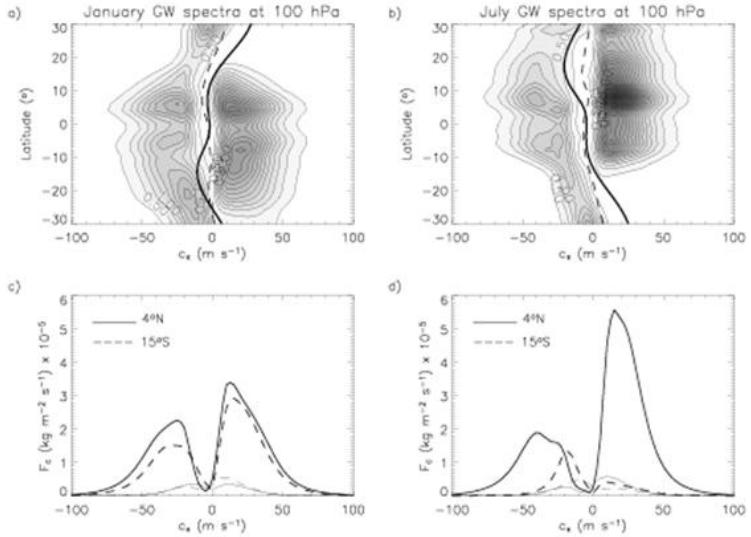


Figure 50: Monthly averaged east-west momentum flux phase speed spectra at 100 hPa as a function of latitude derived from the Beres parameterization for a) January, and b) July. Contours are plotted in intervals of 0.25 x 105 kg m-2 s-1. Thick solid line depicts the zonal mean wind at 100 hPa and the dashed line depicts the zonal mean wind at 700 hPa. In panels c) and d) the thick lines depict cross sections through a) and b) respectively at 4°N and15°S. The thin lines depict the same quantity for the standard simulation.

Stratospheric Trends in Temperature and Water Vapor

Daniel Marsh [ACD], Garcia [ACD], Kinnison [ACD], and Sassi [CGD]

WACCM/MOZART-3 was driven with observed SST for the period 1950-2000, and the results were compared with satellite and ground-based observations of temperature and water vapor to determine whether the model can reproduce observed trends. It was found that model results were generally in good agreement with HALOE observations (1992-2002), both for temperature and water vapor. WACCM tended to underestimate temperature trends only in the upper stratosphere; this discrepancy appears to be related to an underestimate of ozone in that region. Simulated water vapor trends agreed well with HALOE data throughout the lower and middle stratosphere (Figure 51). It was also found that the magnitude of trends was highly dependent on the length of the record analyzed, so trends calculated for periods as short as 10 years cannot be considered stable. Decadal trends appear to be strongly influenced by the presence of low-frequency variability, which in the model arises principally from changes in SST. A paper describing these results is in preparation.

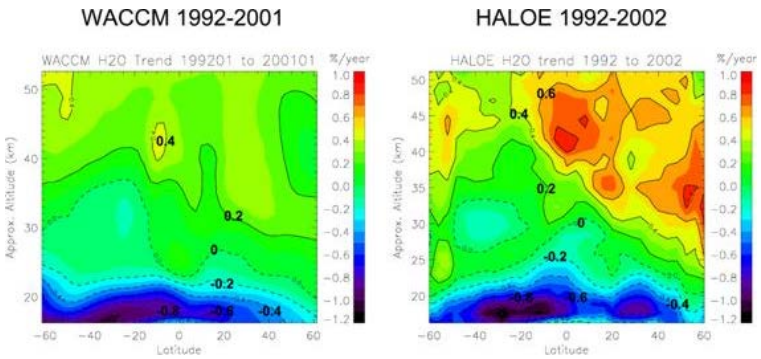


Figure 51: Comparison of WACCM vs. HALOE trends in water vapor. WACCM reproduces HALOE trends in the lower and middle stratosphere. HALOE trends are larger in the upper stratosphere, especially in the northern hemisphere.

Chemical Transition Across the Extratropical Tropopause

(Laura Pan [ACD], Jennifer Wei [Goddard Space Flight Center], and Kinnison [ACD])

Distribution of chemical constituents in the extratropical tropopause region is controlled by both chemistry and dynamics. Correct representation of the chemical distribution and

transition across the tropopause is an important diagnosis for the model performance in the upper troposphere and lower stratosphere region. Large gradients and rapid change in chemical species, especially ozone and water vapor, occur near the extratropical tropopause region making it a significant challenge to models. This study examined the chemical transition in the extratropical tropopause region in the results of several different model runs in comparisons with the aircraft observations. Figure 52 is an example of these comparisons. Both profiles and tracer relationships were examined for runs driven by ECMWF winds, WACCM-1b winds and WACCM2 (interactive chemistry). The analysis shows that results using ECMWF winds are comparable to observed tracer relationships (O_3-CO and O_3-H_2O). The results from WACCM-1b show a significant offset between the thermal tropopause and the chemical transition. This Group is in the process of identifying the component in transport characteristics that may be responsible for this offset. The initial results of examining the WACCM2 show good agreement with the observations. These results are being prepared for publication.

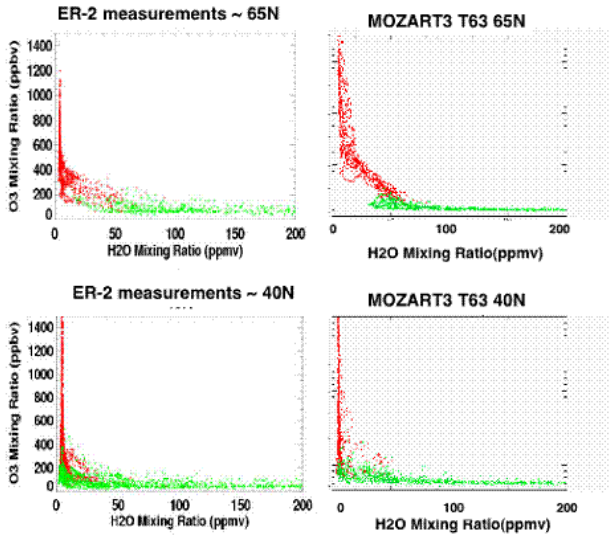


Figure 52: Comparisons of tracer relationship between model results and aircraft observations. The two colors represent data (both model and measurements) above (red) and below (green) the thermal tropopause. Note the 65N and 40N show different characteristics in the transition region. Model results are consistent with the observations.

Structure and Variability of the SE Asia Monsoon System

(Park [Seoul National University], Randel [ACD], Kinnison [ACD], Garcia [ACD])

Satellite measurements of UTLS ozone and water vapor from the Atmospheric Infrared Sounder (AIRS), along with output from WACCM2, are being used to understand stratosphere-troposphere coupling associated with the monsoon circulations. Results from WACCM2 and AIRS (Figure 53) reveal consistent patterns of relatively high water vapor and low ozone within the monsoon anti-cyclone during summer. The synoptic patterns from AIRS water vapor and ozone show both the eastward and westward moving wavelike patterns in northern and southern part of the monsoon anticyclone, respectively. Variations in convective activity with 10-20 day periods are associated with fluctuations in anti-cyclone intensity and structure, as quantified using derived potential vorticity (PV) fields. Consistent patterns are observed in PV, water vapor and ozone, as shown. Analyses of observations and model results will be aimed at quantification of monsoon effects on stratosphere-troposphere exchange. This study is currently underway.

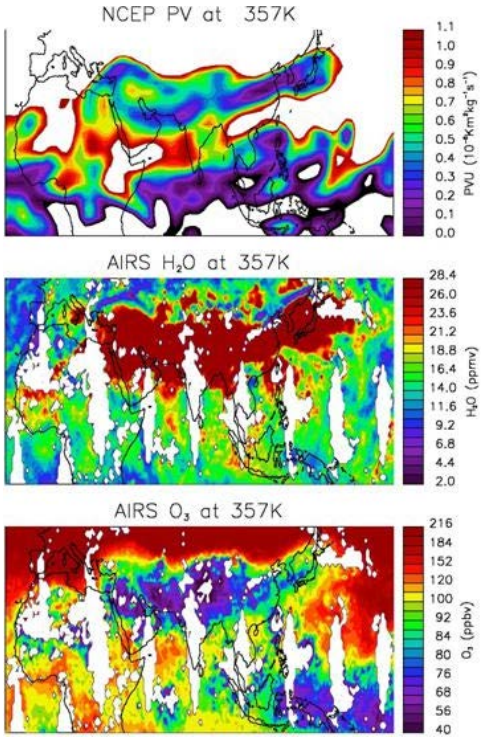


Figure 53: Top panel shows spatial structure of UTLS South Asian monsoon region on August 3, 2003, based on PV on the 357 K isentropic level (~14 km). The relatively low PV region over South Asia (blue region) corresponds to the monsoon anti-cyclone. Lower panels show corresponding water vapor and ozone patterns, derived from AIRS data. Note that relatively high water vapor and low ozone are observed within the anti-cyclone.

Mesospheric Processes

Chemistry of the Middle Atmosphere Sodium Layer

Anne Smith, in collaboration with Jiyao Xu (Chinese Academy of Science), has done several studies related to the chemistry and remote sensing of sodium in the middle atmosphere. In one, A. Smith and Xu used a numerical model of sodium chemistry to examine the sensitivity of sodium chemical lifetime to various environmental factors (e.g., temperature and the concentrations of other reactive gases). The paper also predicts a day/night difference in the sodium chemistry. Xu and A. Smith also collaborated with Qian Wu (HAO) to propose a technique for global observations of nighttime sodium by satellite. At present, there are only limited sodium observations from a few lidar sites. This paper demonstrates that determination of the global sodium distribution from satellite is straightforward and can be done with good accuracy. The measurements would require simultaneous limb measurements of temperature, ozone and sodium airglow emission at altitudes around 80-100 km. Such measurements have all been made separately and are technically feasible.

Atmospheric Tides

A. Smith, in collaboration with Dora Pancheva and Nicholas Mitchell (University of Bath, U.K.) have completed a comprehensive study of the 6-hour tidal oscillation. Although occasional observations of this tidal frequency have been reported through the years, it had never been the subject of an in-depth study. Smith, Pancheva, and Mitchell found that this tidal frequency is a persistent feature of the variability in winds at the Esrange radar station (Sweden). Model simulations reproduce the mean amplitude and seasonal cycle. The model also predicts the global structure. The prediction gives largest amplitudes at high latitudes and indicates that the tide at a given site is composed of migrating and non-migrating contributions.

Oxygen – Hydrogen Chemistry and Emissions in the Mesosphere

Marsh and Smith, in collaboration with Martin Mlynczak (NASA Langley) and James Russell (Hampton University), are using a numerical model to interpret observations of hydroxyl airglow made by the SABER (Sounding of the Atmosphere using Broadband Emission Radiometry) instrument on the TIMED (Thermosphere Ionosphere Mesosphere Energetics Dynamics) satellite. They have found that variations in the airglow are strongly affected by the diurnal tide. Two processes contribute: a) downward vertical motion transports enhanced atomic oxygen which, through a series of chemical reactions, leads to enhanced airglow; and b) the airglow responds to temperature variations because of the temperature dependence of some key reaction rates. Both of these processes play a role in the observed and simulated variability of the emission. Since the chemical reactions that lead to the emission are known, the airglow variations can lead to greater understanding of the composition and its variability.

High-Resolution Dynamics Limb Sounder

HIRDLS was launched on the Aura spacecraft on 15 July 2004 (Figure 54), 16 years to the day from the submission of the original proposal. Here activities will be divided into pre- and post launch phases.

Figure 54: (Credit and copyright (c) Brian Lockett, Goleta Air & Space Museum) NASA's AURA satellite launched from Vandenberg AFB at 3:02 A.M on Thursday, July 15. It will examine the Earth's atmosphere in unprecedented detail.

Pre-launch Activities

Instrument

At the beginning of the period, HIRDLS had been integrated on the Aura spacecraft (S/C), which was about to be tested under the thermal and vacuum (T/V) conditions that it would experience in space. Many members of the HIRDLS Team took part in the month of T/V testing, including John Gille (ACD; CU), Michael Coffey, Bruno Nardi, Thomas Eden, and Michael Dials, Douglas Woodard, and Aaron Lee (CU). An earlier increase in radiometric noise was finally traced to a beating between the chopper frequency and the 13th harmonic of the cooler frequency. Raising the chopper frequency moved this interference out of the range of concern. However, the noise was related to the failure of one of the four cooler motors. During the subsequent T/V testing another section of the cooler electronics failed, limiting the amount of radiometric testing that could be done. After a considerable amount of trouble-shooting, analysis, and reworking of the electronics, the instrument was declared ready to fly, although there were some remaining questions. All tests completed before the cooler failure showed continued excellent performance.

Further testing and flight simulation, led by James Craft and Angela Williams (CU) took place at the S/C integration site in Redondo Beach, CA, before Aura was shipped to the launch site at Vandenberg Air Force Base, on the Pacific coast north of Santa Barbara. After delays of a few weeks due to launcher problems, Aura was launched flawlessly into a sky clear enough that the rocket plume could be seen for a hundred miles or more.

Closely related to this, Eden worked to complete the final data analyses of the radiometric and in–band spectral data sets from the pre–launch calibration, which had taken place the previous year in Oxford. He subsequently assisted in the inclusion and testing of these results in the relevant science–data processing algorithms.

In response to the possibility of a malfunction in the in-flight calibrator (IFC) temperature sensors raised during the instrument calibration phase, Alyn Lambert added the capability of simultaneously retrieving the IFC temperature and atmospheric temperature/pressure to the Level-2 operational software and showed that the scientific goals of the HIRDLS mission could still be achieved.

Algorithm Development

Lambert and Hyunah Lee completed work on the operational Level 2 (L2) algorithms to convert the measured radiances into atmospheric data. They implemented and tested them in the operational environment, showing that they met the data requirements. They also developed a HIRDLS test suite, consisting of a series of four increasingly complex retrieval paths, to help plan and guide the retrieval of HIRDLS products through the early post-launch data.

Charles Cavanaugh developed software to provide the calibrated radiances (L1) needed by the L2 algorithms, while Lawrence Lyjak, William Mankin (retired), Gille and Brent Petersen (CU) created the pre-processor link between L1 and L2 that, inter alia, enhanced the vertical resolution of the retrieved products.

Ken Stone (CU) led the effort to develop a very powerful and flexible automated data processing system, with the help of Thomas Lauren, Greg Young and Vince Dean (CU). Cheryl Craig, worked with Charles Krinsky and Joe McInerny (CU), to develop the operational code.

Lambert and Lee also generated 24 hours of HIRDLS simulated data (radiances and retrieved products) from 4D Mozart model data supplied by Douglas Kinnison which was used in pre-launch inter-comparison and validation exercises by the HIRDLS and Microwave Limb Sounder (MLS) science teams.

In closely related work, Rashid Khosravi developed and implemented two new run modes in the retrieval code for error analysis and diagnostic purposes. One mode calculates the averaging kernels and various components of the total retrieval error, and the other mode calculates weighting functions by a finite difference method. He also analyzed the constituent mixing ratio errors resulting from errors in retrieved temperatures, and a priori errors.

The L2 algorithms require a forward model that must accurately and quickly estimate transmittances and channel radiances for use in the operational retrievals. It must take into account the presence of many target and interfering gases, a wide range of atmospheric and radiative states, operational speed constraints, and requirements on the accuracy and precision of the retrieved science data. Significant progress has been made in addressing these challenges. Gene Francis and David Edwards successfully extended a physically based forward model framework to a fast regression approach incorporating improved spectroscopy that is effective for operational use. Francis, Julia Lee-Taylor, Chris Halvorson and Lambert have tested it using 11 diverse atmospheres, ranging from tropical to winter polar conditions, based on MOZART data. Radiance errors are deviations from a line-by-line reference. Accuracy is generally better than 0.5% and satisfies the operational requirement of < 0.5%-1.0% depending on channel. Radiance accuracy is considerably better than 0.5% for the critical temperature retrievals obtained with the CO_2 channels.

Kinnison, Nardi, Gille and Cora Randel (CU) led the HIRDLS planning for data validation.

Plans were also made to use HIRDLS data in the UT/LS initiative led by ACD. Figure 55, prepared by Lambert, presents maps of simulated HIRDLS retrievals of ozone data on 3 isentropic surfaces in the UT/LS. The violet indicates low tropospheric ozone values in the tropics, with sharp gradients to higher low stratospheric values. The wavy isolines follow the PV tropopause more or less. Motions on isentropic surfaces across the tropopause are expected to be a major mode of Strat-Trop exchange. (HIRDLS data will extend only down to the cloud tops.)

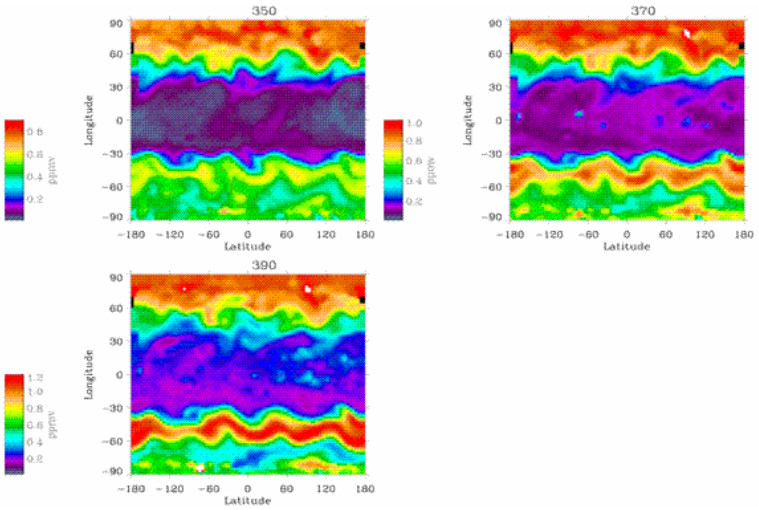


Figure 55: Maps of simulated HIRDLS ozone data on three isentropic surfaces in the Upper Troposphere/Lower Stratosphere (UTLS).

Post-Launch Activities

Once in orbit, the HIRDLS Flight Operations team led by Craft and Williams worked with our colleagues at Oxford University, especially John Barnett and Chris Hepplewhite, to implement the instrument activation plan, which turned on the subsystems one at a time and evaluated them before going to the next step. This also allowed HIRDLS and the S/C to outgas for 25 days. The coolers were slowly turned on without problems and allowed to cool down on 10 August. When the detectors stabilized at their operating temperature (61.6K), the scanner was programmed to obtain 15 minutes atmospheric observations.

The results of these scans were quite surprising and disappointing. The observed radiances were much larger and more uniform spatially and spectrally than atmospheric radiances. The immediate impression was of an obstruction in front of the instrument aperture. In addition, a few days earlier it had been noted that the scanner was not moving as freely as it had on the ground.

NASA immediately formed two review groups to help guide the investigation of the radiance anomaly, and its possible link with the scanner interference. Further scanner motion was barred for the near term. The first tasks were to list all possible causes of the observed anomaly, and then use all available data to narrow the range of possible causes. Most of the above-mentioned team members have played active roles in this. By the end of FY04 an obstruction in the optical train was identified as the most likely cause, and all other mechanisms were on the verge of being formally ruled out. The obstruction is now believed to be a piece of kapton, the plastic sheeting placed around the fore-optics volume to maintain cleanliness, that came loose during the rapid de-pressurization at launch. Present plans are to do further diagnostic motions of the scan mirror, measuring both radiances and drag on the mirror, to get a better understanding of the location of the blockage, then develop a plan for moving it out of the way. Should this fail, the fallback position is to see whether data measured at one end of the aperture, where there is a partial view past the blockage to the atmosphere, can yield useful scientific results.

Research Groups

Global Modeling (GM)

The High Resolution Dynamics Limb Sounder (HIRDLS)

Optical Techniques (OT)

Strategic Initiatives

Biogeosciences Strategic Initiative

Executive Summary

The Biogeosciences Initiative science agenda is organized around issues linking processes across spatial scales. An explicit element of our plan is to use numerical modeling at multiple scales to integrate a wide range of observations. Our approach is based on the recognition that physical and biological processes operating at very small spatial scales have the potential to influence the climate system when integrated globally. It is therefore imperative that we develop a set of diagnostic and prognostic tools that can seamlessly span the spatial scales from single organisms to the entire globe, making optimal use of the observations possible at different scales. For example, the performance of the global land carbon cycle model is being evaluated against global-scale observations of CO_2 concentration, against continental-scale observations of canopy structure from remote sensing platforms, against regional-scale observations of hydrologic outflow, against eddy covariance observations of local carbon, water, and energy fluxes, and against very detailed ecophysiological and biometric observations at the stand and plant scales. This becomes increasingly important as we begin to address human impacts on the global biogeochemical environment and climate system.
The Biogeosciences (BGS) mission encompasses four main tasks:

1. **Global Modeling and Measurements:** Investigate biogeochemical coupling to radiative forcing, climate air quality, and ecosystem function on continental to global scales.
2. **Regional Air Quality and Chemical Processes:** Link process level biogeochemical understanding to regional-scale measurements and models.
3. **Models and Measurements over Heterogeneous and Complex Terrain:** Understand how complex terrestrial landscapes interact with physical processes in the atmosphere to influence biogeochemical and physical ecosystem processes, land-atmosphere exchange, and local climate.
4. **Land Use Changes:** Investigate how human driven changes in land use affect biogeochemical cycles.

These tasks are shared across four divisions, ACD, ATD, CGD and MMM.

BGS Achievements (Division Narratives):

Atmospheric Chemistry Division: ACD

The Atmospheric Chemistry Division (ACD) has a mission goal of advancing our understanding of the role of biosphere-atmosphere interactions in the Earth system and predicting its response to human perturbations. This is being accomplished through multidisciplinary field, laboratory and modeling studies of the processes controlling these interactions at a variety of scales. These studies mainly contribute to BGS Tasks 1 (process and regional scales), with some topics also contributing to Task 2 (global scale).

The BGS initiative contributed during FY04 to the support of Global Modeling Section (GMS) member Elisabeth Holland, and Biosphere-Atmosphere Interactions (BAI) Group members Andrew Turnipseed and Christine Wiedinmyer. Holland is the BGS Program Leader, and Alex Guenther (ACD-BAI) is a BGS Steering Committee member.

Carbon-Nitrogen Cycling (Tasks 1 & 2)

Holland collaborated with Bobby Braswell (University of New Hampshire), James Sulzman and Jean-Francois Lamarque (ACD-GMS) to produce maps of N deposition fluxes from site-network observations for the United States and Western Europe (Figure 56) and to construct continental- scale N budgets.

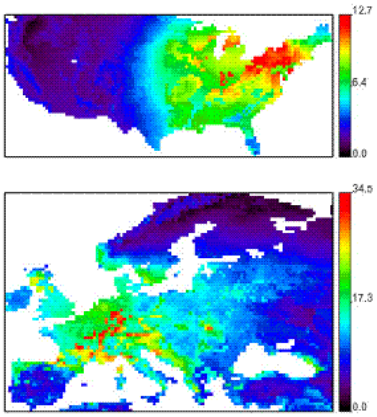


Figure 56: Nitrogen deposition to Western Europe exceeds that to the US:. Nitrogen is being exported from the US.

The U.S. N deposition budget is found to be dominated by oxidized N species, byproducts of fossil-fuel combustion, while the Western European N-deposition budget is dominated by reduced species, by-products of farming and animal husbandry. Western Europe receives 5 times more N in precipitation than the conterminous U.S. Estimated N emissions greatly exceed measured deposition in the U.S., suggesting significant N export or under-sampling of urban influence. In Europe, estimated emissions better balance measured deposition, suggesting that much of the N emitted in Europe is re-deposited there, with possible N import from the U.S. These wet and dry N flux maps are valuable as input into terrestrial biogeochemistry models and for verification of regional and global atmospheric chemistry and transport models. The work is detailed in a paper in press (Holland et al). The data set used for the synsthesis has been published separately through the Oak Ridge National Laboratory Data and Archiving Center (ORNL-DAAC), url: http://daac.ornl.gov/CLIMATE/guides/nitrogen_deposition.html
Holland also collaborated with Wolfgang Knorr, Jo House (Max Planck Institute for Biogeochemistry, Jena, Germany) and Colin Prentice (University of Bristol, UK) in a study which answers a controversy as to whether turnover of soil organic carbon (SOC) has any long-term temperature sensitivity. A 3-pool model (Figure 57) was used to explain that labile SOC undergoes rapid depletion on warming, whereas non-labile SOC shows negligible response on experimental time scales, but is actually more sensitive than labile SOC to temperature in the longer term. These results imply that the long-term positive feedback of soil decomposition in a warming world may be even stronger than predicted by global models. A paper (Knorr et al) is in press in *Nature*.

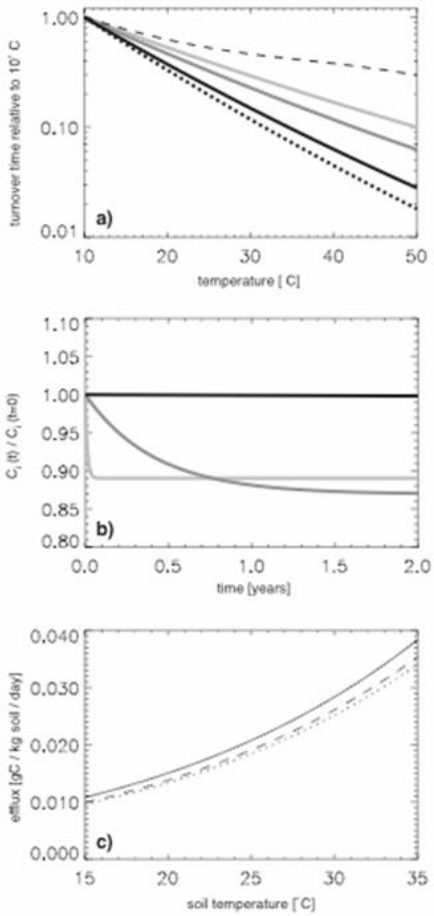


Figure 57: Temperature responses of the 3-pool Arrhenius model. (a) Turnover times of the three pools as a function of temperature (thick lines): fast (light grey), intermediate (medium grey) and slow (black). The dotted black line uses the best fit value for activation energy (Table 1b), the solid line 68,000 J mol^{-1} as a lower bound. The uppermost line shows turnover times calculated with the method of ref. 24. ***(b)*** *Modelled response of the pool sizes to a 2°C warming (grey tones as (a)).* ***(c)*** *Modelled temperature response of CO2 efflux after warming the soil by 2°C for 1 month (dashed) or 1 year (dotted), compared to the temperature response without warming (solid).*

BGS provided inspiration for the "Santa Fe Project", a study by Lamarque of nitrogen deposition on the biosphere and its impact on the carbon cycle. BGS continues to cooperate with the ongoing efforts of the Santa Fe Project. More detail can be found on the ACD website, url: http://www.acd.ucar.edu/chemistry_climate

The remaining portion of the ACD contribution is taken from the above Biogeochemical Cycles section and reflects the figure numbering from that section.

Laboratory Studies (Task 2)

Guenther and other ACD-BAI scientists (James Greenberg, Peter Harley, and Thomas Karl) are using laboratory facilities to characterize the processes that control biogenic emissions. Biogenic emission studies were conducted in the ACD phytotron and growth chamber facilities in collaboration with Emiliano Pegoraro (Edinburgh University, U.K.), Allison Steiner (University of California, Berkeley) and Teresa Nunes (University of Aviero, Portugal). The laboratory studies have shown that isoprene emission is more resistant and recovers more quickly from drought than does photosynthesis and stomatal conductance. Isoprene emission rates show a strong correlation with leaf water potential, providing a useful parameterization for including the effects of drought stress in isoprene emission models. Other experiments have demonstrated that sesquiterpene emission rates from some important tree species are comparable to monoterpene emission rates and exhibit similar temperature dependence. Biogenic methanol emission rates were observed to vary across and within plant species by at least an order of magnitude. Leaf age was identified as the major source of within species variation in methanol emission. Observed light dependent monoterpene emissions varied as a function of growth temperature and certain monoterpenes (e.g., ocimene) were released at elevated levels in response to temperature stress. This work is described by Pegoraro et al., Harley et al., and Nunes et al., which are in preparation for submission to peer-reviewed journals in late 2004.

U.S. Field Studies (Task 2)

BAI scientists investigated biosphere-atmosphere interactions with six U.S. field studies during FY04 and analyzed data from an additional three U.S. field studies. The six FY04 field studies supported the research of investigators from five universities. A study of the

contribution of biogenic isoprene emission to regional aerosol and oxidants was conducted at a poplar plantation in northern Oregon and was conducted in collaboration with Brian Lamb, Halvor Westberg and Adam Hill (Washington State University). The potential allelopathic role of biogenic VOC emissions from invasive Artemesia shrubs in New York was conducted in collaboration with Jed Sparks and Jacob Barney (Cornell University). An aircraft investigation of cicada outbreaks in Indiana was conducted in collaboration with Paul Shepson (Purdue University) and showed that the emissions from decaying cicadas did not have a significant impact on atmospheric chemical composition. Trace gas fluxes over a Colorado grassland were measured in collaboration with Matt Dunn (ASP/University of Colorado) and James Smith (ACD). The observations show that the grassland was a significant source of methanol and a sink for acetic acid and methyl acetate. Ozone deposition was measured at the Niwot Ridge, Colorado AMERIFLUX site in collaboration with Russell Monson (University of Colorado). The negative impact of high O_3 events on the subalpine forests downwind of Denver, Colorado are minimized by their occurrence during late afternoon-early evening periods when plant activity is low due to both water stress and low light levels. Studies of ammonia fluxes from soybean fields in North Carolina were conducted in collaboration with John Walker (North Carolina State University and United States Environmental Protection Agency [USEPA]). Significant fluxes were observed and the results demonstrated the utility of the ammonia CIMS system designed and built by ACD.

FY04 efforts also included a workshop, database development, data analysis and manuscript preparation associated with the Chemical Emissions, Losses, Transformations and Interactions with Canopies (CELTIC) study in Duke Forest, North Carolina led by BAI in collaboration with Chris Geron, Bob Arnts (USEPA) , Walker, Jose Jimenez, Darin Toohey, Alice Delia (University of Colorado), Sparks (Cornell), Mark Potosnak (Desert Research Institute), Greg Huey, David Tanner, Darlene Slusher and Robert Stickel (Georgia Institute of Technology), Kolby Jardine and Bradly Baker (South Dakota Institute of Mining and Technology), Jose Fuentes (University of Virginia) Will Vizuete (University of Texas), Fred Mowry and Jeff Herrick (Duke University), Francesca Rapparini (Istituto di Biometeorologia, Italy), and Rei Rasmussen (Oregon Graduate Institute). The CELTIC results indicate that isoprene emission increases with elevated ozone and, on a canopy scale, with elevated CO_2. Future changes in ozone and CO_2 could thus change regional isoprene emission rates leading to feedbacks. The pine plantation forest floor (soil and leaf litter) was a significant sink of methanol, acetone, acetaldehyde and isoprene. This is not well represented in existing models and could lead to overestimated ambient concentrations. Substantial sesquiterpene emissions observed from pine trees could be the dominant source of biogenic secondary organic aerosol mass under certain environmental conditions. PAN (and PAN-like compounds) were deposited at a much faster rate than is predicted by current models by a factor of 3-5. This has significant implications for the lifetime of PAN in the atmosphere and its role as a transporter of reactive nitrogen in the atmosphere. Simultaneous observations of biogenic VOC and total organic aerosol during CELTIC allowed new constraints on aerosol yields and OH formation due to ozonolysis. The average aerosol yield for alpha-pinene, beta-pinene and d-carene are higher than calculated, supporting recent laboratory studies showing that polymerization reactions could enhance aerosol partitioning (Figure 29). Based on observed isoprene decay within the canopy, the upper limit of nighttime OH mixing ratios is less than reported measurements for other forests. Estimates of biogenic contributions to secondary organic aerosol mass at Duke Forest suggest that biogenic sources dominate which is somewhat surprising for this moderately polluted site.

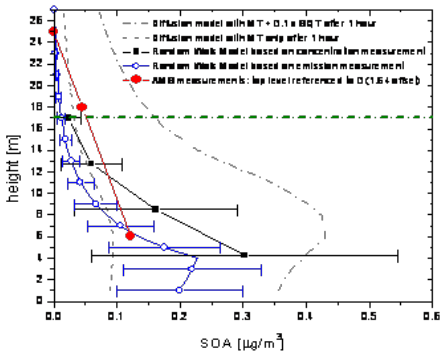


Figure 29: Comparison of SOA growth between different modeling approaches compared to measured gradients (red circles).

Analysis and publication of two other previous U.S. studies were completed in FY04. A tower flux study of isoprene and oxygenated VOC emissions from a northern Michigan deciduous forest was conducted in collaboration with Raymond Fall (University of Colorado) and Armin Hansel (University Innsbruck, Austria). The differences can be explained by the different physiological and phenological processes controlling these emissions. The multiscale (enclosures, tower, tethered balloon, aircraft) Ozarks Isoprene

Experiment (OZIE) study was conducted in collaboration with Brian Lamb and Halvor Westberg (Washington State University), Jay Turner (Washington University), Paul Palmer (Harvard University), Geron and Thomas Pierce (USEPA) and demonstrated that central U.S. oak forests and woodlands have very high isoprene emission rates resulting in elevated regional formaldehyde concentrations. This formaldehyde is often transported northward and eastward towards urban centers such as St. Louis and Chicago, and participates in the production of ozone (Figure 30). Current photochemical models underpredict the magnitude of formaldehyde produced by isoprene oxidation which leads to incorrect chemistry simulations within the urban centers.

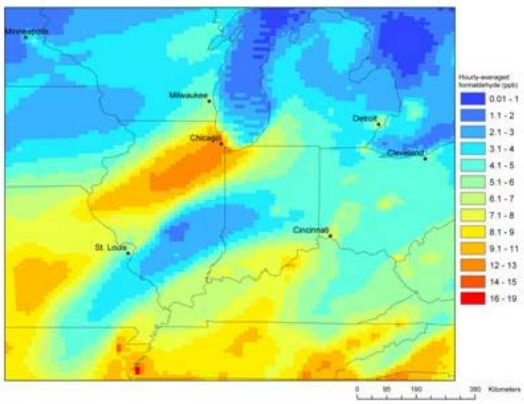


Figure 30: Hourly-averaged formaldehyde concentrations for 06:00 CDT on July 21, 1998, as modeled by CAMx. Winds on this day were predominantly from the south-southwest. A plume of elevated formaldehyde can be seen being transported from the forests of the Ozarks towards the northeast and into the Chicago urban area. The majority of this formaldehyde has been formed from the photooxidation of isoprene emitted from the Oak forests of the Ozarks on July 20.

International Field Studies (Task 2)

BAI scientists participated in international investigations of biosphere-atmosphere interactions in Brazil, Ireland, and Japan during FY04 and analyzed results from previous studies in China, Costa Rica, Brazil, and Finland. Background measurements were made at a primary tropical forest flux tower near Manaus, Brazil in collaboration with Potosnak, Artaxo, Julio Tota and Antonio Manzi (Brazilian National Institute of Amazon Research [INPA], Brazil). Significant flux of monoterpenes was estimated from the vertical profile shown in Figure 31. The contribution of semi-volatile organic gases to secondary organic aerosol mass was studied in Japan in collaboration with Yoshizumi Kajii (Tokyo Metropolitan University). The results indicate that humidity plays a significant role in determining the uptake of some semi-volatile compounds.

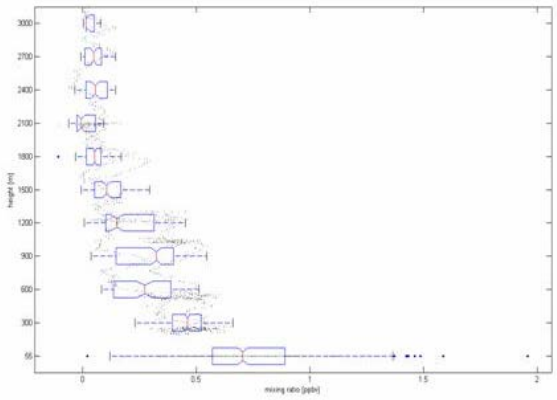


Figure 31: Altitude profile of monoterpenes above the Z34 tower close to Manaus.

BAI scientists participating in the BIOFLUX field study on the Irish coast investigated biogenic fluxes of organic iodide compounds in collaboration with Colin O'Dowd (National University of Ireland), Liisa Pirjola (University of Helsinki, Finland) and Thorsten Hoffman (Institute of Spectrochemistry and Applied Spectroscopy [ISAS], Dortmund, Germany). A tethered balloon system was used to characterize vertical gradients of several alkyl halides including di-iodomethane, ethyl bromide and ethyl iodide. Concentrations decreased with height indicating a surface source of these compounds which are believed to be involved in new particle formation.

Two manuscripts were published in FY04 (Spirig et al., and Boy et al.) describing BAI results from the Origins of Secondary Organic Aerosol (OSOA) study that was conducted at a boreal forest site in Finland in collaboration with Christoph Spirig (Swiss Federal Institute of Technology [ETH] Zurich, Switzerland), Michael Boy and Markku Kulmala

(University Helsinki, Finland). Total monoterpene oxidation rates during the OSOA study were not correlated with particle production events, but there was a strong correlation with ozone indicating that more ozone reactive biogenic compounds, such as sesquiterpenes, may make an important contribution. Vertical gradients of particles above the forest suggest that particle growth occurs throughout the boundary layer.

Tropical forest biogenic emissions were studied in the eastern Amazon (Brazil) in collaboration with Luciana Vanni Gatti and Carla Trostdorf (Energy and Nuclear Research Institue [IPEN], Brazil) and in Costa Rica in collaboration with Deborah Clark (University of Missouri), Sparks, and Potosnak. Seasonal isoprene variations in the Amazon were much higher than expected (more than a factor of 3 higher in the dry season). Tropical forest ecosystems in both Brazil and Costa Rica were both a significant source (daytime) and sink (nighttime) of methanol, acetone, and acetaldehyde. Dry deposition velocities of these and other (e.g., methyl vinyl ketone, methacrolein, and acetonitrile) compounds were a factor of 10-20 higher than estimated from existing deposition models which has important implications for regional and global chemistry and transport models. This work is described in Greenberg et al., 2004; Harley et al., 2004; Trostdorf et al., 2004; and Karl et al., 2004.

Studies of the impact of land cover change on biogenic emissions from Chinese landscapes were conducted in collaboration with Baker, Rassmussen, Bai Jianhui (Institute of Atmospheric Physics [IAP] Chinese Academy of Sciences), Susan Owen (Lancaster University), and Geron. Chinese rubber tree and oil palm plantations have much higher terpenoid emissions than native tropical forests. This suggests that there has been and continues to be significant increases in biogenic VOC emissions in some tropical regions of China. Severe drought results in a dramatic reduction in these emissions demonstrating the equally important role of climate change. These results are described in Baker et al., 2004; and in two manuscripts in preparation.

Regional Modeling Studies, U.S. (Task 2)

Wiedinmyer and Guenther investigated biosphere-atmosphere interactions in the U.S. using regional chemistry and transport models. FY04 studies included an investigation of the impact of future climate and land cover on regional air quality in the Pacific Northwest and north central U.S. in collaboration with Brian Lamb (Washington State University), Cliff Mass (University of Washington) and Susan Fergusen (U.S. Forest Service) and a study of the contribution of sesquiterpenes and other biogenic VOC emissions to secondary organic aerosols in the eastern U.S. in collaboration with Jana Milford (University of Colorado). Both of these projects were initiated in FY04, and efforts were directed at setting up the regional air quality modeling system and developing the emission scenarios.

Regional Modeling Studies, International (Task 2)

Wiedinmyer, Sreela Nandi (ASP/ACD Postdoctoral Fellow), and Guenther investigated biosphere-atmosphere interactions in China, Brazil, and Mexico using regional chemistry and transport models in FY04. The contribution of biogenic VOC emissions to oxidant and particle production in China was studied in collaboration with Xiaoping Wang and Denise Mauzerall (Princeton University). The results indicate that future growth in China's fossil fuel emissions will lead to costly decreases in public health and crop productivity. Much of this region is VOC-limited so changes in biogenic VOC emissions will have important consequences for air quality. The BAI Group also supported regional simulations of air quality in Mexico in preparation for the NCAR-ACD Megacity Impacts on Regional and Global Environments [MIRAGE] study (Xuexie Tie, ACD).

Global Modeling Studies (Task 1)

Wiedinmyer and Guenther investigated global scale biosphere-atmosphere interactions in FY04 using global chemistry and transport models. The contribution of biogenic VOC emissions to global organic aerosol was examined in collaboration with Joyce Penner (University of Michigan). The study showed that uncertainties in biogenic VOC emissions are a significant contributor to the total uncertainty associated with estimates of global radiative forcing of aerosols. A biogenic VOC model was integrated into the NCAR Community Climate System Model [CCSM] Land Surface Model [LSM] and used to investigate the sensitivity of emissions to climate and land cover in collaboration with Sam Levis and Gordon Bonan (CGD). Biogenic VOC emissions were sensitive to climate, and the estimated interannual variability exceeded 10% of the estimated annual anthropogenic emission estimates used for the IPCC emission scenarios. Finally, a study examining interactions among global change (climate and land cover), biogenic isoprene emissions, and the chemical composition of the atmosphere was completed in collaboration with Tie, Ronald Neilson (U.S. Forest Service), and Claire Granier (CNRS). Climate and land cover-driven changes in biogenic VOC emissions impacted simulated regional surface ozone concentrations by as much as -30% to 50% under certain emission and climate scenarios. The ozone production chemistry was shown to change under different emission scenarios (i.e., NO_x versus VOC) and has implications for unhealthy ozone concentrations and future ozone abatement strategies (see Figure 33).

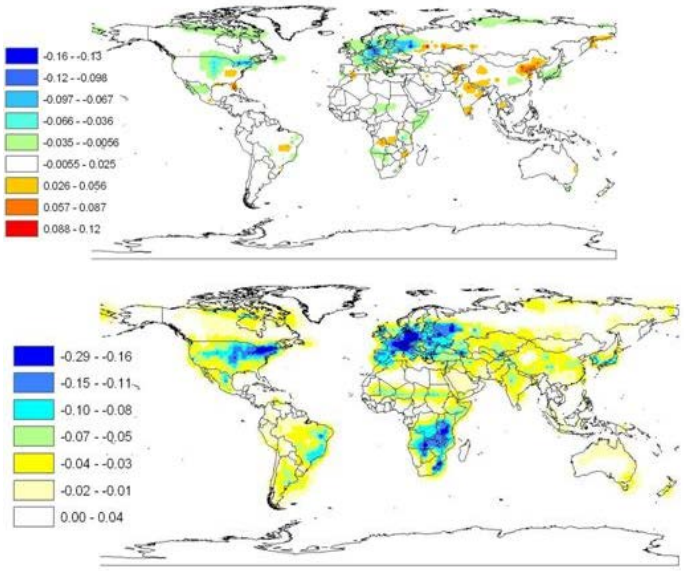


Figure 33: Change in L_N/Q for the month of July for [(FUTVEG-CURCLIM) – (CURVEG-CURCLIM)] (top) and [(FUTVEG-FUTCLIM) – (CURVEG-CURCLIM)] (bottom).

Model and Database Development (Tasks 1& 2)

Guenther and Wiedinmyer also developed a biogenic emission model and database for the scientific and air quality regulatory communities. FY04 accomplishments include the initial release (user's guide and files are available on the NCAR community data portal, https://cdp.ucar.edu/) of the Model of Emissions of Gases and Aerosols from Nature (MEGAN) which predicts biogenic emissions on a global scale at 1 km resolution (Figure 34). MEGAN was also integrated with the NCAR global models, MOZART and the Community Land Model (CLM), and an effort was initiated to integrate MEGAN with regional air quality models.

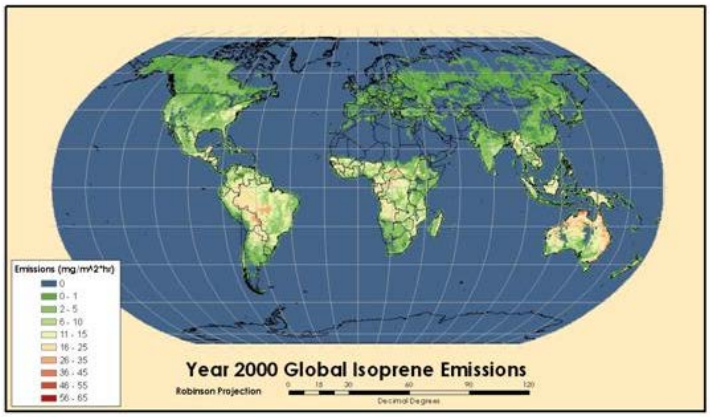


Figure 34: Global annual isoprene emission distribution for the year 2000 estimated by the MEGAN model.

Instrument Development (Task 2)

Turnipseed, Guenther, Greenberg, and Karl developed instruments for investigating biosphere-atmosphere exchange in FY04. This included a Disjunct Eddy Accumulation (DEA) system that captures and stores air based on the vertical wind direction and speed. The concentrations in these stored samples (along with wind statistics) can then be used to determine fluxes of chemical trace species which are difficult to determine by other flux techniques which often need fast (< 1 s) measurement times. This project was in collaboration with Lamb and Mount, Shepson, and Steve Shertz (ATD). Two separate systems developed and evaluated in FY04 allow for DEA flux measurements of volatile organic compounds (VOCs) from both a tower and an aircraft platform.

Climate and Global Dynamics Division: CGD

The Biogeoscience initiative provided support for several projects in the Climate and Global Dynamics Division (CGD)'s Terrestrial Sciences Section (TSS) to implement biogeochemistry in the Community Land Model (CLM) and the Community Climate

System Model (CCSM). This research broadly addresses how biogeochemical coupling of carbon, nitrogen, iron, and sulfur cycles affect climate, air quality, radiative forcing, and ecosystem function on regional to global scales. It involves two specific research agendas, related to mineral aerosols and the terrestrial carbon cycle. Highlights for the past year include the release of version 3 of the model (CLM3) and initial implementations of urban land cover and agricultural land in the CLM. This work mainly contributed to BGS Task 1, with the land-use-alteration studies also contributing to Task 4.

CGD-TSS members supported by BGS include Gordon Bonan, Samuel Levis, Keith Lindsay, Natalie Mahowald, Keith Oleson, Rosenbloom, and Peter Thornton. Bonan, Mahowald and Thornton are members of the BGS Steering Committee. Bonan co-chairs the CCSM Land Model Working Group, Mahowald co-chairs the CCSM Biogeochemistry Working Group, and other TSS scientists actively participate in both working groups, providing strong input to model development and implementing and testing model parameterizations.

Community Land Model (Tasks 1 & 4)

The Community Land Model (CLM) includes biogeophysics and hydrology, the traditional physical core components of land models, and is being further developed to include river routing, biogeochemistry (carbon, nitrogen, mineral aerosols, biogenic volatile organic compounds, water isotopes), and vegetation dynamics. Levis and Bonan analyzed the vegetation simulated by the dynamic global vegetation model in CCSM3. Their analyses showed that the prominent dry biases in the United States and the Amazon result in an inability to grow the expected forest vegetation. Changes to CLM3 that reduce the interception of water and increase transpiration result in a better simulation of vegetation (Figures 58 and 59).

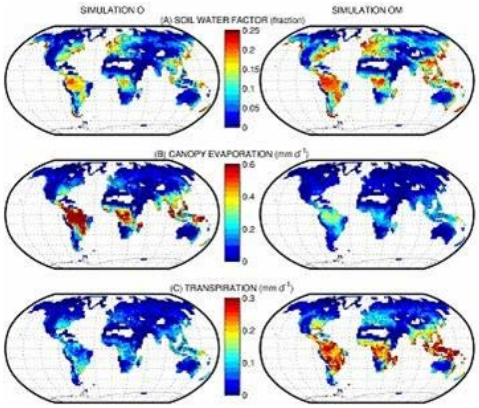


Figure 58: Relative soil water wetness, canopy evaporation, and transpiration simulated by CLM3 (left) and a modified CLM3 (right). The modifications result in relatively wetter soil, reduced interception and canopy evaporation, and increased transpiration.

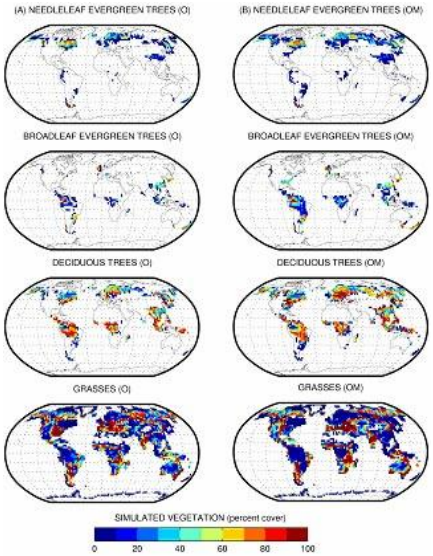


Figure 59: Vegetation simulated by CLM3 with its dynamic global vegetation model. Left: CLM3. Right: CLM3 with modifications that reduce interception and increase transpiration.

The modifications allow for more extensive forests in eastern U.S. and tropical South America.

Land Cover and Land Use Change (Tasks 1 & 4)

A major research focus for CGD-TSS is natural and human-mediated changes in land cover and ecosystem functions and their effects on climate, water resources, and biogeochemistry. TSS scientists worked on several projects to implement land cover and land use change in CLM and to use climate models to study the impact of these processes on climate. This work contributes to the NCAR Weather and Climate Impact Assessment Science Initiative and the NCAR Biogeosciences Initiative.

Johannes Feddema (University of Kansas), Bonan, Oleson, and Linda Mearns (Environmental and Societal Impacts Group (ESIG)) studied the effects of historical and future land cover change on global climate. Climate model simulations were performed with the Parallel Climate Model (PCM) and examined the sensitivity of simulated climate to different specifications of present-day land cover and natural potential vegetation. Uncertainty in the classification of present-day vegetation can produce large differences in the simulated climate. Present-day vegetation has generally cooled surface climate, especially in the mid-latitudes due to the higher albedo of croplands compared to natural vegetation. Climate model simulations using land cover for the year 2100 showed that the land cover forcing of climate can be large, especially in tropical South America and in the United States, where agricultural land is projected to become more extensive by the year 2100.

Bonan, Oleson, and Feddema also worked to develop and implement an urban land cover parameterization for CLM. The parameterization uses concepts from urban canyon models to simulate the radiative balance of a city, turbulent energy fluxes, and the hydrologic cycle.

Agroecosystems differ from other terrestrial ecosystems due to their intensive management. Levis and Bonan worked to implement a crop model in CLM. The CLM is being modified from one crop type with prescribed leaf area index to include corn, wheat, and soybean, and to allow leaf area to grow in response to prevailing atmospheric conditions and management practices. The crop model is based on a model developed by Chris Kucharik, Jon Foley, and colleagues at the University of Wisconsin. This will provide a first order look at the sensitivity of climate to better specification of croplands.

Development of Carbon and Nitrogen Capabilities in CLM (Task 1)

The core biogeochemical capabilities for carbon and nitrogen cycling were implemented in CLM during FY 2003, as described in last years ASR. Over the past year these capabilities have been extensively evaluated and expanded, and long offline and coupled simulations have now been executed in a number of different configurations to demonstrate the readiness of the new model (CLM3-CN, Community Land Model – Carbon Nitrogen) for research applications. Thornton led or performed a range of development, evaluation, and model application activities over the past year, described in the following list:

- Extensive testing of the new algorithm for seasonal and stress deciduous phenology.
- Migration of the CLM2-CN code into the vectorized code base, to form CLM3-CN. Involved a complete reorganization of the implementation and referencing for nested hierarchical data structures. Demonstrated bit-for-bit correspondence with CLM2-CN.
- Added new algorithm for prognostic canopy height as a function of stem mass and realistic allometric relationships.
- Migration of sunlit/shaded canopy integration scheme from CLM2-CN into CLM3-CN. Included an improved treatment of canopy vertical gradient of specific leaf area for the purpose of calculating LAI from prognostic leaf carbon state variable.
- Began discussions of implementation of water and carbon isotopes with David Noone (CU, water) and Ian Baker and Neil Suits (CSU, carbon).
- Collaboration with J.F. Lamarque (ACD) to use nitrogen deposition fields from coupled CAM-chemistry model in offline mode in CLM3-CN and CCSM3 simulations.
- Developed and implemented dynamic woody allocation algorithm.
- Implemented gap phase mortality algorithm.
- Extracted the sun/shade canopy integration code so that it could be incorporated in the CASA effort (Forrest Hoffman, ORNL).
- Developed and implemented biological nitrogen fixation algorithm.
- Began execution of long offline simulations examining the effects of preindustrial vs. current rates of nitrogen deposition, with J.F. Lamarque.
- Began execution of experiments to document the influence of modified canopy integration scheme in the default model (non-CN) and in the CLM3-CN model. Included multiple 40-year experiments, both in offline and in coupled mode (CAM and CLM active).
- Executed a series of experiments (with Mariana Vertenstein, CGD-TSS) to test the shift of CLM surface albedo call to the end of the CLM timestep. This is an important requirement for future implementation of isotopes. Verified that this modification does not changed coupled climate in CAM-CLM active mode.

Community Land Model Diagnostics Package (Task 1)

Since April 2004, Thornton has been leading an effort with Rosenbloom and Sylvia Murphy (CGD) to produce an updated diagnostics package for CLM. This activity was inspired by the need to modify the existing package to include new variables for the CN code, and our discovery that there were many “hard-wired” decisions in the existing package that made this sort of extension extremely tedious. They developed an architecture that allows for very flexible specification of new variables and new plotting types (or “sets”), while still maintaining all the functionality of the original package. They are in the process of implementing this architecture, and progress has been excellent. The combination of Thornton and Rosenbloom’s expertise on the scientific aspects and Murphy’s expertise on NCL has resulted in a very productive collaboration. Next steps include canvassing the land model and biogeochemistry Working Groups to identify new functionality that is required for current and future research efforts, and to implement this functionality.

First Results from CCSM3 with Coupled C and N Cycles (Task 1)

Offline simulations driven by the NCEP/NCAR reanalysis surface weather fields have demonstrated that the new land biogeochemistry behaves reasonably under prescribed atmospheric forcing. The first long simulations coupling the new land model to the atmosphere in CCSM3 (with prescribed ocean and ice boundary conditions) have just been completed, and the results suggest that both the improved canopy integration scheme and the prognostic carbon and nitrogen cycles have a significant impact on the coupled climate simulation. A major contributor to climate feedback in the new model is the prognostic canopy leaf area, which causes the seasonal, interannual, and long-term dynamics of the canopy to respond directly to the model climate, in contrast to the default land model which prescribes the seasonal cycle and spatial distribution of canopy leaf area from satellite observations (Figure 60). Next steps include simulations to quantify the climate feedbacks due to greenhouse forcing from prognostic carbon fluxes on land, and fully coupled simulations including the carbon cycle biogeochemistry of the oceans.

Multi-Century Carbon Cycle Simulations (Task 1)

Lindsay performed a suite of multi-century fully coupled carbon-climate integrations using a modified version of the Climate System Model, Version 1.4 (CSM1.4). A sequence of hundred year spin-up runs were done, with the aim of letting the modeled carbon cycle adjust incrementally to the coupled model climate. These spin-up runs led to a stable multi-century (1000 years) carbon-climate pre-industrial control run. Additionally, a multiple 180 year historical and 100 year future scenario fossil fuel emissions experiments have been completed. These experiments are being analyzed to understate connections and feedbacks between the carbon cycle and the physical climate.

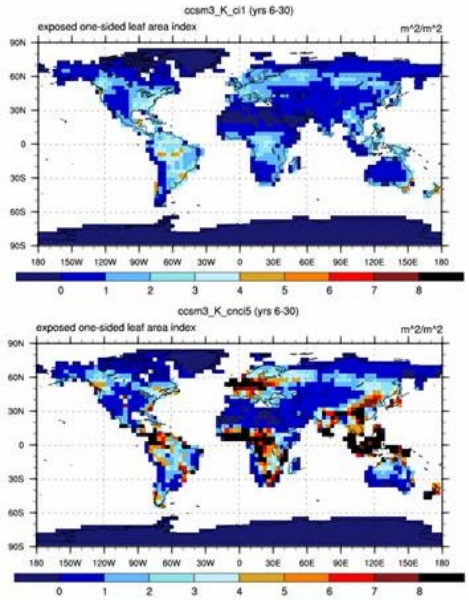


Figure 60. Comparison of annual average leaf area index (LAI) for the default implementation of CLM3 in CCSM3 (top), and for the new implementation of CLM3-CN which includes prognostic carbon and nitrogen cycles (bottom). The CLM3 LAI is derived from remote sensing observations, and does not respond in any way to the modeled climate. The CLM3-CN LAI is a product of the prognostic development of vegetation canopy carbon and nitrogen state variables, with strong seasonal, interannual, and climatological responsiveness to the modeled surface weather and climate fields. The CLM3-CN result in this example is an intermediate result with nitrogen limitations turned off to achieve more rapid canopy development.

Coupled Climate Carbon Cycle Model Intercomparison Project (C4MIP) (Task 1)

Much of the work described above under the general category of CLM-CN development is relevant to the execution of the C4MIP experiments, but three efforts of special relevance to this project are listed here.

- Thornton worked closely with Vertenstein and Brian Kauffman (CGD) to define new requirements for the data atmosphere component of CCSM3, which would allow actual CAM outputs to be read back in and fed to CLM in an offline mode through the coupler. This is an essential step in the involved process of bringing the CN model into steady state for preindustrial conditions. These requirements have been implemented and tested (Kauffman).
- Thornton has defined the spinup protocol for the C4MIP experiments, working closely with Vertenstein and Hoffman to put together a project plan for the numbers and types of simulation segments that are required. Some technical aspects of the spinup are not yet deployed, but they have all been identified and progress is being made to allow the experiments to begin November 1, 2004.
- Thornton has used the C4MIP protocol for prescribed transient landuse changes to define the requirements for the input datasets and the implementation of changing landcover within CLM (with Vertenstein). All of the raw datasets have been assembled and processed to produce both a preindustrial potential vegetation map and a timeseries of landcover from 1900-1990 that includes the fractional gridcell coverage for crops and pasture, and their changes through time. Thornton has also written the requirements for how the CN code needs to handle changes to and from all the possible combinations of landcover. Levis, Oleson, Vertenstein, and Thornton have also defined the requirements for handling water and energy conservation.

High-resolution Carbon Cycle Model User Interface Project (Task 1)

Thornton is PI on a project (started September 2003) sponsored by the NASA Earth Science Technology Office, to develop and implement a research-quality user interface for high-resolution carbon cycle simulation, using the Daymet and Biome-BGC models as technology components. The project involves a close collaboration with researchers in SCD to implement this interface as a web-based tool that can connect remote users to not only a set of state-of-the-art modeling tools, but also the high-end computational and data storage resources required to perform and analyze high-resolution simulations over large regions.
Accomplishments over the past year include:

- Developed a formal System Architecture defining the interactions between software and hardware components, including the implementation of a Grid Service Interface connecting the User Interface with the Computational Engine.
- Replaced the original client-side user interface application with a thin-client Web Portal User Interface
- Introduced a project and data object model to manage the complex input and output requirements for the core science codes
- Introduced a user authentication system to manage certification across distributed secure resources
- Replaced the user-mediated interaction with the supercomputer resource from the original prototype with an automated job execution interface and job management service
- Introduced Grid-based automated storage and retrieval mechanisms interfacing with the Mass Storage System.

Mineral Aerosols in CCSM (Tasks 1 & 4)

Mahowald's work has focused on three main issues: understanding the anthropogenic portion of desert dust, the climate and biogeochemical impacts of desert dust, and incorporating desert dust into the CCSM. In collaboration with university researchers (Jean-Louis Dufresne (UCSB/CNRS France), Chao Luo (University of California, Santa Barbara), Masaru Yoshioka (University of California, Santa Barbara), Mahowald contributed to two papers (one submitted, one published) on the relative proportion of anthropogenic mineral aerosol sources to the total sources, using Total Ozone Measuring Spectrometer Absorbing Aerosol Index (TOMS AII) and comparisons to observations. Additionally, she has one submitted article with a SOARS student (G. Rivera) and a university researcher (Chao Luo (University of California, Santa Barbara)) using desert dust storm data to constrain the land use fraction of current desert dust concentrations. Additionally she contributed to a paper looking at the importance of diurnal (surface energy flux processes) and synoptic processes in modulating the desert dust cycle (with Chao Luo (University of California, Santa Barbara) and Charles Jones (University of California, Santa Barbara).
Mahowald contributed to two papers dealing with the biogeochemical implications of mineral aerosols (with Greg Okin (Virginia), Ed Boyle (Massachusetts Institute of Technology) and many others). She authored an additional paper evaluating the atmospheric phosphorous sources over the Amazon (with university collaborators), which is in preparation. She worked with Jenny Hand (ASP) to develop the first modeling study of atmospheric iron in mineral aerosols as it is processed in the atmosphere and has a paper published on this topic, which is of great importance to the ocean biogeochemistry

community. Mahowald's research also examined the impact of desert dust on African easterly waves as derived from observations with Charles Jones (University of California, Santa Barbara) and Chao Luo (University of California, Santa Barbara).
Mahowald has continued to improve the CCSM desert dust modeling codes and has looked at the response of atmospheric mineral aerosols and seasalts to climate change, using the CCSM in slab ocean model mode, for the current climate, preindustrial, doubled-CO2 and the last glacial maximum. This work is being done in collaboration with Phil Rasch (CGD-CMS), Charlie Zender (University of California, Irvine), Levis (CGD-TSS), Masaru Yoshioka (University of California, Santa Barbara) and Bette Otto-Bliesner (CCR).

Carbon in the Mountains Experiments: CME and ACME

The Biogeosciences Initiative sponsored the Airborne Carbon in the Mountains Experiment (ACME), an integrated program to quantify carbon fluxes in mountain and mountain-valley complex landscapes using airborne and ground-based flux measurement techniques. ACME is based in the Atmospheric Technology Division (ATD) with collaborations from scientists in CGD and MMM. External collaborators include University of Colorado (Russ Monson, Susan Buhr), Colorado State University (Dennis Ojima), University of Miami-Florida (Leolen Sternberg), University of Montana, and guest scientists from the University of Utah, Scripps Institution of Oceanography, and Washington State University. David Schimel (CGD) is principal investigator. ACME is coordinated with the Carbon in the Mountains Experiment (CME), a 5-year collaborative project between CU, CSU, U. Miami, and NCAR ATD, CGD, and MMM. CME is funded by the NSF Biocomplexity Initiative and also contributes to the NASA Interdisciplinary Science Program, and the interagency North American Carbon Program.
BGS supports the ACME contributions of Britton Stephens and Steven Shertz (both ATD), Jielun Sun and Sean Burns (both MMM), and Steven Aulenbach (CGD). The CME and ACME programs contribute to BGS Tasks 2 and 3.

The Airborne Carbon in the Mountains Experiment (ACME) combines measurements and innovative modeling techniques at regional scales. Techniques for quantifying carbon fluxes in complex landscapes are urgently required because much of the actively growing forest in Northern Hemisphere mid-latitudes occurs in such regions. Mountainous terrain also confers methodological advantages. Much of the uncertainty in carbon models is in the respiratory processes or the release of photosynthetically fixed carbon back to the atmosphere. This measurement is challenging in level landscapes, since eddy covariance fails in (common) stable nighttime conditions. In the mountains, concentration measurements in nighttime drainage flows allow “scaling up” of respiratory fluxes to airshed or “carbonshed” scales. This gives access to a key unknown quantity at a range of large scales.

ACME/CME studies were carried out in summer 2004. The airborne program (ACME I) involved 54 flight hours using the NCAR C-130 and explored a number of techniques for estimating carbon fluxes, in particular separating nighttime and daytime fluxes. The ground-based component, the Carbon in the Mountains Experiment (CME) deployed three Integrated Surface Flux Facility (ISSF) towers on Niwot Ridge, Colorado from July-October 2004, extending and complementing a permanent 2-tower flux array maintained by the US Geological Survey (USGS), and the University of Colorado. Each ACME flight included overpasses of the CME site, allowing extension of the results across scales. The combined experiment provides an innovative way of estimating landscape-scale parameters for land surface models, and a way of validating these models against regional airborne measurements. The separation of the airborne program into daytime (photosynthesis-respiration) and nighttime (respiration alone) fluxes allows the model to be tested much more rigorously than in previous studies where 24-hour measurements were made (Figures 61 and 62). This study is a pathfinder for upcoming intensives of the North American Carbon Program where this and other approaches for analyzing large-scale observations, model development, and model testing will be explored.

Figure 61: Morning and afternoon flight segments of a typical ACME day. Upper left: Early morning vertical profiling and low-level survey flights, along with the upwind segment of a semi-lagrangian flight (extension to the Northwest). Upper right: Afternoon flights showing the downwind segment of the semi-lagrangian experiment and low-level eddy covariance surveys.

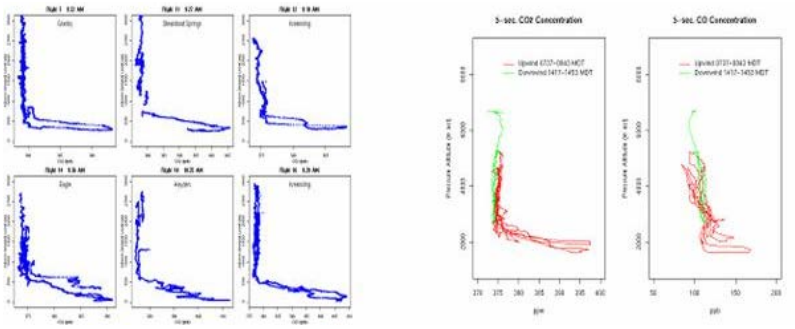


Figure 62: Typical profiles from the ACME campaign. Lower left: Morning profiles indicating large accumulation of respired CO_2 in the nocturnal boundary layer. These accumulations, also evident in low-level survey flights, suggest that large-scale drainage flows may be used to develop integrated estimates of respiration in the mountains. Lower right: Morning and afternoon profiles of CO_2 from the semi-lagrangian experiment; CO profiles used to correct for pollution signals.

Carbon in the Mountains Experiment (CME) (Tasks 2 & 3)

Russ Monson (CU, principal Investigator), David Schimel (CGD), Britton Stephens (ATD), and Jielun Sun (MMM) are co-investigators in the CME project. Intensive observations at the Niwot Ridge Research Site in the first 6 months were conducted to investigate the local forest CO_2 exchange. To enhance the existing carbon-cycle measurements (by CU and Dean Anderson, USGS) at this site, ATD staff (Steve Oncley, Steve Semmer, Kurt Knudson, Gordon Maclean) deployed 3 additional towers with instrumentation for measuring temperature, humidity, 3-dimensional winds, CO_2 fluxes, and high-accuracy CO_2 concentrations at multiple levels up to 30 m. The CO_2 concentration instruments included the HYDRA system with 18 inlets developed and deployed by Tony Delany (ATD) Burns, and Sun (MMM), and three new AIRCOA units with six inlets each developed and deployed by Stephens and Andy Watt (ATD, see below). The tower measurements allow quantification of nighttime advective fluxes and can be inverted to estimate respiration. An animation in the MMM scientific report (Figure 40 animation) depicts CO_2 evolution at the CME site.

The CME tower studies will be analyzed using a unique carbon process data assimilation model developed by University of New Hampshire and NCAR scientists including Schimel, which allows forest carbon fluxes from eddy covariance and advective techniques to be inverted into estimates of ecosystem model parameters. Preliminary studies have already demonstrated that key ecosystem parameters can be retrieved using this method. The model is being extended to include satellite vegetation estimates, water cycle measurements and isotopes. The process model currently being used (SPACENET) is a simplified version of the Common Land Model (CLM). As the information content of the flux data are better understood, we will begin assimilating parameters and states in the full CLM. Results from the SPACENET and CLM assimilations can be compared to fluxes estimated from the airborne program (ACME) using the CSU coupled atmospheric-land surface model (RAMDAS).
[ISFF field project web page: http://www.atd.ucar.edu/rtf/projects/cme04/]
[ISFF web page: http://www.atd.ucar.edu/rtf/facilities/isff/]

Airborne Carbon in the Mountains Experiment (ACME I) (Tasks 2 & 3)

ATD, MMM and CGD staff (Stephens, Sun, Schimel, Aulenbach, Bill Sacks and Teresa Campos) conducted the first Airborne Carbon in the Mountains Experiment (ACME I) in May and July 2004 to explore methods for constraining regional-scale CO_2 fluxes over complex terrain and to collect measurements useful for devising and testing strategies for long-term monitoring of these fluxes. A total of 54 hours were flown on the NCAR C-130 aircraft over large regions of the Colorado Rocky Mountains, making continuous measurements of CO_2, CO, O_3, and water vapor concentrations (Campos, ATD), and collecting discrete flask samples for ^{13}C and ^{18}O isotope ratios in CO_2 (University of Utah). In addition to these primary measurements, a number of other activities were conducted, including, measurements from the MCR scanning radiometer with thermal and vegetation channels (Mark Tschudi, ATD), collection of flask samples for radiocarbon measurements and for verification of our *in situ* CO_2 and CO measurements (Scripps Institution of Oceanography), and collection of high rate CO_2, CO, O_3, and water vapor data for direct eddy-correlation flux estimates (Campos, ATD). Our airborne measurements will be compared to and integrated with the extensive ongoing carbon and ecosystem measurements at Niwot Ridge and an enhanced network of ground-based measurements deployed as part of the broader Carbon in the Mountains Experiment (CME).
The flights were conducted according to a combination of experimental designs, including morning to afternoon Lagrangian flux measurements, regional survey measurements for

assimilation into a high-resolution ecosystem-atmosphere model, morning profile sampling of nocturnally respired CO_2 and its concentration by topography and dispersion by turbulence, flask sampling to resolve elevation gradients in isotope signatures, and direct flux and eddy covarianve measurements. Preliminary data analysis results are encouraging. During the Lagrangian experiments and regional surveys, CO_2 drawdowns of several ppm were observed in the daytime boundary layer, representing significant CO_2 uptake by the forests and strong signals for use in the analyses. Also, in large mountain valleys we observed on the order of 30 ppm of respired CO_2 pooling as deep as 1000 ft. overnight and persisting until 10 AM, which may suggest techniques for making respiration estimates on relatively large scales. Results are being analyzed using a mesoscale data assimilation system based on the RAMDAS coupled atmospheric-land surface model (CSU). Our results are already helping the community adapt plans for the North American Carbon Program to improve constraints on mountain carbon fluxes.
[collaborative web page with preliminary results and photos: http://swiki.ucar.edu/acme]

CO_2 transport over complex terrain (Tasks 2 & 3)

In addition to their CME and ACME work, Sun and Burns (MMM) collaborated with Monson (University of Colorado) to collect meteorological, carbon dioxide, and flux data from the CU tower at Niwot Ridge as part of the ongoing Ameriflux program. The Ameriflux tower network, which covers North and South America, aims to improve the continental scale carbon budget.

The importance of downward transport of CO_2 is becoming clear to the AmeriFlux scientific community, but the details of the mechanism and timing of such transport are still uncertain. Some researchers believe that observations from single towers may miss the advected CO_2 at night, but can capture the missed CO_2 during the day through observations of the CO_2 turbulent transport. In addition, there is confusion on how to handle both horizontal and vertical advection of CO_2. The combined dataset from the Niwot Ridge pilot experiment and 5 years of CU tower data are unique for examining all these issues.

Sun is systematically analyzing the data to examine all the CO_2 transport mechanisms over the Niwot Ridge complex environment, including vertical and horizontal advection of CO_2, horizontal turbulent transport of CO_2, diurnal variation of CO2 storage, and detailed vertical turbulent transport of CO_2 within and above the canopy layer. She has found that the advection of CO_2 over mountain areas is clearly associated with local circulations, consisting of both horizontal and vertical advections even below 21m, and is sensitive to major steep slopes and small gullies embedded in these steep slopes. The local circulation reverses between night and day. The night-time CO_2 transport over the slope explained the high CO_2 observed at the North Park during ACME. Sun also found that CO_2 respiration from the ground cannot be effectively ventilated through the canopy, due to an unstable layer close to the ground resulting from shading by the canopy. CO_2 advection could therefore play an important role even during daytime, when it was previously thought to be unimportant.

These observations provide critical information to the many on-going long term observational programs, which currently ignore horizontal transport in the global CO_2 budget. They will be used to fully resolve the atmospheric transport of CO_2 in order to accurately measure the net ecosystem carbon exchange, and as input to a regional-scale data-assimilation model to improve our understanding of the processes controlling carbon cycling by mountain forests.

Tower data collection and analysis will continue throughout FY05. Sun plans to work to understand all the physical transport mechanisms over complex terrain and integrate the local CO_2 balance. She also hopes to implement these new physics into numerical modes to improve assimilations of CO_2 transport over complex terrain.

Atmospheric Technology Division: ATD

The Atmospheric Technology Division, the Atmospheric Chemistry Division, and the Biogeosciences Initiative have been collaborating for several years to fund development and field support of airborne and tower-based in situ trace gas instruments. Supported developments include measurements of water vapor and ozone at fast-response in addition to carbon dioxide and carbon monoxide. The activities have been successful on several fronts in maintaining and improving the quality of community-requestable instrumentation and data sets.

Airborne CO_2 Measurements (Task 2)

Teresa Campos (ATD) and co-workers modified the airborne CO_2 instrument to enable high rate measurements of CO_2 by the eddy covariance method. Preliminary results

indicate successful deployment during the GOTEX campaign off the coast of Mexico (Ken Melville (Scripps Institute of Oceanography, and Carl Friehe (UC-Irvine)) and during ACME (Russell Monson, U Colorado, Schimel (CGD), Sun (MMM), and Stephens (ATD)). Spectral analysis of GOTEX marine boundary layer data imply an instrument frequency response of 4-Hz, and time series analysis implied a mixing ratio measurement precision of 0.2 - 0.3 ppmv (1-s for a 1-second average). The flux artifact of this sensor due to air motion sensitivity was quantified in both marine and terrestrial boundary layer environments during both missions by introduction of calibration gas into the sample cell during a portion of a boundary layer transect. Sensitivity to correlated air motion sensitivity was observed in GOTEX data only at frequencies lower than 2 Hz. However, the amplitude of these fluctuations is a factor of 50 smaller than the equivalent power spectral content of ambient data obtained in the marine boundary layer at the same altitude (Figures 6 and 7 from the above section on Chemistry Community Instruments). Preliminary ACME results from intercomparison to analyses of flask samples (Heather Graham and Ralph Keeling, Scripps Institute of Oceanography) imply an accuracy of ± 0.2 ppmv. Also preliminarily, this result has been reproduced by intercomparison to CME ground network working standards provided and analyzed by the CO_2 calibration facility (Stephens, ATD-RAF).

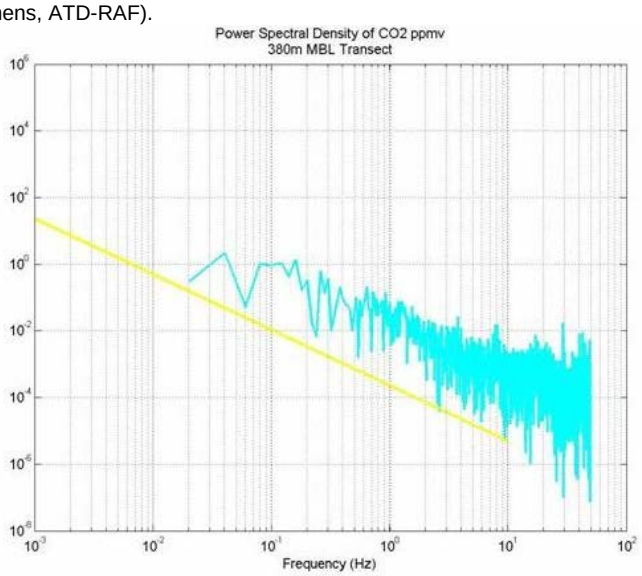


Figure 6: Power spectral distribution of two-minute ambient CO_2 measurements of marine boundary layer air during the 2004 Gulf of Tehuantepec Experiment. Observations were made at 380 msl off the coast of Salina Cruz, Mexico.

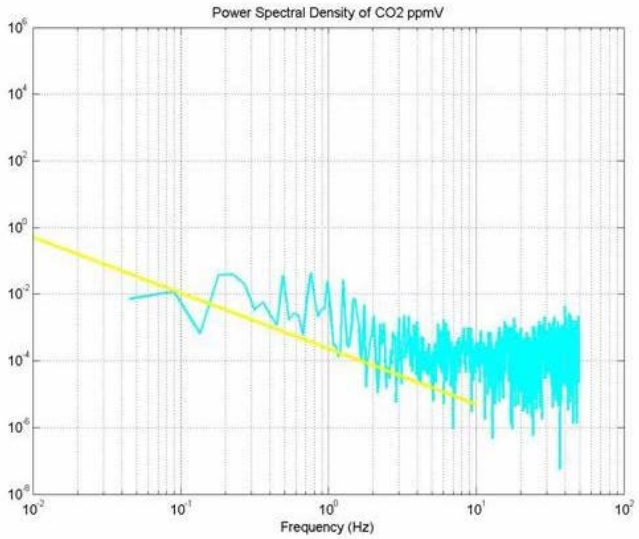


Figure 7: The power spectral distribution of a two-minute time series during which CO_2 calibration gas was sampled in-flight at 380 msl in the marine boundary layer. The measurement represents a quantification of the spectral dependence of the air motion sensitivity of the CO_2 sensor.

Tower CO_2 Measurements: Autonomous Inexpensive Robust CO_2 Analyzer (AIRCOA) (Task 2)

In support of the CME deployment and future experiments to measure local and regional CO_2 variations, Britton Stephens and Andrew Watt (both ATD) developed an autonomous,

inexpensive, and robust CO_2 analyzer [AIRCOA]. Four AIRCOA units were constructed after initial design testing and three of these were deployed in the field during the CME campaign. These units measure CO_2 concentrations at 6 levels on a tower, producing individual measurements every 2.5 minutes precise to 0.1 ppm CO_2 and closely tied to the WMO CO_2 scale. A key component in the robustness of these analyzers is near real-time data processing with extensive automated diagnostic tests to verify normal operation, with new results available from a web interface every day.
[online diagnostics and results http://raf.atd.ucar.edu/~stephens/AIRCOA]

NCAR CO_2 and O_2 Calibration Facility (Task 2)

ATD staff (Stephens, Shertz, and Watt) have completed assembly of primary components of the NCAR CO_2 and O_2 Calibration Facility. These include a box to hold 25 large high-pressure gas cylinders oriented horizontally and insulated as necessary to prevent fractionation, a control module to selectively deliver pressure-regulated gases from these cylinders to a cryogenic drier and the concentration instrumentation, a high-precision commercial CO_2 analyzer, a repackaged version of the RAF Oxygen Analyzer (ROXAN), and a suite of long-term (~20 years) calibration standards tied to Scripps Institution of Oceanography and NOAA CMDL WMO calibration scales. This facility was used to calibrate over 30 CO_2 reference cylinders used in the CME and ACME campaigns.
[online diagnostics and results http://raf.atd.ucar.edu/~stephens/CALFAC]

Synthesis of Global Light Aircraft CO_2 Data (Task 2)

In collaboration with CSU, NOAA CMDL, LSCE (France), U. Heidelberg (Germany), Max Planck Institute for Biogeochemistry (Germany), Tohoku U. (Japan), NIES (Japan), and CSIRO (Australia), Stephens completed a synthesis of vertical profile CO_2 data from 20 sites around the world to define the vertical distribution of CO_2 in the atmosphere. These results have been compared to output from the 16 TransCom 3 Project models to test their representation of vertical tracer transport. Stephens presented an invited seminar on this project at NOAA CMDL and a publication based on this work is in preparation.

Wisconsin Tall-Tower Atmospheric O_2 Measurements (Task 2)

Stephens concluded three and half years of atmospheric O_2 measurements at the WLEF tall-tower research site, and returned equipment to the lab for reconditioning while future deployments are considered. Stephens presented an invited seminar on these measurements at the APO Conference in Jena, Germany and several publications based on this work are in preparation.

Publications 2003-2004

(Note: Bold=university authors; *=institutional authors)

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Wildfires Strategic Initiative

This work represents the activities of the ACD-BAI Group for the Wildfires Strategic Initiative.

Laboratory Studies

ACD-BAI scientists (Alex Guenther, Jim Greenberg, Peter Harley and Thomas Karl) are using laboratory facilities to characterize the processes that control biomass burning. Biomass burning studies were conducted in the NCAR-ACD laboratory roasting/burning chamber facility in collaboration with Hans Friedli (ASP) and in the United States Department of Agriculture (USDA) Missoula fire laboratory burn facility in collaboration with Robert Yokelson and Theodore Christian (both of University of Montana). The laboratory biomass burning studies demonstrated that oxygenated VOC and nitrogen compound emissions from fires are higher than most previous estimates and likely have an important role in fire dynamics (i.e., fuel ignitability) and regional air quality. This research also suggests that emissions of some compounds from smoldering fires (including charcoal production and post flaming phase pyrolysis) are underestimated in existing fire emission inventories. Three manuscripts (Karl et al., Greenberg et al., Christian et al.) describing these results are in preparation for submission to peer-reviewed journals.

International Field Study

ACD-BAI scientists (Thomas Karl and Alex Guenther) participated in international investigations of biomass burning in FY04. The FY04 CAPOS study in the Brazilian Amazon used airborne and ground measurements to characterize the primary emission composition of VOCs and other gases from tropical fires and within aging plumes in collaboration with Bob Yokelson, Theodore Christian (University of Montana), Don Blake (University of California, Irvine), Paulo Artaxo (University of Sao Paulo, Brazil), Joao Caravalho (CPTEC, INPE, Brazil). The aircraft observations generally confirmed the emission profiles measured in the laboratory studies described above (Figure 32).

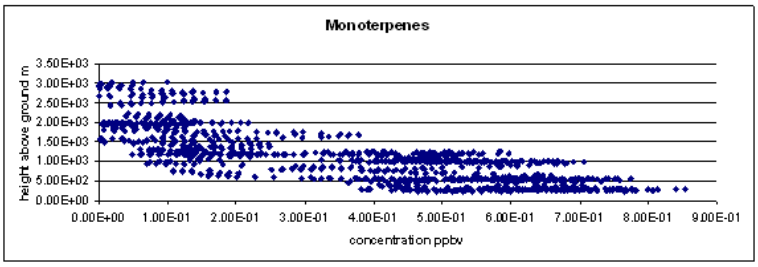

Figure 32: Altitude profile of monoterpenes above the Z34 tower close to Manaus

Modeling Studies

ACD-BAI scientists (Christine Wiedinmyer, Sreela Nandi and Alex Guenther) investjjigated impacts of fires on atmospheric chemistry using regional chemistry and transport models. FY04 studies included an investigation of the impact of future climate and landcover on regional air quality in the Pacific Northwest and NorthCentral U.S. in collaboration with Brian Lamb (Washington State University), Cliff Mass (University of Washington) and Susan Fergusen (U.S. Forest Service). Another study focused on the influence of biomass burning on regional air quality in the Brazilian Amazon (with Hsiao-ming Hsu, MMM/RAP). This project included a detailed sensitivity study of emission inputs which demonstrated that there is a large difference in the fire emissions predicted using different methods recommended in the literature. The BAI Group also supported regional simulations of air quality in Mexico in preparation for the NCAR-ACD MIRAGE study with Xuexie Tie (ACD).

A modeling framework was developed to predict daily emissions from fires for all of North America at a 1km resolution for easy use in regional air quality model simulations. Fire emission inventories developed by this model will allow air quality modelers to include fire emissions with their model simulations and determine if fire emissions have a large impact

on their air quality.

Upper Troposphere/Lower Stratosphere Strategic Initiative

The goal of the UTLS initiative is to plan and to conduct integrated studies of Upper troposphere and Lower Stratospheric dynamics, chemistry, microphysics and radiation using the new HIAPER aircraft in conjunction with observations from the NASA A-Train satellites and with NCAR modeling tools. During FY04, the UTLS initiative focused on four areas of activities. These are field campaign planning, model development, instrument development, and satellite data analyses.

Following the NSF's strategy of "Progressive Science", a series of field campaigns is planned starting by transport studies using simple payload and existing instruments. A Stratosphere-Troposphere Analyses of Regional Transport (START) experiment is planned and proposed for the HIAPER progressive science period (July to December 2005). The START project aims to conduct an exploratory study of transport in the extra-tropical upper troposphere and lower stratosphere, while also testing the capabilities of HIAPER. Scientifically, the objectives of the START experiment are to (1) characterize the dynamic structure of the upper troposphere around the subtropical jet; (2) characterize the structure of the chemical transition layer from the troposphere to the stratosphere; and (3) examine the impact of deep convective outflow on the UTLS chemical composition, and ice and aerosol microphysics. Testing and achieving confidence in the performance of the basic payload of instruments is also an important component of this experiment. Laura Pan (NCAR/ACD) and Linnea Avallone (CU-Boulder) are co-principal investigators for this proposal. Co- Investigators are Elliot Atlas (University of Miami), Ken Bowman (Texas A&M University), James Bresch (NCAR/MMM), Teresa Campos (NCAR/ACD/ATD), Andy Heymsfield (NCAR/MMM), Jennie Moody (University of Virginia), Don Lenschow (NCAR/MMM/ATD), Rushan Gao (NOAA/AL), Brian Ridley (NCAR/ACD), Steve Wofsy (Harvard University), and Mark Zahniser (Aerodyne Research, Inc.).

UTLS initiative coordinates and collaborates with the community effort of instrumentation development for HIAPER. A main function for the initiative is to identify instrumentation needs for the key science issues. One of the instruments under development, led by Alan Fried (ACD/ATD), is the new high performance airborne difference frequency generation instrument for the measurement of CH_2O on HIAPER. The trace gas formaldehyde (CH_2O) is one of many important atmospheric trace species involved in ozone production and radical formation. The joint ATD/ACD Analytical Photonic and Optoelectronics Laboratory (*APOL)* has been actively involved in a long-term effort to carry out ever more accurate and precise measurements of this gas throughout the troposphere and lower stratosphere. An important component of this effort is the development of advanced autonomous instruments for operation on HIAPER.

Although we continue to make steady progress in the performance of our present airborne CH_2O instrument, which employs a liquid-nitrogen cooled tunable diode laser (TDLAS), new technologies are critically needed to improve the performance even further, to significantly reduce system weight and size, and to eliminate the need for periodic operation intervention. To address this critical need, the *APOL* group has been developing an alternative system based upon difference frequency generation (DFG) to achieve these various goals.

Among the on going UTLS modeling effort, Mary Barth (ACD/MMM) in collaboration with William Skamarock and Si-Wan Kim implemented a simple gas and aqueous-phase chemistry mechanism into the WRF model to begin investigations on the effect of convection on the chemical environment. Convection plays an important role in transporting pollutants from the surface to the upper troposphere, scavenging soluble species and depositing much of the soluble species to the surface, and converting species chemically in the cloud drops. Simulations of the 10 July 1996 STERAO storm were performed to provide a way to evaluate the modeled chemistry results with observations. Sensitivities of the chemical species distributions to the cloud microphysics representation are currently being investigated. This WRF-AqChem model will continued to be developed by incorporating the aqueous chemistry modules into the community WRF-Chem model, by incorporating lightning production of NOx and interactions between gas and ice phase species.

Satellite data analyses provide a global picture and context for more detailed balloon and in-situ aircraft observations. Bill Randel (ACD) and Andrew Gettelman (ACD/CGD) are leading the activities using different sets of satellite data in the UT/LS. These data sets include both temperature and chemical species from a variety of platforms, including high resolution temperature measurements from GPS radio occultation, temperature, water vapor and cloud fields from the Atmospheric Infrared Sounder (AIRS) on the AQUA satellite. UT/LS satellite analyses are tightly coupled to efforts in other areas. Satellite

observations are used to extend field campaign data, as well as employing data from aircraft to validate satellites, as indicated in Figure 63. In addition, satellite analyses are linked to global modeling efforts, providing validation for global models.

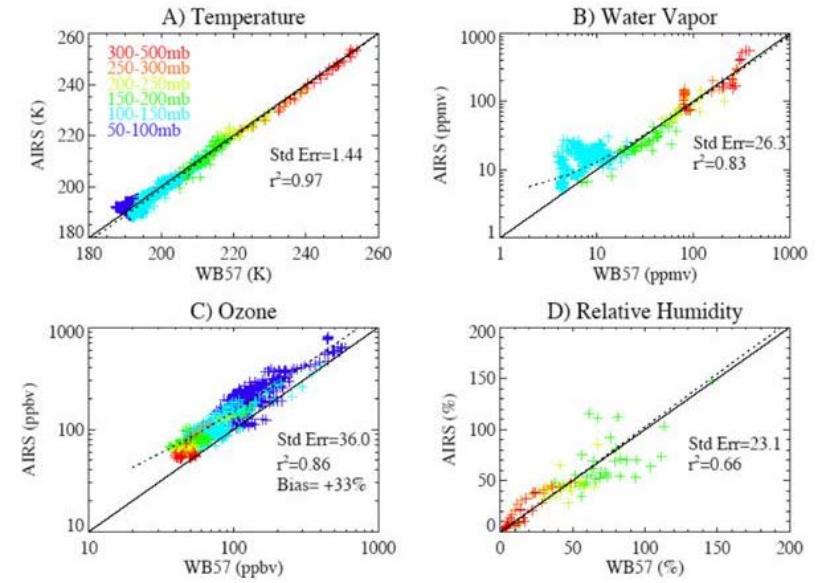

Figure 63: Comparisons between in situ WB57 aircraft observations and AIRS satellite retrievals during the PreAVE mission off of Costa Rica in January 2004 showing excellent agreement for A) Temperature B) Water Vapor C) Ozone and D) Relative Humidity. Standard error and r^2 values are indicated. Solid lines are 1:1 line, dotted lines are linear fits.

Megacity Impact on Regional and Global Environments (MIRAGE) Strategic Initiative

The MIRAGE Strategic Initiative supported coordination and modeling activities related to studies of air pollution in and around megacities. Xuexi Tie, Sasha Madronich, and visiting graduate students Zhuming Ying (York University) and GuoHui Li (TAMU), are collaborating with Georg Grell of NOAA/FSL to implement in WRF-Chem chemical modules developed at ACD and to apply the model to the planning of a major international field campaign, MIRAGE-Mex, planned for early 2006 by ACD on behalf of the atmospheric sciences community. The WRF-Chem model was successfully ported over the central Mexico region, with emissions data for Mexico City and the surrounding region, and was used to perform simulations at various resolutions (4 km, 6 km, and 12 km). Mexico City emissions were implemented through a collaboration with Aron Jazcilievich (UNAM). Preliminary results show that the modeled temperatures and winds reproduce well the observed diurnal cycles, but with a cold bias indicating that the “heat island” of the city is not yet well represented by the model. The diurnal cycles and magnitudes of surface concentrations of CO, NO_x (NO +NO_2), and O_3 within Mexico City compare well with observations, and show that the model is able to capture high pollution events. In anticipation of the MIRAGE-Mex field campaign, the interactions of urban outflow plume with the surrounding region were studied. For this study, Alex Guenther and Christine Wiedinmyer provided current estimates of regional biogenic (vegetative) emissions, and Jean Francois Lamarque provided biomass burning emissions. Preliminary results show that this interaction leads to more regional O_3 production than would be expected from the three sources (urban, biogenic, and biomass burning) taken in isolation (Figure 15 from above section on WRF-Chem). These preliminary results have been presented at conferences (Tie, X, and S. Madronich, Modeling of Mexico City Air Pollution and Outflow with WRF-Chem, 5th WRF/14th MM5 User’s Workshop, June 22-25, 2004, Boulder, CO; Tie, X, and S. Madronich, Effect of mobile, biomass burning, and biogenic emission on Mexico City’s Air Pollution and Outflow, 13th International Scientific Symposium of Transport and Air Pollution, Boulder, September 13-15, 2004, Boulder, CO.)

The MIRAGE Strategic Initiative also sponsored three international researchers (Ashesh Prosad Mitra from India, Ioana Ionel from Rumania, and Aron Jazcilievich from Mexico) and two students (Gretchen Stevens from Harvard University and Faustino Reyes from UNAM, Mexico), to attend and present results of their research at the 13th International Symposium on Transport and Air Pollution, held at NCAR on 13-15 Sept. 2004.

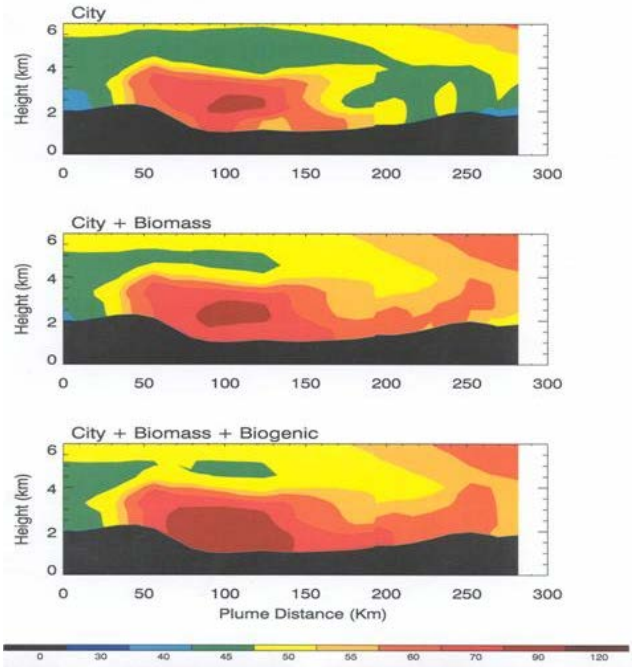

Figure 15: Ozone (O_3) concentrations simulated with the WRF-Chem model, showing the interaction between the Mexico City pollution plume with regional biomass burning and biogenic emissions. Upper panel shows the O_3 resulting from urban emission only. Middle panel includes effects adding biomass burning emissions, which contribute NO_X in the NO_X-limited regime (far-field, ca. 200-300 km). Lower panel adds biogenic emissions, which contribute hydrocarbons in the hydrocarbons-limited regime (near-field, 50-150 km).

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Education and Outreach

Educational Activities

Teaching Arrangements

Eric Apel, Adjunct Associate Professor, University of Miami
John Gille, Adjunct Professor, University of Colorado at Boulder
Elisabeth Holland, Guest Lecturer, University of Colorado at Boulder
Elisabeth Holland, Affiliate Professor, Colorado State University
Sasha Madronich, Director and Principal Lecturer, University of Arapaca, Chile
William Mankin, Lecturer, Central Baptist Theological Seminary

Advising on Graduate Research

Frank Flocke (Sandra Lopes), University of Applied Science, Wiesbaden, Germany
John Gille (Odele Hofman), University of Colorado at Boulder
Alex Guenther (Kolby Jardine), State University of New York, Stony Brook
Alyn Lambert (Graham Ewen), University of Oxford, United Kingdom
Sasha Madronich (Katja Dzepina), University of Colorado at Boulder
John Orlando (Camilla Bacher), University of Copenhagen, Denmark
William Randel (Mijeong Park), Seoul National University, Korea
James Smith (Matthew Dunn), University of Colorado at Boulder
James Smith (Sara Lance), Georgia Institute of Technology
Xuexi Tie (Guohui Li), Texas A&M University
Xuexi Tie (JiWen Fan), Texas A&M University
Xuexi Tie (Zhuming Yang), York University

Member of Thesis Committee

Rolando Garcia (Natalia Calvo), University of Madrid, Spain
Alex Guenther (John Ortega), University of Colorado at Boulder
Peter Harley (Jennifer Funk), State University of New York, Stony Brook
Sasha Madronich (Sophie Laval), University of Paris, France

William Mankin (Loic Jounot), University of Toronto
James Smith (Matthew Dunn), University of Colorado at Boulder
James Smith (Sara Lance), Georgia Institute of Technology
John Orlando/Geoffrey Tyndall (Camilla Bacher) University of Copenhagen, Denmark
Christine Wiedinmyer (Tanarit Sakulyanontvittaya) University of Colorado at Boulder

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Other Educational Programs

The SOARS Program is designed to further science education and provide access to careers in the atmospheric and related sciences for students of minority groups that are historically under-represented in the science community. Each student is teamed with a science mentor, a writing mentor and a community mentor. In FY04, ACD mentored the following students:

NAME	SCIENCE MENTOR	WRITING & COMMUNICATION MENTOR	COMMUNITY MENTOR
Cherelle Blazer	John Orlando and Geoff Tyndall		
Rebecca Chan		Christina Book	
Anthony Didlake			Elisabeth Holland
Deanna Hence		Sreela Nandi	
Damian Mattis	James Smith		
Andro Rios	Steven Massie		Kathleen Barney
Melanie Zauscher		Barry Lefer	

ACD SOARS Proteges and Mentors: Front: A. Rios, D. McKenna, Back: G. Tyndall, S. Nandi, D. Hence, K. Barney, S. Massie, C. Blazer, D. Mattis, C. Book, E. Holland, A. Didlake, R. Chan.

Internship Program, Louis Pasteur Institute, France

ACD participates in a program with the Louis Pasteur Institute in France for students who have completed a degree in instrument design. The program is designed to increase the students' experience, technical skills and language skills and to give them an opportunity to function independently. The students work half-time at NCAR for an eight-month period with one of the science groups in the division. In FY04, ACD hosted the following students:

Maxime Jager – Mentor: **Eric Apel**
Vincent Schell – Mentor: **Sue Schauffler**

Seminars and Presentations

ACD Seminar Program

Date	Speaker/Institution	Topic
October 9, 2003	**Kunihiko Kodera** Meteorological Research Institute, Japan	Influences of the solar cycle on the tropical troposphere through a strato-spheric dynamical process: Implication for the ENSO cycle
October 10, 2003	**Manfred Wendisch** Institute for Tropospheric Research, Germany	Absorption of solar radiation: How well can we model and measure it?
October 13, 2003 Joint with CGD	**Amy Braverman** California Institute of Technology	Reducing size and complexity of very large satellite data sets
December 15, 2003	**Warwick Norton** University of Oxford, United Kingdom	A new idea on what drives the annual cycle in tropical tropopause temperatures
January 15, 2004	**Rolf Muller** Forschungszentrum Julich, Germany	The Chemical Langrangian Model of the Atmosphere (CLaMS): Application to problems of chemistry and transport in the stratosphere
February 2, 2004	**Kennth Bowman** Texas A&M University	Some results from the Tropical Rainfall Measuring Mission (TRMM)
February 23, 2004	**Karen Rosenlof** NOAA/Aeronomy Laboratory	Changes in tropical upwelling: A possible cause for changes in stratospheric water vapor
March 8, 2004	**Jerry Mahlman**	The science of global warming: The perfect public policy storm

	NCAR	
March 15, 2004	**B. C. Low** NCAR	An introduction to the hydromagnetic solar corona
April 6, 2004	**Alex Guenther** NCAR	Biogenic VOC emissions and the chemical composition of the atmosphere
April 12, 2004	**John Orlando** NCAR	The atmospheric chemistry of biogenic hydrocarbons
May 3, 2004	**Daniel Marsh** NCAR	Testing our understanding of the meso- sphere and lower thermosphere using new observations from the TIMED-SABER instrument
May 17, 2004	**Chris Cantrell** NCAR (on assignment to NSF)	Mysteries of the research funding process exposed: Experiences as an NSF Program Director
May 24, 2004	**Rainer Volkamer** Massachusetts Institute of Technology	UV-vis absorption cross-section of glyoxal: Applications in mechanism development of VOC and field studies
June 7, 2004	**Denise Mauzerall** Princeton University	Air pollution in Asia: From local impacts on agriculture and health to inter-annual variability in trans-Pacific transport
August 6, 2004	**Peter Bernath** University of Waterloo	The atmospheric chemistry experiment (ACD): Mission overview
August 9, 2004	**Adrian Sandu** Virginia Institute of Technology	Variational data assimilation for air quality models
September 17, 2004	**Giovanni Lonati** Milan Technical University, Italy	Air quality in the city of Milan (Italy): The role of traffic emissions

Seminars/Presentations by ACD Staff

Name	Presented at	Title
Eric Apel	UT/LS Workshop October 2003	Measurement and instrumentation strategy: GC-MS system that measures carbonyls, alcohols, CGCs and NMHCs
Mary Barth	NCAR/ASP April, 2004	Cloud chemistry from the global scale to the microscale
Mary Barth	Seoul National	Cloud chemistry from the global

	University, Korea, May, 2004	scale to the microscale
Teresa Campos	NCAR UT/LS Workshop October, 2003	Instrumentation Issues
Teresa Campos	Raytheon Space Systems, October 2003	An Introduction to NCAR's Airborne Plat
Teresa Campos	NOAA ETL Flux Measurement Tecniques Workshop, April, 2004	Improvements in fast response airborne CO_2 measurements from the NSF/NCAR C-130
Cheryl Craig	Oxford/U.S. HIRDLS meeting, November, 2003	Level 2 Processor
David Edwards	NARSTO Emission Inventory Workshop, October, 2003	Carbon monoxide measurements from Terra/MOPITT: Improving CO emissions
David Edwards	NASA Earth Science and Technology Strategy Team Meeting, October, 2003	The MOPITT Mission
David Edwards	MOPITT-2 Science Team Meeting, March, 2004	MOPITT: What we have learned so far
David Edwards	American Geophysical Union, May, 2004	Satellite observations of African biomass burning emissions and their impact on tropospheric air quality
David Edwards	8^{th} International Global Atmospheric Chemistry Conference, May, 2004	Observations of carbon monoxide and aerosol from the Terra satellite: Northern Hemisphere variability
David Edwards	American Geophysical Union, May, 2004	Observations of carbon monoxide and aerosol from the Terra satellite: Northern Hemisphere variability
David Edwards	Joint EPA/NASA/NOAA Workshop on Air Quality and Related Climate Change Issues, September, 2004	Satellite observations of pollutant transport in the troposphere
Fred Eisele	NSF Workshop on Science Opportunities for a Multi- disciplinary Long-Range Aircraft for Antarctic Research, September, 2004	Airborne atmospheric chemistry
Louisa Emmons	State University of New York at Stony Brook, October, 2003	Examining tropospheric carbon monoxide with satellites, models and isotopes
Louisa Emmons	CCSM Workshop on Isotopes in the Earth system, January, 2004	Carbon-13 Isotopes in MOZART

Alan Fried	INTEX Science Team Meeting, July, 2004	Airborne measurements of formaldehyde
Rolando Garcia	AGA/ICMA Workshop, July, 2004	Vertical coupling in the atmosphere/ ionosphere system
Rolando Garcia	SPARC 3rd General Assembly, August, 2004	Stratospheric processes and their relation to climate
Rolando Garcia	NASA/EOS Science Meeting, October, 2004	Solar radiation and climate
John Gille	Aura Science Team meeting, October, 2003	Update on HIRDLS Status: Instrument and algorithms
John Gille	Aura Science Team meeting, July, 2004	Overview of the HIRDLS Experiment on EOS Aura
James Greenberg	Instituto Nacional de Pesquisas da Amazonia, Brazil, August, 2004	Low temperature pyrolosis of vegetation
Alex Guenther	Cornell University, October, 2003	Biogenic trace gases and biocomplexity
Alex Guenther	NARSTO Workshop, October, 2003	Leaf, canopy, landscape and regional measurements for developing and evaluat- ing biogenic VOC emission models
Alex Guenther	University of Montana, October, 2003	Wildfires Initiative
Alex Guenther	State University of New York, April, 2004	Biogenic VOC emissions, Chemistry and Climate
Alex Guenther	Institute of Biometeor- ology, Italy, May, 2004	The biosphere and global atmospheric chemistry
Alex Guenther	IGBP Workshop, May, 2004	Gaps in understanding the biogenic sources of organic aerosols and the tools and research needed to fill them
Alex Guenther	IGBP, June, 2004	GEIA
Alex Guenther	National Institute of Amazon Research, Brazil, July, 2004	Biosphere-atmosphere exchange of reactive gases and their impact on air quality and climate
Samuel Hall	AIRS-II Field Science Meeting, November, 2003	Tunable diode laser hygrometer
Shu-Peng Ho	COSMIC Retreat, October, 2003	Improvement of GPS super- reflection effect using AIRS measurements
Shu-Peng Ho	MODIS Science Team Meeting, July, 2004	Improvement of global MOPITT 4.7 im surface emissivity by using MODIS measurements and its

		impacts on the retrieval of tropospheric carbon monoxide profiles
Elisabeth Holland	American Geophysical Union, December, 2003	Biogeochemical cycles
Elisabeth Holland	University of Colorado, February, 2004	The IPCC process
Elisabeth Holland	University of North Dakota, March, 2004	The global N cycle
Elisabeth Holland	University of North Dakota, March, 2004	On being a woman in Science
Elisabeth Holland	University of Colorado, March, 2004	The global N cycle
Elisabeth Holland	CCSM Workshop, July, 2004	Biogeochemical cycles
Elisabeth Holland	Chemistry-Climate Workshop, July, 2004	Biogeochemical cycles
Douglas Kinnison	University of Colorado, May, 2004	Introduction to the Whole Atmosphere Community Climate Model
Sasha Madronich	Arizona State University, January, 2004	How will megacities affect regional and global air quality?
Sasha Madronich	NCAR Colloquium on Climate and Health, July, 2004	Air pollution and atmospheric chemistry
Daniel Marsh	NCAR/ASP, December, 2003	Toward a consistent view of the mesosphere and lower thermosphere
Daniel Marsh	TIMED Science Working Group Meeting, March, 2004	Testing middle-atmospheric ozone photochemistry with TIMED satellite observations
Daniel Marsh	National Institute of Amazon Research, Brazil, March, 2004	Numerical modeling of mesosphere-stratosphere-thermosphere
Daniel Marsh	VII Conference of the Latin American Association of Space Geophysics, March, 2004	The mesosphere and lower thermosphere
Daniel Marsh	2004 CEDAR Workshop, June, 2004	On the variability of OH Meinel emissions observed by TIMED-SABER
Laura Pan	NASA Ames SOFIA Workshop, June, 2004	Issues of stratosphere-troposphere exchange in the middleworld
Laura Pan	SPARC Assembly, August, 2004	Lagrangian model simulation of mixing near the tropopause

William Randel	World Climate Research Program, November, 2004	Stratospheric temperature trends derived from satellite data
William Randel	NCAR Summer Colloquium, June, 2004	Radio Occultation and the Tropopause
William Randel	Quadrennial Ozone Symposium, July, 2004	Challenges for understanding global ozone variability
William Randel	AURA Rocket Launch, August, 2004	Science applications for HIRDLS
William Randel	NASA Solar Occultation Science Team Meeting,	Long-term changes in stratospheric water vapor
Anne Smith	American Geophysical Union, December, 2003	Oxygen-hydrogen chemistry and emissions in the mesosphere: Modeling and SABER observations
Anne Smith	American Geophysical Union, December, 2003	The EEA method of chemical lifetime calculation and its application to the sodium layer
Anne Smith	NCAR/ASP, January, 2004	Large scale dynamics and energetics of the mesosphere
Anne Smith	NCAR/HAO MLT Group, February, 2004	The 6-hour tide
Anne Smith	TIMED Science Working Group Meeting, March, 2004	Oxygen-hydrogen chemistry and emissions in the mesosphere: Modeling and SABER observations
Anne Smith	CEDAR Workship, June, 2004	Observations and modeling of the 6-hour tide
Anne Smith	IAGA/ICMA Workshop, July, 2004	Short-term variability of tides
James Smith	University of California at Riverside, May, 2004	Recent insights into the formation, growth, and composition of atmospheric nanoparticles
James Smith	Annual Meeting of the American Association for Aerosol Research, May, 2004	The chemical composition of atmospheric ultrafine particles during nucleation events
Xuexi Tie	WRF Workshop, June, 2004	Modeling of Mexico City air pollution and its outflow with WRF-Chem
Xuexi Tie	Monitoring Science and Technology Symposium, September, 2004	Impact of biomass burning and biogenic emission on the evolution of Mexico City's air pollution plume
Christine Wiedinmyer	Young Scientist Conference on Climate Change, November, 2003	Changes in biogenic isoprene emissions: How do they affect regional and global atmospheric chemistry?
Christine Wiedinmyer	USDA Forest Service Monitoring Science and Technology	Fire emissions modeling for North America

	Symposium, September, 2004	

Miscellaneous Informal Educational Activities

William Bradley and **Julia Lee-Taylor** participated in the UCAR-sponsored Super Science Saturday.

Louise Emmons participated in the Women in Science Program for 4th grade girls at Nashoba Brooks School, Concord, Massachusetts.

Peter Harley was an invited lecturer at the Climate and Global Change Teachers Workshop, July 2004.

Alan Fried (with Dirk Richter, ATD) gave a presentation at Holy Family High School Career Day, April 2004.

John Gille gave a presentation to the GLOBE workshop for teachers, July, 2004.

William Mankin taught (with Distinguished Professor Richard Olsen) a graduate course in environmental ethics at Central Baptist Theological Seminary.

William Mankin taught a three-session series of study on environmental ethics at the First Baptist Church of Kansas City Missouri.

William Mankin led a workshop on environmental ethics at the annual meeting of the American Baptist Churches of the Rocky Mountains.

Steven Massie participated in an interview with a Chicago-based television meteorologist on the topic of possible effects of forest fires on weather in the Chicago area.

Christine Wiedinmyer gave a lecture and participated in a group tour with visiting 5th grade class from Montclaire Academy.

Daniel Ziskin gave a guest lecture at Naropa University on the topic of faith-based environmental activism.

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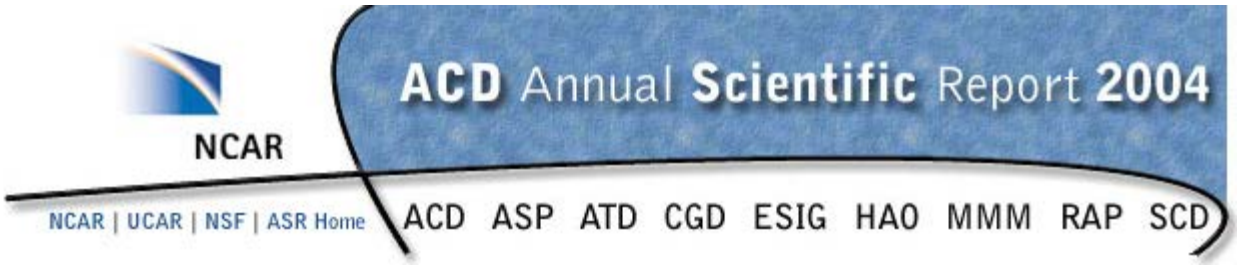

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Community Service

Editorships of Peer-Reviewed Journals

Chris Cantrell, Associate Editor, Journal of Geophysical Research-Atmospheres, 2001-Present

David Edwards, Associate Editor, Journal of Quantitative Spectroscopy and Radiative Transfer, December 2002-2005

Rolando Garcia, Guest Editor, Journal of Atmospheric and Solar Terrestrial Physics, special issue on Vertical Coupling in the Atmosphere/Ionosphere System (proceedings of Bath, U.K. Workshop), 2004

Alex Guenther
- Associate Editor, Atmospheric Environment, 2000-Present
- Associate Editor, Atmospheric Chemistry and Physics, 2002-Present

Alyn Lambert, Co-Editor, European Geophysical Society Journal Atmospheric Chemistry and Physics, 2001-Present

Daniel McKenna, Co-Editor, Special issue of Atmospheric Chemistry and Physics, “Data Exploitation and Modeling for the Upper Troposphere and Lower Stratosphere”, 2004

William Randel, Associate Editor, Journal of the Atmospheric Sciences, 2004

Workshops

Elisabeth Holland was Chair of the organizing committee for the Nitrogen Science Plan Workshop, November, 2003.

Jean-Francois Lamarque (with Jeff Kiehl, CGD) organized the second Chemistry-

Climate Interactions workshop, Santa Fe, New Mexico, February, 2004.

Sasha Madronich organized the 13th International Symposium on Transport and Air Pollution, September, 2004.

Laura Pan organized the UTLS workshop, October, 2003.

William Randel was co-organizer of a SPARC Workshop on stratospheric temperature trends, November, 2003.

Christine Wiedinmyer was a group leader for the 2004 UCAR/NCAR Junior Faculty Forum on Future Scientific Directions, 2004.

Service on Scientific Committees and Panels

Alan Fried
- Program Chair and Co-Organizer, International Topical Meetings, Laser Application to Chemical Analysis, 2006
- Member, Program Committee for the International Topical Meetings, Laser Applications to Chemical Analysis, 2004
- Member, International Advisory Committee for the Fifth Conference on Tunable Diode Laser Spectroscopy, 2005
- Session Convener, Tropospheric Photochemistry, 2004 Fall American Geophysical Union Meeting, 2004

John Gille
- Member, SPARC Science Steering Group, 1993-Present
- Member, COSPAR Organization Committee for Section A Biennial Meetings, 1996-Present

Daniel McKenna
- Member, NASA Middle Atmospheric Science Peer Review Panel, 2003
- Member, Atmospheric Chemistry and Physics Advisory Board, 2004

Alex Guenther
- Organizer, Session of the Gordon Research Conference, 2004
- Member, Steering Committee, IGBP-GEIA, 2004
- Member, Steering Committee, IGBP-iLEAPS, 2004

Elisabeth Holland
- Member, NRC BASC Committee, 2004
- Steering Committee Chair, U.S. Nitrogen Science Plan, 2004
- Member, External Advisory Committee to the Bio-Atmosphere Research Training Grant, University of Michigan, 2004
- Member, SOARS Steering Committee, 2004

Daniel Marsh
- Panel Member, 2004 CEDAR Workshop, 2004
- Member, International Commission on the Middle Atmosphere, 2003-Present

Steven Massie, Member, AURA Education Committee, 2004

Brian Ridley, Member, Advisory Panel EOS/ATD, 2004

William Randel
- Member, NRC Board on Atmospheric Sciences and Climate, 2004
- Initiative Leader, SPARC Project on Detection, Attribution and Predication of Stratospheric Change, 2004
- Member, Scientific Steering Committee for the Network for the Detection of Stratospheric, 2004
- Member, WCRP Panel for Coordinated Observation and Prediction of the Earth System, 2004
- Member, NASA Science Teams: SAGE, AIRS and HIRDLS, 2004

Anne Smith
- Member, Science Working Group for the TIMED satellite, 2004
- Member, Review Panel, NASA Space Science, 2004

James Smith, Member, 13th International Symposium on Transport and Air Pollution, 2004

Community Facilities

The MOPITT Group developed the General Line-by-Line Atmospheric Transmittance and Radiance Model 2 (GENLN2) and GENLN3. A software package providing detailed spectroscopic calculations for use in atmospheric flux measurements, remote sensing applications, and laboratory experiments is currently in use by the IPCC groups at NCAR and NOAA and in a study involving the retrieval of stratospheric O_3 profiles by NASA Goddard Space Flight Center and the University of Maryland at College Park.

The Whole Atmosphere Community Climate Model (WACCM) continues to be available to the scientific community.

The BAI Group provided the Model of Emissions of Gases and Aerosols from Nature (MEGAN). The model is used to estimate fluxes of trace gases and aerosols that are used as boundary conditions in chemistry and transport models. The model description and driving variable databases are available on the NCAR community data portal.

The RGP Group supports the Tropospheric Ultraviolet-Visible (TUV) radiation model which is available to researchers in the scientific community.

The POP group deployed and maintained two research seatainers at the Marshall site for aerosol research for use by the university community. During this past year, groups from the University of Colorado and the University of Minnesota used this facility.

The GM Group continues to support the ROSE 3-dimensional chemical dynamical model and the Nitric Oxide Empirical Model (NOEM) of nitric oxide in the lower thermosphere based on SNOE observations.

Miscellaneous Community Service

Chris Cantrell served as Associate Program Director for the Atmospheric Chemistry Program, Atmospheric Sciences Division, Geosciences Directorate, National Science Foundation from August 2003 through August 2004.

Louisa Emmons updated the MOZART webpage and the model source code is now available for download through the ACD website.

Gene Francis
- provided extensive support and expertise with the GENLN codes to the University of Maryland and to NASA Goddard.
- provided MOPITT forward model expertise to Texas A&M University.

Alan Fried (and Dirk Richter, ATD) co-authored a book chapter, “Imaging of Optical Fiber Coupled Near-Infrared Laser Sources for Difference Frequency Generation”.

John Gille guided the development of the HIRDLS instrument and data system which are designed to provide detailed atmospheric data to the atmospheric science community.

Shu-Peng Ho helped the Jet Propulsion Laboratory team with MOPITT data analysis.

Elisabeth Holland worked on the development of a database for the Nitrogen Deposition onto the United States and Western Europe, Oak Ridge National Laboratory, Data Access and Archiving Center.

Thomas Karl
- trained a graduate student at Stony Brook University in using the PTRMS and related technologies for VOC emission measurements.
- supervised an undergraduate student at the University of Sao Paulo during the aircraft phase of the CAPOS 2004 study.
- instructed a technician at the LBA Central Office in Manaus in new methods for surface layer flux measurements.

Douglas Kinnison
- trained CU/LASP staff in running the MOZART model.
- gave the MOZART+3 model to the University of Illinois, Urbana Champagne.

Sasha Madronich
- is the organizer of the MIRAGE-Mex Community field campaign.
- is the Coordinating lead author of Chapter 2 of the IPCC Special Report on Ozone and Climate.

Daniel Marsh is the organizer of bi-monthly, Boulder-wide discussion groups on the mesosphere and lower-thermosphere.

William Randel is the lead author for an ongoing IPCC report on ozone and the global climate system.

Brian Ridley
- prepared/tested a sensitive nitric oxide instrument for loan to Dr. Alex Pszenny and his group at the University of New Hampshire for their deployment at an offshore site as part of the ground-based component of the international ICART air quality program

conducted in summer 2004.
has provided advice to a student at Purdue University on the design and construction of a sensitive NO analyzer over the past year.

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Awards

Awards/Fellowships

Jack Calvert
Fellow, American Geophysical Union
Fellow, Ohio Academy of Science
Fellow, American Institute of Chemists

John Gille
Fellow, American Meteorological Society
Fellow, American Association for the Advancement of Science

David Hansen
Fellow, American Geophysical Union

Brian Ridley
Fellow, American Geophysical Union

ISI Highly Cited Authors 2004

Jack Calvert
Rolando Garcia
Brian Ridley

SOARS Award for 5 Year Service

Sue Schauffler
Mary Barth
Alex Guenther
Elisabeth Holland

Julia Lee-Taylor
Steve Massie

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Publications

(Note: Bold=university authors; *=institutional authors)

Apel, E., A. Hills, R. Lueb, S. Zindel, S. Eisele and **D. Riemer**, 2003: A fast-GC/MS system to measure C2 to C4 carbonyls and methanol aboard aircraft. *J. Geophys. Res., 108*(D20), 8794, doi:10.1029/2002JD003199.

Boering, K., T. Jackson, K. Hoag, A. Cole, M. Perri, M. Thiemens and E. Atlas, 2004: Observations of the anomalous oxygen isotopic composition of carbon dioxide in the lower stratosphere and the flux of the anomaly to the troposphere. *Geophys. Res. Lett.*, *31*, L03109, doi:10.1029/2003GL018451.

Bremer, H., J. Kar, J. Drummond, F. Nichitu, J. Zou, J. Liu, J. Gille, M. Deeter, G. Francis, D. Ziskin and J. Warner, 2004: Spatial and temporal variation of MOPITT CO in Africa and South America: A comparison with SHADOZ ozone and MODIS aerosol, 2004: *J. Geophys. Res., 109*, D12304, doi:10.1029/2003JD004234.

Cantrell, C., G. Edwards, S. Stephens, R. Mauldin, M. Zondlo*, E. Kosciuch, F. Eisele, R. Shetter, B. Lefer, S. Hall, F. Flocke, A. Weinheimer, A. Fried, E. Apel, **Y. Kondo, D. Blake, N. Blake, I. Simpson, A. Bandy, D. Thornton, B. Heikes**, H. Singh*, **W. Brune, H. Harder, M. Martinez, D. Jacob**, M. Avery*, J. Barrick*, G. Sachse*, J. Olson*, J. Crawford* and **A. Clarke**, 2003: Peroxy radical behavior during the Transport and Chemical Evolution over the Pacific (TRACE-P) campaign as measured aboard the NASA P-3B aircraft. *J. Geophys. Res., 108*(D20), 8797, doi:10.1029/2003JD003674.

Carmichael, G., Y. Tang, G. Kurata, I. Uno, D. Streets*, **J.-H. Woo, H. Huang, J. Yienger**, B. Lefer, R. Shetter, **D. Blake**, E. Atlas, A. Fried, E. Apel, F. Eisele, C. Cantrell, M. Avery*, J. Barrick*, G. Sachse*, **W.**

Brune, S. Sandholm, Y. Kondo, H. Singh*, **R. Talbot, A. Bandy, D. Thornton, A. Clarke and B. Heikes**, 2003: Regional-scale chemical transport modeling in support of the analysis of observations obtained during the TRACE-P experiment. *J. Geophys. Res., 108*(D21), 8823, doi:10.1029/2002JD003117.

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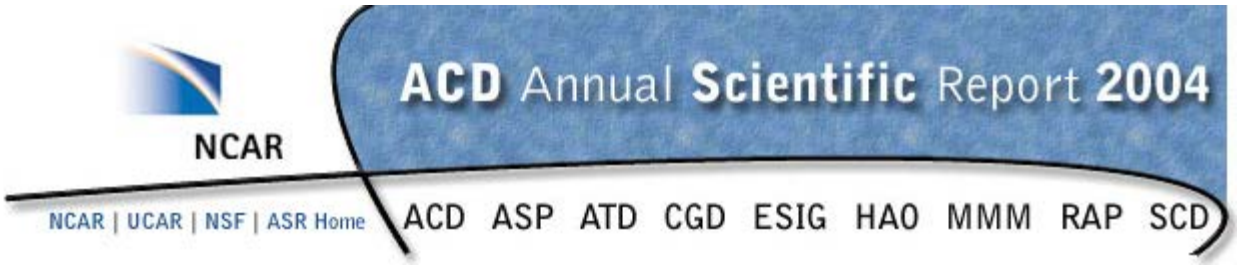

People

Division Staff

DIVISION OFFICE
Daniel McKenna, Director
Sue Schauffler, Deputy Director
Teresa Rivas
Caron Chambers
Christina Book

ADMINISTRATIVE SUPPORT
Kathleen Barney
Donna Sanerib
Marilena Stone
Jack Wainwright
Barbara Tunison

COMPUTING SUPPORT
Garth D'Attilo
Timothy Fredrick
Daniel Packman

TECHNICAL SUPPORT
William Bradley
Roger Hendershot
Rudy Montoya
John Vander Pol

SENIOR RESEARCH ASSOCIATES
Fred Eisele

AFFILIATE SCIENTISTS
Elliot Atlas
Dieter Ehhalt
Aaron Goldman

SENIOR SCIENTIST EMERITUS
Jack Calvert
William Mankin

ATMOSPHERIC ODD NITROGEN
Frank Flocke
Frank Grahek
David Knapp
Denise Montzka

ATMOSPHERIC RADIATION INVESTIGATION AND MEASUREMENT
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Samuel Hall
Edward Riedel

Brian Ridley
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Jean-Francois Lamarque
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LABORATORY KINETICS

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MEASUREMENT OF POLLUTION IN THE TROPOSPHERE

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Gene Francis
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Sasha Madronich
Xuexi Tie
Francis Vitt
Stacy Walters

STRATOSPHERIC/TROPOSPHERIC MEASUREMENTS

Amy Lueb
Sue Schauffler
Verity Stroud

Visitors & Collaborators

Name	Affiliation	Start Date	End Date	Research Interest
Aben, Ilse	National Institute for Space Research, The Netherlands	collaborator		
Agostini, Alessandro	Ente per le Nuovo tecnologie, l'Energia e l'Ambiente, Italy	09/13/2004	09/15/2004	Transport and air pollution
Alexander, Joan	Northwest Research Laboratory	10/27/2003	10/28/2003	Upper Troposphere/Lower Stratosphere
Anderson, Bruce	National Aeronautics And Space Administration-Langley	collaborator		
Anderson, Tad	University of Washington	06/16/2004	06/17/2004	Global Modeling
Andre, Michel	Institut National de Recherche sur les Transports et leur Sécurité, France	09/13/2004	09/15/2004	Transport and air pollution
Andre, Jean-Marc	Institut National de Recherche sur les Transports et leur Sécurité, France	09/13/2004	09/15/2004	Transport and air pollution
Arai, Yosuke	Keio University, Japan	09/13/2004	09/15/2004	Transport and air pollution
Artaxo, Paulo	University of Sao Paulo, Brazil	collaborator		
Atherton, Cynthia	Lawrence Livermore National Laboratory	10/27/2003	10/28/2003	Upper Troposphere/Lower Stratosphere
Atjay, Delia Elisabeta	Eidgenossische Materialprufungs-und Forschungsanstalt, Switzerland	09/13/2004	09/15/2004	Transport and air pollution
Attie, Jean-Luc	Laboratorie d' Aerologie, Toulouse, France	collaborator		
Aumont, Bernard	University of Paris	collaborator		
Avallone, Linnea	University of Colorado at Boulder	10/27/2003	10/28/2003	Upper Troposphere/Lower Stratosphere
Avery, Melody	National Aeronautics And Space Administration-Langley	collaborator		
Backman, Leif	Finnish Meteorological Institute	10/18/2004	10/22/2004	Global Modeling
Bais, Alkis	Aristotle University of Thessaloniki, Greece	collaborator		
Baker, Bradley	South Dakota School of Mines	11/14/2003	11/18/2003	Biosphere-Atmosphere Carbon and Nitrogen Cycles
		collaborator		
Balser, Teri	University of Wisconsin	11/14/2003	11/18/2003	Biosphere-Atmosphere Carbon and Nitrogen Cycles
Bandy, Alan	Drexel University	collaborator		
Barket Jr., Dennis	Griffin Analytical Technologies	collaborator		
Barney, Jacob	Cornell University at New York	07/12/2004	07/16/2004	Biosphere-Atmosphere Carbon and Nitrogen Cycles
		collaborator		
Baron, Jill	Colorado State University	11/14/2003	11/18/2003	Biosphere-Atmosphere Carbon and Nitrogen Cycles
Barrick, John	National Aeronautics And Space Administration-Langley	collaborator		
Baumgardner, Darrel	Universidad Nacional Autonoma de Mexico	collaborator		

Belote, Angela	Unaffiliated	06/07/2004	09/30/2005	Biosphere-Atmosphere Carbon and Nitrogen Cycles
Bergmann, Dan	Lawrence Livermore National Laboratory	10/27/2003	10/28/2003	Upper Troposphere/Lower Stratosphere
Berkowitz, Carl	Pacific Northwest National Laboratory	collaborator		
Bernath, Peter	University of Waterloo, Ontario	08/06/2004	08/06/2004	Atmospheric Chemistry
Bertman, Steven	Western Michigan University	11/14/2003	11/18/2003	Biosphere-Atmosphere Carbon and Nitrogen Cycles
Blake, Donald	University of California	collaborator		
Blake, Nicole	University of California	collaborator		
Bofinger, Neville	Queensland University of Technology, Australia	collaborator		
Bohn, Birger	Institut fur Chemie und Dynamik der Geosphare, Forschungszentrum Juelich, Germany	collaborator		
Bond, D.	Texas A & M University	collaborator		
Bowman, Kenneth	Texas A & M University	01/05/2004	7/31/2004	Data Analysis & Assimilation
Bowman, Kevin	Jet Propulsion Lab	10/27/2003	10/28/2003	Upper Troposphere/Lower Stratosphere
		collaborator		
Boy, Michael	University of Helsinki, Finland	collaborator		
Boyer, Elizabeth	Syracuse University of New York	11/14/2003	11/18/2003	Biosphere-Atmosphere Carbon and Nitrogen Cycles
Bradford, Mark	Duke University	11/14/2003	11/18/2003	Biosphere-Atmosphere Carbon and Nitrogen Cycles
Brasseur, Guy	Max Planck, Hamburg	collaborator		
Browell, Edward	National Aeronautics And Space Administration-Langley	collaborator		
Brown, Robert	Aerodyne Research, Inc.	09/13/2004	09/15/2004	Transport and air pollution
Brune, William	Pennsylvania State University	10/27/2003	10/28/2003	Upper Troposphere/Lower Stratosphere
		collaborator		
Calovi, Laurence	Service d'Etudes Techniques des Routes et Autoroutes, France	09/13/2004	09/15/2004	Transport and air pollution
Campbell, Colleen	University of Michigan	collaborator		
Caplain, Isabelle	Universite des Sciences et Technologie de Lille 1, France	09/13/2004	09/15/2004	Transport and air pollution
Caravalho, Joao	Center for Weather Forecasts and Climate Studies, National Institute for Space Research, Brazil	collaborator		
Cardenas, Beatriz	Centro Nacional de Investigacion y Capacitación Ambiental, Mexico	09/13/2004	09/15/2004	Transport and air pollution
Cardenas, Eusebio	Universidad Autonoma del Estado de Mexico	09/13/2004	09/15/2004	Transport and air pollution
Carmichael, Gregory	University of Iowa	06/16/2004	06/17/2004	Global Modeling
		collaborator		
Carroll, Mary Anne	University of Michigan	11/14/2003	11/18/2003	Biosphere-Atmosphere Carbon and Nitrogen Cycles
		collaborator		
Cautenet, Sylvie	Laboratoire de Meteorologie Physique, Clermont-Ferrand, France	collaborator		
Cazier, Fabrice	Universite du Littoral ccte d'opale, France	09/13/2004	09/15/2004	Transport and air pollution
Chai, Tianfeng	University of Iowa	06/16/2004	06/17/2004	Global Modeling
Chambers, Adam	National Renewable Energy Laboratory	09/13/2004	09/15/2004	Transport and air pollution
Chandra, Sushil	National Aeronautics And Space Administration	collaborator		
Chatfield, Robert	National Aeronautics And Space Administration-Ames	collaborator		
Choi, W.	Seoul National University	collaborator		
Christian, Theodore	University of Montana	collaborator		
Clark, Deborah	University of Missouri	collaborator		
Clarke, Antony	University of Hawaii	10/27/2003	10/28/2003	Upper Troposphere/Lower Stratosphere
		collaborator		
Clerbaux, Cathy	Service Aéronomie, Universite Paris 6, France	07/15/2003	12/31/2004	Measurements of Pollution In The Troposphere

Cleveland, Cory	University of Colorado at Boulder	11/14/2003	11/18/2003	Biosphere-Atmosphere Carbon and Nitrogen Cycles
Coelho, Margarida	Instituto de Engenharia Mecanica, Portugal	09/13/2004	09/15/2004	Transport and air pollution
Cohen, Ronald	University of California at Berkeley	10/27/2003	10/28/2003	Upper Troposphere/Lower Stratosphere
Coheur, Pierre-Francois	Universite Libre de Bruxelles, Belgium	05/02/2004	06/07/2004	Measurements of Pollution in the Troposphere
Cooper, Owen	National Oceanic and Atmospheric Administration	10/27/2003	10/28/2003	Upper Troposphere/Lower Stratosphere
Crawford, James	National Aeronautics And Space Administration-Langley	collaborator		
Cryer, David	Leeds University, United Kingdom	09/13/2004	09/15/2004	Transport and air pollution
Curtis, Peter	Ohio State University	11/14/2003	11/19/2003	Biosphere-Atmosphere Carbon and Nitrogen Cycles
Czech, E.	National Aeronautics And Space Administration-Ames	collaborator		
Dabberdt, Walter	Vaisala, Inc.	09/13/2004	09/15/2004	Transport and air pollution
Davis, Douglas	Georgia Institute of Technology	collaborator		
Day, Douglas	University of California	collaborator		
Deister, Ursula	Fachhochschule Weisbaden, Germany	04/14/2004	04/19/2004	PAN
Delia, Alice	University of Colorado	collaborator		
DeMott, Paul	Colorado State University	10/27/2003	10/28/2003	Upper Troposphere/Lower Stratosphere
Denman, Kenneth	University of Victoria, B.C. Canada	08/23/2004	08/24/2004	Global Modeling
Dessler, Andrew	University of Maryland	10/27/2003	10/28/2003	Upper Troposphere/Lower Stratosphere
		collaborator		
DiCarlo, Piero	Pennsylvania State University	collaborator		
Doddridge, Bruce	National Science Foundation	10/27/2003	10/28/2003	Upper Troposphere/Lower Stratosphere
Duhl, Tiffany	University of Colorado at Boulder	05/24/2004	10/24/2006	Biosphere-Atmosphere Interactions
Dunkerton, Timothy J.	Northwest Research Associates	collaborator		
Dunlea, Edward	University of Colorado at Boulder	09/13/2004	09/15/2004	Transport and air pollution
Dussault, David	Aerodyne Research, Inc.	09/13/2004	09/15/2004	Transport and air pollution
Dzepina, Katja	Rudjer Boskovic Institute, Croatia	08/19/2002	12/31/2003	Regional Modeling/Process Studies
Edwards, Gavin	Purdue University	collaborator		
Ehhalt, Dieter	Forschungszentrum Juelich, Germany	08/20/2004	09/30/2004	Upper Troposphere/Lower Stratosphere
Eldering, Annmarie	Jet Propulsion Laboratory	10/27/2003	10/28/2003	Upper Troposphere/Lower Stratosphere
		collaborator		
Evans, Matthew J.	Harvard University	collaborator		
Fahey, David	National Oceanic and Atmospheric Administration	10/27/2003	10/28/2003	Upper Troposphere/Lower Stratosphere
		collaborator		
Faiz, Asif	World Bank, Washington, DC	09/13/2004	09/15/2004	Transport and air pollution
Fall, Greg	University of Michigan	04/05/2004	04/10/2004	Global Modeling
Fall, Raymond	University of Colorado at Boulder	collaborator		
Faloona, Ian	University of California, Davis	11/14/2003	11/19/2003	Biosphere-Atmosphere Carbon and Nitrogen Cycles
Fehsenfeld, Fred	National Oceanic and Atmospheric Administration	collaborator		
Feichter, Johann	Max-Planck Institut fur Meteorologie	collaborator		
Feilberg, Karen	University of Copenhagen, Denmark	11/08/2004	12/10/2004	Lab Kinetics
Fergusen, Susan	United States Forest Service	collaborator		
Field, Brenda	Harvard University	collaborator		
Figueiras, Sandra	Environmental Technology Dept., Fachhochschule Weisbaden, Germany	09/01/2003	04/30/2004	Stratosphere/Troposphere Measurements
		collaborator		
Filley, Timothy	Purdue University	11/14/2003	11/19/2003	Biosphere-Atmosphere Carbon and Nitrogen Cycles
Feichter, Johann	Max-Planck Institut fur Meteorologie	collaborator		
Folkins, Ian	Dalhousie University, Canada	10/27/2003	10/28/2003	Upper Troposphere/Lower

				Stratosphere
Fridlind, Ann	National Aeronautics And Space Administration-Ames	collaborator		
Friehe, Carl	University of California, Irvine	collaborator		
Fromm, Michael	University of Maryland	10/27/2003	10/28/2003	Upper Troposphere/Lower Stratosphere
Frost, Greg J.	University of Colorado at Boulder	collaborator		
Fu, Qiang	University of Washington	10/27/2003	10/28/2003	Upper Troposphere/Lower Stratosphere
Fuelberg, Henry	Florida State University	collaborator		
Fuentes, Jose	University of Virginia	collaborator		
Gaffney, Jeffrey	Argonne National Laboratory	09/13/2004	09/15/2004	Transport and air pollution
Gao, Ru-Shan	National Oceanic and Atmospheric Administration	10/27/2003	10/28/2003	Upper Troposphere/Lower Stratosphere
		collaborator		
Gatti, Luciana Vanni	Energy and Nuclear Research Institue, Brazil	collaborator		
Gense, Nicolas	Netherlands Organization for Applied Scientific Research-Automotive, The Netherlands	09/13/2004	09/15/2004	Transport and air pollution
Gerbig, Christoph	University of Washington	10/27/2003	10/28/2003	Upper Troposphere/Lower Stratosphere
Geron, Christopher	Environmental Protection Agency	collaborator		
Gertler, Alan	Desert Research Institute	09/13/2004	09/15/2004	Transport and air pollution
Ghimire, Ajaya	University of Minnesota	03/31/2004	04/06/2004	Photochemical Oxidation
Gilbert, Nicolas	Health Canada	09/13/2004	09/15/2004	Transport and air pollution
Goldan, Paul	National Oceanic and Atmospheric Administration	collaborator		
Goodale, Christy	Cornell University	11/14/2003	11/19/2003	Biosphere-Atmosphere Carbon and Nitrogen Cycles
Gopalan, Arun	National Aeronautics And Space Administration-Goddard	02/13/2004	02/23/2004	High-Resolution Dynamics Limb Sounder
Graham, Lisa	Environment Canada	09/13/2004	09/15/2004	Transport and air pollution
Granier, Claire	University of Paris-6	07/28/2004	09/25/2004	Regional Process Studies
		collaborator		
Grechko, Evgeny I.	Obukhov Institute of Atmospheric Physics, Moscow	collaborator		
Grell, George	National Oceanic and Atmospheric Administration	collaborator		
Griffeon, Eric	Meteorological Service of Canada	collaborator		
Grossenbacher, John	Griffin Analytical Technologies, Inc.	collaborator		
Hair, Jonathan	National Aeronautics And Space Administration-Langley	10/27/2003	10/28/2003	Upper Troposphere/Lower Stratosphere
Hakami, Amir	California School of Technology	06/16/2004	06/17/2004	Global Modeling
Hansel, Armin	University of Innsbruck, Austria	collaborator		
Harder, Hartwig	Pennsylvania State University	collaborator		
Hartley, Anne	Florida International University	11/14/2003	11/19/2003	Biosphere-Atmosphere Carbon and Nitrogen Cycles
Hartman, Kate	Clark University	06/07/2004	08/20/2004	Biosphere-Atmosphere Interactions
Hasson, Alam	California State University	collaborator		
Heeb, Norbert	Eidgenossische Materialprufungs-und Forschungsanstalt, Duebendorf, Switzerland	09/13/2004	09/15/2004	Transport and air pollution
Heikes, Brian	University of Rhode Island	10/27/2003	10/28/2003	Upper Troposphere/Lower Stratosphere
		collaborator		
Hendricksen, P.	Netherlands Organization for Applied Scientific Research-Automotive, The Netherlands	09/13/2004	09/15/2004	Transport and air pollution
Henze, Daven	California School of Technology	06/16/2004	06/17/2004	Global Modeling
Herman, Redina	University of Illinois	10/27/2003	10/28/2003	Upper Troposphere/Lower Stratosphere
Hermann, Robert	Jet Propulsion Laboratory	collaborator		
Herrick, Jeffrey	Environmental Protection Agency	01/27/2004	02/04/2004	Biosphere-Atmosphere Interactions

		collaborator		
Heymsfield, Gerry	National Aeronautics And Space Administration-Goddard	collaborator		
Heikes, Brian	University of Rhode Island	collaborator		
Hill, Adam	Washington State University	collaborator		
Hoffman, Thorsten	Institute of Space and Atmospheric Sciences, Germany	collaborator		
Hofzumahaus, Andreas	Institut fur Chemie und Dynamik der Geosphare, Forschungszentrum Juelich, Germany	collaborator		
Holton, James	University of Washington	10/27/2003	10/28/2003	Upper Troposphere/Lower Stratosphere
Hornicek, Karel	Road and Motorway of the Czech Republic	09/13/2004	09/15/2004	Transport and air pollution
Hosick, Theresa	Environmental Protection Agency	09/13/2004	09/15/2004	Transport and air pollution
Howarth, Robert	Cornell University	11/14/2003	11/19/2003	Biosphere-Atmosphere Carbon and Nitrogen Cycles
Huey, Greg	Georgia Institute of Technology	collaborator		
Hugrel, Charlotte	Institut National de Recherche sur les Transports et leur Sécurité, France	09/13/2004	09/15/2004	Transport and air pollution
Iida, Kenjiro	University of MInnesota	03/03/2004	03/07/2004	Photochemical Oxidation Products
Iniestra, Rodolfo	Instituto Nacional de Ecologia, Mexico	09/13/2004	09/15/2004	Transport and air pollution
Ionel, ing. Habil Ioana	University Politehnica Timisoara, Romania	09/13/2004	09/15/2004	Transport and air pollution
Irion, William	Jet Propulsion Laboratory	collaborator		
Jacob, Daniel	Harvard University	collaborator		
Jaekel, Evelyn	Institut fur Troposharenforschung Leipzig e.v. Germany	07/21/2003	10/15/2003	Atmospheric Radiation Investigation & Measurements
Jager, Maxime	Institut de Louis Pasteur	10/01/2003	05/31/2004	Standards and Intercomparisons
		collaborator		
Jardine, Kolby	State University of New York, Stony Brook	06/07/2004	08/20/2004	Biosphere-Atmosphere Interactions
		collaborator		
Jazcilevich, Aron	Centro de Ciencias de la Atmósfera, Mexico	09/13/2004	09/15/2004	Transport and air pollution
		collaborator		
Jensen, Eric	National Aeronautics and Space Administration	10/27/2003	10/28/2003	Upper Troposphere/Lower Stratosphere
Jianhui, Bai	IAP-Chinese Academy of Sciences	collaborator		
Jiang, Yi	University of Washington	06/16/2004	06/17/2004	Global Modeling
Jimenez, Jose-Luis	University of Colorado at Boulder	09/13/2004	09/15/2004	Transport and air pollution
		collaborator		
Jobson, Bertron T.	Pacific Northwest National Laboratory	collaborator		
Jobson, Thomas	University of Colorado at Boulder	collaborator		
Johnson, Brian	Ball Aerospace & Technologies Corporation	10/27/2003	10/28/2003	Upper Troposphere/Lower Stratosphere
Johnston, Paul	National Institute of Water and Atmospheric Research, Lauder, New Zealand	collaborator		
Jourmard, Robert	Institut National de Recherche sur les Transports et leur Sécurité, France	09/13/2004	09/15/2004	Transport and air pollution
Junkermann, Wolfgang	Institut fur Meteorologie und Klimaforschung, Forschungszentrum Karlsruhe, Garmisch-Partenkirchen, Germany	collaborator		
Kajii, Yoshizumi	Tokyo Metropolitan University	07/18/2004	07/22/2004	Biosphere-Atmosphere Interactions
		collaborator		
Khattatov, Boris	Fusion Numerics Industries	06/01/2004	05/31/2005	Measurements of Pollution in the Troposphere, High Resolution Dynamics Limb Sounder
Kim, Si-Wan	Yonsei University, South Korea	06/01/2004	09/30/2004	Boundary Layer & Turbulence Group
Kodera, Kunihiko	Meteorological Research Institute, Japan	10/08/2003	10/10/2003	Global Modeling

		12/07/2004	12/10/2004	
Koike, Makoto	Nagoya University, Japan	collaborator		
Kondo, Yutaka	University of Tokyo, Japan	collaborator		
Konopka, Paul	Forschungszentrum Juelich, Germany	07/26/2004	07/31/2004	Upper Troposphere/Lower Stratosphere
		collaborator		
Krewson, Kay	University of Miami	06/10/2004	10/31/2004	Stratosphere-Troposphere Measurements
Kraus, Andreas	Grunenthal GmbH, Aachen, Germany	collaborator		
Krol, Martin	Institute for Marine and Atmospheric Research, Utrecht, Netherlands	collaborator		
Kucera, Paul	University of North Dakota	collaborator		
Kulmala, Markku	University of Helsinki, Finland	collaborator		
Kuster, William	National Oceanic and Atmospheric Administration	collaborator		
Kylling, Arve	Norwegian Institute for Air Research, Norway	collaborator		
Lack, Daniel	Queensland University of Technology, Australia	collaborator		
Lamb, Brian	Washington State University	11/14/2003	11/19/2003	Biosphere-Atmosphere Carbon and Nitrogen Cycles
		collaborator		
Lee, Shanhu	University of Denver	10/27/2003	10/28/2003	Upper Troposphere/Lower Stratosphere
Lefer, Barry	University of Houston	09/01/2004	12/31/2004	Atmospheric Radiation Investigations & Measurements
Lei, Wenfang	Texas A & M University	collaborator		
Leriche, Maud	Laboratoire de Meteorologie Physique, Clermont-Ferrand, France	collaborator		
Lesher, Robert	Pennsylvania State University	collaborator		
Li, Guohui	Texas A&M University	08/22/2003	12/22/2003	Global/Regional Modeling
Li, Lihua	National Aeronautics And Space Administration-Goddard	collaborator		
Litvak, Marcy	University of Texas	11/14/2003	11/19/2003	Biosphere-Atmosphere Carbon and Nitrogen Cycles
Lloyd, Steven A.	Johns Hopkins University, Maryland	collaborator		
Logan, Jennifer	Harvard University	10/27/2003	10/28/2003	Upper Troposphere/Lower Stratosphere
Lonati, Giovanni	Dipartimento di Ingegneria Idraulica,-Ambientale, Politecnico di Milano, Italy	09/13/2004	09/15/2004	Transport and air pollution
Lonneman, Bill	Environmental Protection Agency	collaborator		
Luo, Johnny	Colorado State University	10/27/2003	10/28/2003	Upper Troposphere/Lower Stratosphere
Machemer, Steve	Environmental Protection Agency	09/13/2004	09/15/2004	Transport and air pollution
Madronich, Monica	University of Colorado at Boulder	05/01/2002	12/31/2004	Biosphere-Atmosphere Interactions
Mahoney, Michael	Jet Propulsion Laboratory	10/27/2003	10/28/2003	Upper Troposphere/Lower Stratosphere
Mak, John	State University of New York, Stony Brook	07/28/2004	07/30/2004	Global Modeling
Manney, Gloria	Jet Propulsion Laboratory	10/27/2003	10/28/2003	Upper Troposphere/Lower Stratosphere
Manzi, Antonio	Brazilian National Institute of Amazon Research, Brazil	collaborator		
Marcy, Timothy	National Oceanic and Atmospheric Administration	10/27/2003	10/28/2003	Upper Troposphere/Lower Stratosphere
		collaborator		
Mari, Celine	Laboratoire d' Aerologie, Toulouse, France	collaborator		
Martin, Timothy	Karl-Franzens Universitat, Graz, Austria	collaborator		
Martinez, Marcy	Pennsylvania State University	collaborator		
Mass, Clifford	University of Washington	collaborator		
Matsunaga, Sou	Hokkaido University, Japan	04/15/2003	01/18/2005	Biosphere-Atmosphere Interactions
Matthes, Katja	Free University Berlin, Germany	05/01/2004	05/01/2005	Regional Modeling and Process Studies
Mauzerall, Denise	Princeton University	collaborator		

Mayer, Bernhard	Deursches Zentrum fur Luft-und Raumfahrt, Germany	collaborator		
McGill, Matthew	National Aeronautics And Space Administration-Goddard	collaborator		
McKee, Michael	Auburn University, New York	collaborator		
McKenzie, Richard	National Institute of Water and Atmospheric Research, Lauder, New Zealand	collaborator		
McKinney, Karina	University of Massachusetts	collaborator		
McMillan, Wallace	University of Maryland	collaborator		
McMurry, Peter	University of Minnesota	05/20/2004	05/21/2004	Photochemical Oxidation
Melville, Kenneth	Scripps Institute of Oceanography	collaborator		
Merkel, Aimee	University of Colorado at Boulder	02/10/2003	02/9/2005	Regional Process Modeling
Metcalf, Andrew	Pennsylvania State University	collaborator		
Milford, Jana	University of Colorado at Boulder	collaborator		
Mitchell, Nicholas	University of Bath, United Kingdom	collaborator		
Mittal, Moti L.	National Physical Laboratory, India	collaborator		
Mitra, Ashesh Prosad	National Physical Laboratory, India	09/13/2004	09/15/2004	Transport and air pollution
		collaborator		
Mlynczak, M.	National Aeronautics And Space Administration-Langley	collaborator		
Monks, Paul S.	University of Leicester, United Kingdom	collaborator		
Monson, Russell	University of Colorado at Boulder	11/14/2003	11/19/2003	Biosphere-Atmosphere Carbon and Nitrogen Cycles
		collaborator		
Montzka, Steve	National Oceanic and Atmospheric Administration	collaborator		
Moody, Jennie Lynne	University of Virginia	10/27/2003	10/28/2003	Upper Troposphere/Lower Stratosphere
Moore, Katharine	Unaffiliated	12/3/2001	08/31/2004	Photochemical Oxidation
Morita, Akihiro	Institute of Molecular Science, Japan	collaborator		
Mowry, Fred	Duke University	collaborator		
Moya-Nunez, Mireya	Universidad National Autónoma de Mexico	09/13/2004	09/15/2004	Transport and air pollution
Mueller, Martin	Dresdner Bank, Frankfurt, Germany	collaborator		
Munger, William	Harvard University	11/14/2003	11/19/2003	Biosphere-Atmosphere Carbon and Nitrogen Cycles
Murazaki-Adachi, Kazuyo	Meteorological Research Institute, Japan	11/25/2002	11/24/2003	Regional and Process Studies
		06/01/2004	06/07/2004	Global Modeling
		08/17/2004	08/17/2004	Data Analysis & Assimilation
Murphy, Daniel	National Oceanic and Atmospheric Administration	10/27/2003	10/28/2003	Upper Troposphere/Lower Stratosphere
Murphy, Jennifer	University of California	collaborator		
Nadelhoffer, Knute	University of Michigan	11/14/2003	11/19/2003	Biosphere-Atmosphere Carbon and Nitrogen Cycles
Nagel, Carsten	AUDI Automotive, Germany	09/13/2004	09/15/2004	Transport and air pollution
Nandi, Sreela	Unaffiliated	08/04/2004	08/05/2005	Biosphere-Atmosphere Interactions
Neilson, Ronald	United States Forest Service	collaborator		
Nenes, Athanasios	Georgia Institute of Technology	collaborator		
Neuman, Andrew	National Oceanic and Atmospheric Administration	collaborator		
Nevison, Cynthia	University of Colorado at Boulder	08/31/2003	09/30/2005	Global Modeling
Newell, Reginald	Massachusetts Institute of Technology	collaborator		
Niu, Jianguo	Chiba University, JAPAN	01/22/2001	04/01/2004	Measurements of Pollution In The Troposphere
Noone, David	University of Colorado at Boulder	collaborator		
Nouali, Habiba	Universite du littoral, Cote d'opule, France	09/13/2004	09/15/2004	Transport and air pollution
Novelli, Paul	National Oceanic and Atmospheric Administration	collaborator		
Nowak, John	National Oceanic and Atmospheric Administration	collaborator		
Noziere, Barbara	University of Miami	08/04/2003	10/08/2003	Heterogeneous Chemistry
Ntziachristos, Leonidas	Aristotle University, Greece	09/13/2004	09/15/2004	Transport and air pollution
Nunes, Teresa	Universidad de Averió, Portugal	03/19/2003	05/10/2003	Biosphere-Atmosphere Interactions

		09/22/2003	10/22/2003	Biosphere-Atmosphere Interactions
		collaborator		
O'Dowd, Colin	National University of Ireland	collaborator		
Oettl, Dietmar	Graz University of Technology, Austria	09/13/2004	09/15/2004	Transport and air pollution
Ojima, Dennis	Colorado State University	11/14/2003	11/19/2003	Biosphere-Atmosphere Carbon and Nitrogen Cycles
Ollinger, Scott	University of New Hampshire	11/14/2003	11/19/2003	Biosphere-Atmosphere Carbon and Nitrogen Cycles
Olsen, Jennifer	National Aeronautics And Space Administration-Langley	collaborator		
Olsen, Mark	National Aeronautics And Space Administration-Goddard	10/27/2003	10/28/2003	Upper Troposphere/Lower Stratosphere
Olszyna, Kenneth	Tennessee Valley Authority	collaborator		
Oltmans, Samuel	National Oceanic and Atmospheric Administration	collaborator		
Osses, Mauricio	University of Chile	09/13/2004	09/15/2004	Transport and air pollution
Ott, Lesley	University of Maryland	collaborator		
Owen, Susan	Lancaster University	collaborator		
Palmer, Paul	Harvard University	collaborator		
Pancheva, Dora	University of Bath, United Kingdom	collaborator		
Park, Mijeong	Seoul National University, South Korea	6/28/2004	6/30/2005	Regional Process Studies
Parrish, David	National Oceanic and Atmospheric Administration	collaborator		
Pegoraro, Emilliano	University of Edinburgh, United Kingdom	collaborator		
Penner, Joyce	University of Michigan	collaborator		
Petropavlovskikh, Irina	University of Colorado at Boulder	collaborator		
Pfister, Gabriele	National Institute Water & Atmospheric Research, New Zealand	05/01/2002	07/19/2004	Measurements of Pollution In The Troposphere
Pfister, Leonhard	National Aeronautics And Space Administration-Ames	10/27/2003	10/28/2003	Upper Troposphere/Lower Stratosphere
Pickering, Kenneth	University of Maryland	10/27/2003	10/28/2003	Upper Troposphere/Lower Stratosphere
		collaborator		
Pierce, Thomas	Environmental Protection Agency	collaborator		
Pilewski, Peter	University of Colorado at Boulder	collaborator		
Pimentel, Andre	National Aeronautics And Space Administration-Goddard	collaborator		
Pinty, Jean-Pierre	Laboratoire d' Aerologie, Toulouse, France	collaborator		
Pirjola, Liisa	University of Helsinki, Finland	collaborator		
Popp, Peter	National Oceanic Atmospheric Administration	10/27/2003	10/28/2003	Upper Troposphere/Lower Stratosphere
		collaborator		
Potosnak, Mark	Desert Research Institute	11/14/2003	11/19/2003	Biosphere-Atmosphere Carbon and Nitrogen Cycles
		06/21/2004	06/25/2004	Biosphere-Atmosphere Carbon and Nitrogen Cycles
		collaborator		
Pressley, Shelly	Washington State University	11/14/2003	11/19/2003	Biosphere-Atmosphere Carbon and Nitrogen Cycles
Prather, Michael	University of California, Irvine	collaborator		
Pryor, Sara	Indiana University	11/14/2003	11/19/2003	Biosphere-Atmosphere Carbon and Nitrogen Cycles
Pzenny, Alex	University of New Hampshire	collaborator		
Randall, Cora	University of Colorado at Boulder	10/27/2003	10/28/2003	Upper Troposphere/Lower Stratosphere
Randerson, James	University of California, Irvine	collaborator		
Rapparini, Francesca	Istituto di Biometeorologia, Italy	collaborator		
Rasmussen, Rei	Oregon Graduate Institute	collaborator		
Ravishankara, A.R.	National Oceanic and Atmospheric Administration	10/27/2003	10/28/2003	Upper Troposphere/Lower Stratosphere
Ray, Eric	National Oceanic and Atmospheric Administration	10/27/2003	10/28/2003	Upper Troposphere/Lower Stratosphere
Reise, Martin	Forschungszentrum Juelich, Germany	10/27/2003	10/29/2003	Global Modeling
Ren, Xinrong	Pennsylvania State University	collaborator		
Reyes, Faustino	National Autonomous University of Mexico	09/13/2004	09/15/2004	Transport and air pollution

Ricciardulli, Lucrezia	Remote Sensing Systems	03/11/2004	04/03/2004	Regional Modeling and Process Studies
		09/03/2004	09/17/2004	Regional Modeling and Process Studies
Richard, Erik	National Oceanic and Atmospheric Administration	10/27/2003	10/28/2003	Upper Troposphere/Lower Stratosphere
Richards, Nigel	University of Leicester, UK	10/13/2003	10/26/2003	Measurements of Pollution In The Troposphere
Riemer, Daniel	University of Miami	08/18/2003	12/06/2003	Standards and Intercomparisons Project
		03/16/2004	03/21/2004	Standards and Intercomparisons Project
		06/01/2004	06/31/2004	Standards and Intercomparisons Project
		collaborator		
Rivas, Miguel	Universidad de Tarapaca, Chile	07/16/2004	07/31/2004	Regional Modeling and Process Studies
Roberts, Andrew	National Aeronautics And Space Administration-Johnson Space Flight Center	10/27/2003	10/28/2003	Upper Troposphere/Lower Stratosphere
Roberts, James	National Oceanic and Atmospheric Administration	01/16/2003	01/15/2004	Antarctic Tropospheric Chemistry Investigation
		03/30/2004	12/31/2004	Antarctic Tropospheric Chemistry Investigation
		collaborator		
Rosenlof, Karen	National Oceanic and Atmospheric Administration	10/27/2003	10/28/2003	Upper Troposphere/Lower Stratosphere
Rosen, Rebecca	University of California	collaborator		
Roth, Ernst-Peter	Institut fur Physikalisches Chemie, Universitat Gesamthochschule Essen, Germany	collaborator		
Ruggaber, Ansgar	Meteorologisches Institut, Universitat Munchen, Germany	collaborator		
Russell, James	Hampton University	collaborator		
Saavedra, Maribel	National University of Mexico	07/10/2004	07/17/2004	Biosphere-Atmosphere Interactions
Sabutis, Joseph	New Mexico Highlands University	10/27/2003	10/28/2003	Upper Troposphere/Lower Stratosphere
Sachse, Glen	National Aeronautics And Space Administration-Langley	collaborator		
Sakulyanontvittaya, Tanarit	University of Colorado at Boulder	05/24/2004	10/24/2006	Biosphere-Atmosphere Interactions
Salas, Louis	National Aeronautics And Space Administration-Ames	collaborator		
Sandholm, Scott	Georgia Institute of Technology	collaborator		
Saxer, Christian	Eidgenossische Materialprufungs-und Forschungsanstalt, Duebendorf, Switzerland	09/13/2004	09/15/2004	Transport and air pollution
Schade, John	Arizona State University	11/14/2003	11/19/2003	Biosphere-Atmosphere Carbon and Nitrogen Cycles
Schell, Vincent	Institut de Louis Pasteur	10/01/2003	05/31/2004	Stratosphere/Troposphere Measurements
		collaborator		
Schmidt, Steven	University of Colorado at Boulder	11/14/2003	11/19/2003	Biosphere-Atmosphere Carbon and Nitrogen Cycles
Schmitt, Rainer	Meteorologie Consult GmbH, Glashuetten, Germany	collaborator		
Schultz, Martin	Max-Planck Institut fur Meteorologie, Germany	02/22/2004	03/05/2004	Global Modeling
		collaborator		
Seakins, Paul	University of Leeds, United Kingdom	collaborator		
Seastedt, Timothy	University of Colorado at Boulder	11/14/2003	11/19/2003	Biosphere-Atmosphere Carbon and Nitrogen Cycles
Seinfeld, John	California School of Technology	06/16/2004	06/17/2004	Global Modeling
Senff, Christoph	National Oceanic and Atmospheric Administration	10/27/2003	10/28/2003	Upper Troposphere/Lower Stratosphere
Sharman, C.	National Physical Laboratory, India	collaborator		

Shaw, Cynthia Ann	University of Colorado at Boulder	06/01/2003	05/31/2005	Global Modeling
Shepson, Paul	Purdue University	11/14/2003	11/19/2003	Biosphere-Atmosphere Carbon and Nitrogen Cycles
		collaborator		
Shirley, Terry	Pennsylvania State University	collaborator		
Sievering, Herman	University of Colorado at Boulder	11/14/2003	11/19/2003	Biosphere-Atmosphere Carbon and Nitrogen Cycles
Simpson, Isobel J.	University of California	collaborator		
Singh, Hanwant	National Aeronautics and Space Administration	collaborator		
Slusher, Darlene	Georgia Institute of Technology	collaborator		
Smalley, Robert	University of Leeds, United Kingdom	09/13/2004	09/15/2004	Transport and air pollution
Smith, Steven	Pacific Northwest National Laboratory	collaborator		
Soltic, Patrik	Eidgenossische Materialprufungs-und Forschungsanstalt, Switzerland	09/13/2004	09/15/2004	Transport and air pollution
Sparks, Jed	Cornell University	11/14/2003	11/19/2003	Biosphere-Atmosphere Carbon and Nitrogen Cycles
		collaborator		
Spiridonov, Vlado	Hydrometeorological Institute, Skopje, Macedonia	collaborator		
Spirig, Christoph	Swiss Federal Institute of Technology, Zurich, Switzerland	collaborator		
Staehelin, Johannes	Swiss Federal Institute of Technology, Zurich	09/13/2004	09/15/2004	Transport and air pollution
Steffen, William	Royal Swedish Academy of Sciences, Sweden	02/26/2004	02/27/2004	International Geosphere – Biosphere program
Steiner, Allison	University of California at Berkeley	collaborator		
Stenchikov, Georgiy	Rutgers University	collaborator		
Stephens, Carol	University of Miami	01/18/2004	02/07/2004	Stratosphere/Troposphere Measurements Project
Stephens, Sherry	Unaffiliated	08/28/2000	12/31/2004	Atmospheric Radical Studies
Stevens, Gretchen	Harvard University	09/13/2004	09/15/2004	Transport and air pollution
Stewart, Glen	University of Colorado at Boulder	10/27/2003	10/28/2003	Upper Troposphere/Lower Stratosphere
Stickel, Robert	Georgia Institute of Technology	collaborator		
Stock, Martin Paul	Institut fur Physik der Atmosphare, Germany	9/13/2004	12/10/2004	Atmospheric Odd Nitrogen
Stohl, Andreas	National Oceanic Atmospheric Administration	10/27/2003	10/28/2003	Upper Troposphere/Lower Stratosphere
Stolzenburg, Mark	Particle Technology Lab	03/03/2004	03/07/2004	Photochemical Oxidation Products
Stroud, Craig	Unaffiliated	07/05/2001	10/30/2004	Regional Process Studies
Strow, Larrabee	University of Maryland	collaborator		
Sturm, Peter	Graz University of Technology, Austria	9/13/2004	9/15/2004	Transport and air pollution
Stutz, Jochen	University of California	9/13/2004	9/15/2004	Transport and air pollution
Sugiyama, Masakazu	University of Tokyo, Japan	collaborator		
Swanson, Aaron	University of California	01/02/2003	12/31/2004	Upper Troposphere/Lower Stratosphere
Swartz, William H.	Johns Hopkins University, Maryland	collaborator		
Sundu, Adrian	Virginia Technological Institute	06/16/2004	06/17/2004	Regional Modeling and Process Studies
		08/04/2004	08/11/2004	Regional Modeling and Process Studies
Talbot, Robert	University of New Hampshire	collaborator		
Tanner, David	Georgia Institute of Technology	collaborator		
Teklemariam, Thomas	Cornell University	11/14/2003	11/19/2003	Biosphere-Atmosphere Carbon and Nitrogen Cycles
Thompson, Anne	National Aeronautics And Space Administration-Goddard	collaborator		
Thornberry, Troy	National Oceanic Atmospheric Administration	11/14/2003	11/19/2003	Biosphere-Atmosphere Carbon and Nitrogen Cycles
		collaborator		
Thornton, D.C.	Drexel University	collaborator		
Thornton, Joel	University of Toronto	collaborator		
Throop, Heather	University of Arizona	11/14/2003	11/19/2003	Biosphere-Atmosphere Carbon and Nitrogen Cycles

Tomaszewski, Timothy	University of Colorado at Denver	11/14/2003	11/19/2003	Biosphere-Atmosphere Carbon and Nitrogen Cycles
Toohey, Darin	University of Colorado at Boulder	10/27/2003	10/28/2003	Upper Troposphere/Lower Stratosphere
		collaborator		
Torres, Omar	University of Maryland	collaborator		
Tota, Julio	Brazilian National Institute of Amazon Research, Brazil	collaborator		
Townsend, Alan	University of Colorado at Boulder	11/14/2003	11/19/2003	Biosphere-Atmosphere Carbon and Nitrogen Cycles
Trainer, Michael	National Oceanic Atmospheric Administration	10/27/2003	10/28/2003	Upper Troposphere/Lower Stratosphere
Trepte, Charles	National Aeronautics And Space Administration-Langley	collaborator		
Treseder, Kathleen	University of California, Irvine	11/14/2003	11/19/2003	Biosphere-Atmosphere Carbon and Nitrogen Cycles
Trostdorf, Carla	Energy and Nuclear Research Institue, Brazil	collaborator		
Tsubota, Yukimasa	Keio University, Japan	09/13/2004	09/15/2004	Transport and air pollution
Turner, Jay	Washington University	collaborator		
Turquety, Soline	Harvard University	05/13/2004	05/14/2004	Measurements of Pollution in the Troposphere
Urbanski, Shawn	United States Department of Agriculture	04/15/2004	04/15/2005	Regional Modeling and Process Studies
Vanchindorj, Ulzisisaikhan	University of Colorado at Boulder	06/21/2004	01/05/2005	Biosphere-Atmosphere Carbon and Nitrogen Cycles
VanWeele, Michel	Royal Netherlands Meteorological Institute	collaborator		
Vay, Stephanie	National Aeronautics And Space Administration-Langley	collaborator		
Vizuete, Will	University of Texas	collaborator		
Volkmar, Henning	Volkswagen Automobiles, Germany	09/13/2004	09/15/2004	Transport and air pollution
Volkamer, Rainer	Massachusetts Institute of Technology	05/23/2004	05/27/2004	Atmospheric Chemistry
Vukicevic, Tumislava	Colorado State University	06/16/2004	06/17/2004	Global Modeling
Walker, John	Environmental Protection Agency	01/212004	02/28/2004	Biosphere-Atmosphere Interactions
		collaborator		
Wallington, Timothy J.	Ford Motor Company	collaborator		
Wang, Chien	Massachusetts Institute of Technology	collaborator		
Wang, Pao	University of Wisconsin	10/27/2003	10/28/2003	Upper Troposphere/Lower Stratosphere
Wang, Xiaoping	Princeton University	collaborator		
Waters, Joe	Jet Propulsion Laboratory	10/27/2003	10/28/2003	Upper Troposphere/Lower Stratosphere
Waugh, Darryn	Johns Hopkins University	10/27/2003	10/28/2003	Upper Troposphere/Lower Stratosphere
Weber, Rodney	Georgia Institute of Technology	collaborator		
Webster, Christopher	Jet Propulsion Laboratory	collaborator		
Wei, Jennifer	University of Maryland	10/27/2003	10/28/2003	Upper Troposphere/Lower Stratosphere
Weilenmann, M.	Eidgenossische Materialprufungs-und Forschungsanstalt, Switzerland	09/13/2004	09/15/2004	Transport and air pollution
Weinstock, Elliot	Harvard University	collaborator		
Weiss, Ray	Scripps Institution of Oceanography	collaborator		
Weiss, Stuart	Creekside Center for Earth Sciences	11/14/2003	11/19/2003	Biosphere-Atmosphere Carbon and Nitrogen Cycles
Wendisch, Manfred	Institute for Tropospheric Research, Germany	10/07/2003	10/10/2003	Atmospheric Radiation Investigation & Measurements
Wennberg, Paul	California Institute of Technology	10/27/2003	10/28/2003	Upper Troposphere/Lower Stratosphere
Wert, Brian	Unaffiliated	collaborator		
Westberg, Halvor	Washington State University	collaborator		
Whiteway, James	York University	10/27/2003	10/28/2003	Upper Troposphere/Lower Stratosphere
Wiegand, Aaron	Queensland University of Technology, Australia	collaborator		

Williams, Eric	National Oceanic and Atmospheric Administration	collaborator		
Williams, Mark	University of Colorado at Boulder	collaborator		
Wilson, James	University of Denver	10/27/2003	10/28/2003	Upper Troposphere/Lower Stratosphere
Wine, Paul	Georgia Institute of Technology	collaborator		
Wohrnschimmel, Henry	Eidgenossissche Technische Hochschule Zurich, Switzerland/Centro Nacional de Investigacion y Capacitacion Ambiental, Mexico	09/13/2004	09/15/2004	Transport and air pollution
Wong, Sun	University of Maryland	collaborator		
Wooldridge, Paul	University of California	collaborator		
Worden, Helen	California Institute of Technology	10/27/2003	10/28/2003	Upper Troposphere/Lower Stratosphere
Worden, John	California Institute of Technology	10/27/2003	10/28/2003	Upper Troposphere/Lower Stratosphere
		01/22/2004	01/23/2004	Regional Modeling
		collaborator		
Wu, Dong	Jet Propulsion Laboratory	10/27/2003	10/28/2003	Upper Troposphere/Lower Stratosphere
Xu, Jiyao	Chinese Academy of Sciences, China	10/01/2003	02/28/2004	Global Modeling
Ying, Zhuming	Centre for Research in Earth and Space Science, China	03/11/2003	03/10/2005	Regional Modeling and Process Studies
Yokelson, Robert	University of Montana	collaborator		
Yoshino, Miori	University of Colorado at Boulder	06/07/2004	08/20/2004	Biosphere-Atmosphere Interactions
Young, Valerie	Ohio University	collaborator		
Yurganov, Leonid	Obukhov Institute of Atmospheric Physics, Moscow	collaborator		
Zavala, Miguel	Massachusetts Institute of Technology	09/13/2004	09/15/2004	Transport and air pollution
Zhang, Qi	University of Colorado at Boulder	09/13/2004	09/15/2004	Transport and air pollution
Zhang, R.	Texas A & M University	collaborator		
Ziemke, Jerrold	National Aeronautics And Space Administration	collaborator		
Zuk, Miriam	Instituto Nacional de Ecologia, Mexico	09/13/2004	09/15/2004	Transport and air pollution
Zvirin, Yoram	Israel Institute of Technology	09/13/2004	09/15/2004	Transport and air pollution

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Director's Message

Tom Bogdan, William (Al) Cooper and Maura Hagan

We collectively report on ASP activities during the past year. Tom Bogdan directed the ASP for much of the time that William (Al) Cooper was on leave working at the National Science Foundation. Maura Hagan served as the Acting ASP Director during the last quarter.

ASP's role and mission as an integrator within NCAR, brings together the most talented of early career scientists who can be mentored by more senior divisional scientists. This permits the exchange of ideas and fosters mutual educations. ASP functions as a natural catalyst for spurring multi-disciplinary research activities capable of crossing the science and service boundaries of divisions and programs. In turn, many of these young scientists return to the atmospheric sciences community and strengthen ties between our national center and the universities. They are also invited to attend regular seminars and workshops including the Early Career Scientists Assembly annual forum on future scientific directions. Several of ASP's projects direct attention to timely scientific areas needing special emphasis and promote continuing education of topics in atmospheric science. The most important component of our program is the postdoctoral fellowship program, which has been a part of NCAR for thirty-nine years and has brought over 400 postdoctoral scientists to NCAR. Each year approximately 10 new postdoctoral scientists come to NCAR, usually for two-year appointments. They conduct their research in collaboration with NCAR scientists and work in all areas in which NCAR is involved. NCAR benefits from continuous contact with some of the brightest and most promising young scientists in our field and from the lasting associations that result. The postdoctoral scientists benefit from the opportunity to work with NCAR scientists, from exposure to the breadth of science at NCAR, and from the independence they are encouraged to develop. Many former fellows now occupy prominent positions at UCAR universities or at NCAR, and many of the present collaborations between NCAR and university scientists derive from associations that developed in the postdoctoral program.

The ASP also promotes the examination of research areas that merit special emphasis, either because they are particularly timely or because they seem under-emphasized relative to their importance. This is primarily accomplished by convening workshops and by supporting appropriate visitors. As part of this effort, ASP hosts an annual summertime colloquium that brings graduate students to NCAR for an intensive set of lectures presented by selected scientists from within and outside NCAR. Last summer ASP co-hosted two colloquia. The first was on the topic of "Atmospheric Remote Sensing Using the Global Positioning System" organized by Bill Kuo and co-hosted by COSMIC (UOP). The second was on the topic of "Climate and Health" organized by Linda Mearns and co-hosted by ESIG, NOAA and NASA.

The ASP also provides organizational support for the Early Career Scientists Assembly (ECSA) and their activities, including the Junior Faculty Forum. The second annual ECSA Junior Faculty Forum was held at NCAR on 23-25 June 2004. Participants included 40 early career researchers from 19 universities and institutions in the U.S., Switzerland, Canada, and the United Kingdom. They discussed two topics; the sun-climate connection, and the role of coastal zones in global biogeochemistry. For the first time, this year the ECSA invited National Science Foundation and NASA representatives to participate in the fora, wherein they discussed issues surrounding funding opportunities, grants and ethics. Another function of the ASP is to promote new science initiatives and programs that do not have a natural home in any one of the NCAR divisions. The Geophysical Turbulence Program seeks to represent interests in turbulence throughout NCAR. This very active program normally hosts two annual workshops, sponsors a seminar series, and in other ways helps coordinate and promote turbulence research at NCAR. We are also the administrative home for the NCAR Scientist Assembly (NSA). Finally, ASP supports the NCAR Aerosol Program in its interdivisional effort to serve the diverse community of aerosol researchers at NCAR and in the research community by initiating activities that improve communication and promote collaborative research through a Research Discussion series under the leadership of Jim Smith (ACD), chair.

The ASP also includes: the NCAR Graduate Fellowship Program, which provides a few opportunities for graduate students to conduct Ph.D. research projects at NCAR in collaboration with NCAR scientists; some Senior Research Associates; and several seminar series including the NCAR-wide "Showcase Seminars" that highlight significant advances at NCAR and the "Thompson Lectures" that bring prominent scientists to NCAR to interact with the postdoctoral fellows. We also established plans to develop a new Faculty Exchange Program during the past year. We expect to announce the program details and invite applications in early 2005. For more information on the ASP mission and plans, see the ASP Strategic Plan.

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ASP Executive Summary

The overarching objectives of the Advanced Study Program (ASP) are to support and complement the full NCAR program, and to help NCAR and the scientific communities that it serves to prepare for the future. The ASP encourages the development of young scientists in atmospheric and related research, directs attention to timely scientific areas needing special emphasis, helps to organize new science initiatives, supports interactions with universities, and promotes continuing education at NCAR. The postdoctoral fellowship program continues to be the most important component of the ASP. The fellows conduct their research in collaboration with NCAR scientists throughout the institution and have access to diverse advanced training opportunities to enhance their professional development. The ASP also promotes the examination of research areas that are in need of special emphasis, either because they are particularly timely or they deserve exacting attention. The ASP convenes workshops and colloquia, and supports appropriate visitors to accomplish these objectives. Additionally, the ASP provides organizational support for a research program that spans most divisions at NCAR. The ASP support of the Geophysical Turbulence Program (GTP) includes the administration of the annual GTP workshops, seminar series, and visitor program. Other ASP activities include support for NCAR visitors, particularly those with interdisciplinary interests and related to NCAR educational activities. The ASP also promotes visits to universities through a Visiting Scholars Program. Some of the more notable ASP accomplishments during the past year are summarized in the following paragraphs.

Scientist I Search

As a result of the third recent NCAR-wide search for entry-level scientists, seven new Scientist I appointments were made in FY-2004. The three searches have led to the appointment of 29 new early-career scientists since 2001, resulting in a pronounced change in the demographic distribution of the NCAR scientific staff and a significant infusion of youthful vigor into the NCAR scientific program.

The ASP Postdoctoral Fellowships

During FY-2004, 31 postdoctoral fellows conducted research at NCAR in the Advanced Study Program. These fellows work in all divisions and programs at NCAR, so many of the details of their scientific achievements appear in the reports from those divisions and programs. We include brief examples of contributions to NCAR science in our section on Postdoctoral Research Summaries. A description of the fellowship program can also be found in the ASP Postdoctoral Fellowship Announcement.

The NCAR Graduate Fellowship Program

Following a modest re-instatement of the NCAR Graduate Fellowship Program in the previous year, ASP supported the work of four graduate fellows at NCAR in FY-2004. These graduate students now constitute a cohort who share interests in aerosols and so can interact with and support each other as they pursue their graduate research at NCAR. Examples of the research begun by these Fellows are included in the section on Graduate Research Summaries, and more information about this program can be found in the ASP NCAR Graduate Fellowship Announcement.

Summer Colloquia

ASP co-hosted two summer colloquia in 2004. The first, on atmospheric remote sensing using the global positioning system (GPS), was co-hosted with the UCAR Office of Program's COSMIC program and organized by Y.-H. Kuo

(NCAR/UCAR), C. Rocken (UCAR), S. Sokolovskiy (UCAR), E.R. Kursinski (University of Arizona), and G. Hajj (Jet Propulsion Laboratory). This two-week colloquium brought together 51 student participants and 31 lecturers for tutorials and discussion sessions. Fifty-one students from 36 universities and institutions and from 11 countries attended, so the colloquium had a strong international character. As the COSMIC array of GPS satellites approaches operational status, the training received by these students should place them in prime position to exploit the new scientific opportunities that array will offer.

GPS field trip participants at National Central University, Chung-Li City, Taiwan

The second colloquium was held 21-28 July on climate and health and was coordinated by Linda Mearns of the Environmental and Societal Impacts Group, Doug Nychka of the Geophysical Statistics Project and Jonathan Patz of Johns Hopkins Bloomberg School of Public Health. Thirty-one lecturers from 16 organizations and universities of the U.S. and the United Kingdom presented talks and hands-on interactive exercises to the 43 participants representing 26 universities and institutions of the U.S., Canada, Germany, Austria, Kenya, Israel, Spain, the West Indies and the United Kingdom.

Climate and Health Colloquium participants and lecturers

Scientists Assembly Support

The ASP also provides organizational support for the Early Career Scientists Assembly (ECSA) and their activities, including the Junior Faculty Forum. The second annual ECSA Junior Faculty Forum was held at NCAR on 23-25 June 2004. Participants included 40 early career researchers from 19 universities and institutions in the U.S., Switzerland, Canada, and the United Kingdom. They discussed two topics: the sun-climate connection and the role of coastal zones in global biogeochemistry. For the first time, this year the ECSA invited National Science Foundation and NASA representatives to participate in the fora, wherein they discussed issues surrounding funding opportunities, grants and ethics.

The NCAR Scientists Assembly (NSA) is also supported by ASP and assumed a more active role in the NCAR reorganization process. Joe Tribbia was appointed the NCAR Science Advisor and will work closely with the two sciantist assemblies in FY05.

Geophysical Turbulence Program (GTP) Highlights

In February 2004 the Geophysical Turbulence Program (GTP) held a three-day workshop on The Cumulus Parameterization Problem in the Context of Turbulence Studies. The 44 participants, representing 18 universities or institutions of the US, England, France and Germany, discussed cumulus convective dynamics as an example of turbulent fluid flow. This interdisciplinary workshop was coordinated by Jun-Ichi Yano (Meteo France), Joe Tribbia and Mitch Moncrief (CGD/MMM of NCAR), Leo Donner (NOAA, Geophysical Fluid Dynamics Laboratory), and Wojciech Grabowski (MMM, NCAR). GTP also sponsored a two-day symposium in honor of Douglas K. Lilly's contributions to Atmospheric Turbulence and Mesoscale Meteorology [link], a seminar series [link], and an active visitor program in addition to the fundamental research activities summarized in the GTP section [link] of this report.

Annick Pouquet, as Principal Investigator on a CMG grant through NSF hired postdoctoral fellow Pablo Mininni (University of Buenos Aires) and graduate fellow Jonathan Graham (University of Colorado) to work on modeling of MHD turbulence. A set of comparisons for 2D MHD has been made between the DNS code, which solves the primitive unmodified MHD equations, and the so-called alpha model developed by Holm and his collaborators. The comparisons are favorable for the evolution of the long-wavelength parts of the spectra.

Dynamo action in the regime of low ratio of kinematic viscosity to magnetic diffusivity, or low magnetic Prandtl number PM as in the molten part of the interior of the earth is being presently investigated. The critical magnetic Reynolds number for dynamo action has an abrupt eightfold increase for lower values of PM when compared to PM=1, and then reaches a plateau. The problem is linked to turbulence which renders the dynamo difficult to start by blurring so to speak magnetic field lines.

GTP members made substantial progress with the Geophysical and Astrophysical Spectral element Adaptive Refinement (GASPAR) code development. It is now about 62,000 lines, and is in beta-phase for its two-dimensional version. FY-2004

work focused on completing the testing of the adaptive refinement, implementing several new time-stepping schemes, and writing a memory manager for (dynamic allocation of) temporary space. Results from these efforts were presented at three scientific conferences in FY-2004. As a first step in validation of GASpAR for turbulent flows, a series of computations using standard accurate pseudo-spectral methods will be performed as a base data set against which to compare GASpAR results. It is anticipated that the 2-d code will enter production in calendar 2004 (early FY-2005).

In addition, a part-time graduate student, Wilfred Thompson, completed work on a server-client-based tool, GProbe, which provides a GASpAR user with on-the-fly diagnostics, enabling the user to monitor run performance. The monitor is written in Java with a MySQL database on the server enabling the client to perform playback and display. This student also modified the GBin I/O software within GASpAR to accommodate proper output synchronization on multiprocessors, when the number of finite elements on each processor may differ (even substantially).

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ASP Achievements

To illustrate the nature and scope of the research conducted by ASP personnel, we provide short descriptions of individual research projects in this section. The ASP seeks to maintain involvement in the full complement of NCAR research. Thus, almost all of the research projects that we highlight were conducted in collaboration with NCAR scientists in other divisions and programs, and in many cases more thematic descriptions of the research programs are available in the reports of those NCAR units. We link this Annual Scientific Report to those of related divisions, institutes, and programs as appropriate.

Postdoctoral Fellows

The Advanced Study Program supports postdoctoral fellows who work throughout NCAR. These fellowships permit scientists near the beginning of their careers to work with considerable independence, to collaborate with the NCAR scientific staff, to maintain links between NCAR and the university community (to which most of these fellows return), and to add energy and creativity to the NCAR research programs. The research of some of the postdoctoral fellows is described below.

Weather and Mesoscale Meteorology

Simulations of severe storms: George Bryan (ASP/MMM) used high-resolution numerical simulations to study convective systems that produce severe weather. Utilizing NCAR supercomputers, Bryan explicitly simulated turbulent processes within clouds, including the entraining eddies that dilute convective clouds. He found that environmental perturbations modulate convective system structure and evolution. For example, a standard idealized numerical simulation without perturbations was compared to one with small-amplitude random perturbations. The design of the latter simulation was guided by the fact that the atmosphere is constantly perturbed by variations in terrain, land use, and boundary layer turbulence. The results showed that the convective system in the simulation without perturbations was stronger: Cloud tops were 4 km higher, and total surface precipitation was 25% greater than in the simulation with perturbations. This result occurred because perturbations facilitate the generation of turbulent eddies, which enhance entrainment and dilute the cores of the large convective cells. Because the simulation with perturbations is probably more realistic, this result suggests that standard idealized simulations with smooth environments and coarse resolution produce convection that is anomalously strong.

Topics in mesoscale meteorology: Huaqing Cai (ATD) completed a detailed study of a dryline that was observed during the IHOP field program of 2002. This study demonstrated the important role of the dryline as an initiator of convection. Cai also applied tractal geometry to comparisons between tornadic and nontornadic mesocyclones, in order to characterize their differences and help understand which characteristics lead to tornadoes.

Land Surface-Hydrology Model Development and Testing: During 2004 David Gochis (ASP/RAP) contributed to the continuing development and testing of the hydrologically-enhanced version of the Noah land surface model (now called 'Noah-distributed'). Gochis and Fei Chen (RAP) conducted various tests to assess the scale-dependency of surface hydrological states and fluxes to model representation using data from the CASES-97 field campaign. Adaptations included adding both so-called full Noah model disaggregation schema and a routing disaggregation scheme to the standard Noah land surface model. Key results indicate that horizontal routing processes at progressively finer spatial resolution of terrain features produce marked heterogeneity in land surface conditions. Even in comparatively flat terrain,

such as that of CASES, the difference in hydrological states and fluxes between routing versus non-routing simulations can be appreciable and need to be accounted for in long-term climate simulation and data assimilation algorithms.

Data assimilation using mesonet observations: Joshua Hacker (ASP/MMM) found that surface-layer (screen-height) observations, such as exist in a typical mesonet, are under-utilized in current data assimilation (DA) algorithms because of weak coupling with the free atmosphere aloft. But, simulation and short-range forecasts of near-surface conditions could benefit from these data. The Ensemble Kalman Filter data assimilation algorithm, which uses anisotropic and flow-dependent covariance information to spread the influence of an observation, is appropriate for this task. Hacker in collaboration with Chris Snyder (MMM) used a column planetary boundary layer (PBL) model to successfully assimilate simulated observations. They also performed parameter estimation experiments to show that observations can be used to correct erroneous parameters in such a model.

Adaptive observations and data assimilation - In data assimilation, observations are combined with other sources of information about the present state of the atmosphere, such as a previous forecast, to create an analysis that provides the initial condition for a new forecast. Observations of the true state of the atmosphere are essential to obtaining a good forecast, but it is impossible to assimilate observations covering the entire atmosphere. Christine Johnson (ASP/CGD/MMM) sought to develop ways to determine which observations are most influential in the analysis and assimilation and are therefore most important to include. She addressed this question by considering how information from observations interacts with the model dynamics within advanced data assimilation schemes, such as four-dimensional variational data assimilation. She employed simple mid-latitude storm track models to compare various adaptive-observation strategies.

Applications of two-moment representations of microphysics in mesoscale models: Axel Seifert (ASP/MMM/RAP) tested the value of two-moment microphysical representations in several different settings, including precipitation formation in deep convective storms over Florida and in mesoscale convective systems. A systematic comparison of different bulk microphysical schemes, including the two-moment scheme, revealed that the effect on precipitation from mesoscale convective systems was relatively minor. However, he found that there was a substantial difference in anvil formation and on transport of ice to the upper troposphere when the two-moment scheme was used.

Climate Studies

The production of gravity waves by convection: Jadwiga Beres (ASP/ACD/CGD/HAO) implemented a new method of specifying the gravity wave spectrum above convection into the Whole Atmosphere Community Climate Model (WACCM). This parameterization is interactive with the underlying convection and introduces realistic spatial and temporal distributions of gravity wave activity while relating gravity wave characteristics to the underlying wave source. The new scheme improves the structure of the tropical stratospheric and mesospheric Semi-Annual Oscillations (SAO) in WACCM and gives insight to the wave motions that might be responsible for extra-tropical mesospheric forcing. The newly implemented scheme also provides a new direction for gravity wave parameterizations as the gravity wave forcing is no longer fixed and will follow changes in tropospheric climate. This allows for more accurate studies of effects of changing climate on the middle atmosphere and on examining the feedbacks between the troposphere and the middle atmosphere. (Cf. Beres et al, submitted, J. Geophys. Res, 2004)

Stochastic Parameterization: Judith Berner (ASP/CGD) explored the use of stochastic representations to parameterize unknown or unresolved processes in models. She explored obtaining such stochastic representations in two different ways: via finer-scale models that can characterize such processes explicitly, and via analysis of what unresolved processes are needed to obtain the correct moments for resolved processes. Both approaches provide an opportunity to represent, not only the mean, but also the variance in parameterizations, and so to characterize an important aspect of model error.

Storm tracks and northern anticyclones in the CCSM: Richard Cullather (ASP/CGD) in collaboration with James Hurrell (CGD) compared some features of weather as produced in the CCSM to observations. They showed that anticyclones in the model are weaker and of shorter duration in the model than in observations, and the North Atlantic storm track is more zonal in the simulations than in observations. In the course of this work, they also developed a feature-tracking algorithm to help automate the analysis and make it more objective.

Multifractal characterization of tropical convective systems: Wen-wen Tung (ASP/CGD) determined multifractal dimensions for complex convective systems in the tropics, for time scales ranging from diurnal to synoptic-scale. Tung used a multiplicative cascade model to reproduce the dimensions. The techniques and results can be used to judge how skillfully a model represents tropical convection, particularly in regard to extreme events.

Geophysical Turbulence

Steps toward a model of the dynamo effect: Pablo Mininni (ASP/GTP) investigated the origin of magnetic fields in

planets and stars which is usually attributed to the dynamo effect, a magnetohydrodynamic (MHD) instability governed by two parameters: the magnetic Reynolds number R M (ratio of induction to Ohmic dissipation) and the magnetic Prandtl number P M (ratio of fluid viscosity to magnetic diffusivity). Little is known for fluids with small P M, although they are common in nature. The ability to probe small P M, and to examine in detail the large-scale behavior of turbulent flows depends critically on the ability to resolve a large number of spatial and temporal scales, or else to model them adequately. Theory demands that computations of turbulent flows reflect a clear scale separation between the energy-containing, inertial and dissipative ranges. To this end, and to reach a better understanding of MHD turbulence and dynamo action, a combination of direct numerical simulations (DNS), the new Lagrangian-averaged model for MHD (or LAMHD, in collaboration with Annick Pouquet (CGD), David C. Montgomery (Dartmouth University) and D. Holm(Los Alamos National Laboratory)), and LES (in collaboration with Jean-François Pinton (Ecole Normale Supérieure de Lyon), Yannick Ponty (Observatoire de la Cote d'Azur), and Helene Politano (Observatoire de la Cote d'Azur)) is being adapted to this problem. After validating the models, this combination will be suited to the study of the low magnetic Prandtl number regime at high resolution, as is needed to model the geo-dynamo.

Lagrangian velocity correlations and tropospheric dispersion: Jai Sukhatme (ASP/GTP) estimated the Lagrangian velocity correlation functions (LVCF) associated with mid-latitude tropospheric flow from daily wind data. A decomposition of the velocity field into time mean and transient (or eddy) components helped to illustrate the nature of the LVCF's. Meridional and zonal characteristics were considered separately. The zonal LVCF was found to be non-exponential and, for a broad set of intermediate timescales, better described as a power law. The implied long-time correlation in the zonal flow results in a super-diffusive zonal absolute diffusion regime. On the other hand, the meridional LVCF decays rapidly to zero. Interestingly, before approaching to zero it shows a region of negative correlation. A physical argument based on the rotational inhibition of latitudinal excursions, mediated through the time mean flow, can account for this anticorrelation. As a result the meridional absolute diffusion, apart from showing the classical asymptotic ballistic and diffusive regimes, displays transient sub-diffusive behavior.

Studies of Solar and Upper-Atmosphere Physics

Ion-induced production of new particles by Galactic Cosmic Rays: Jan Kazil (ASP/HAO) and Edward Lovejoy (NOAA) used new laboratory measurements of particle nucleation by sulfuric acid and ion production rates from Galactic Cosmic Rays to predict the rate of new particle formation in the troposphere and stratosphere and the dependence of that rate on the solar cycle (Kazil and Lovejoy, 2004).

Causes of high spectral width in ionospheric Doppler-radar measurements: The SuperDARN (Super Dual Auroral Radar Network) array consists of coherent high-frequency radars that can measure the spectral width of the Doppler shift produced in the ionosphere. Large spectral widths, greater than 200 m/s, are sometimes observed, and the transition from low to high values has been interpreted as an indicator of the boundary between open and closed magnetic field lines. Using intercomparisons among radars, Emma Kavanagh (ASP/HAO) showed that the spectral width depends on the pointing angle of the radar, and this called into question its use as a proxy for magnetic-field-line boundaries. Her study considered possible causes of this directional dependence and suggested that it may arise from directional variability in the electric field in these regions.

Instabilities of downflow plumes in the solar atmosphere: In collaboration with Mark Rast (HAO) Matthias Rempel (ASP/HAO) used the FLASH code (from the University of Chicago) to study the stability of downflow plumes in a strongly stratified atmosphere. He found that the instabilities in plumes simulated in the adaptive-grid FLASH code evolve in ways that are fundamentally different from instabilities in corresponding simulations that use the fixed-grid finite-difference code of Rast. The difference arises from different ways in which viscosity is represented in the two simulations.

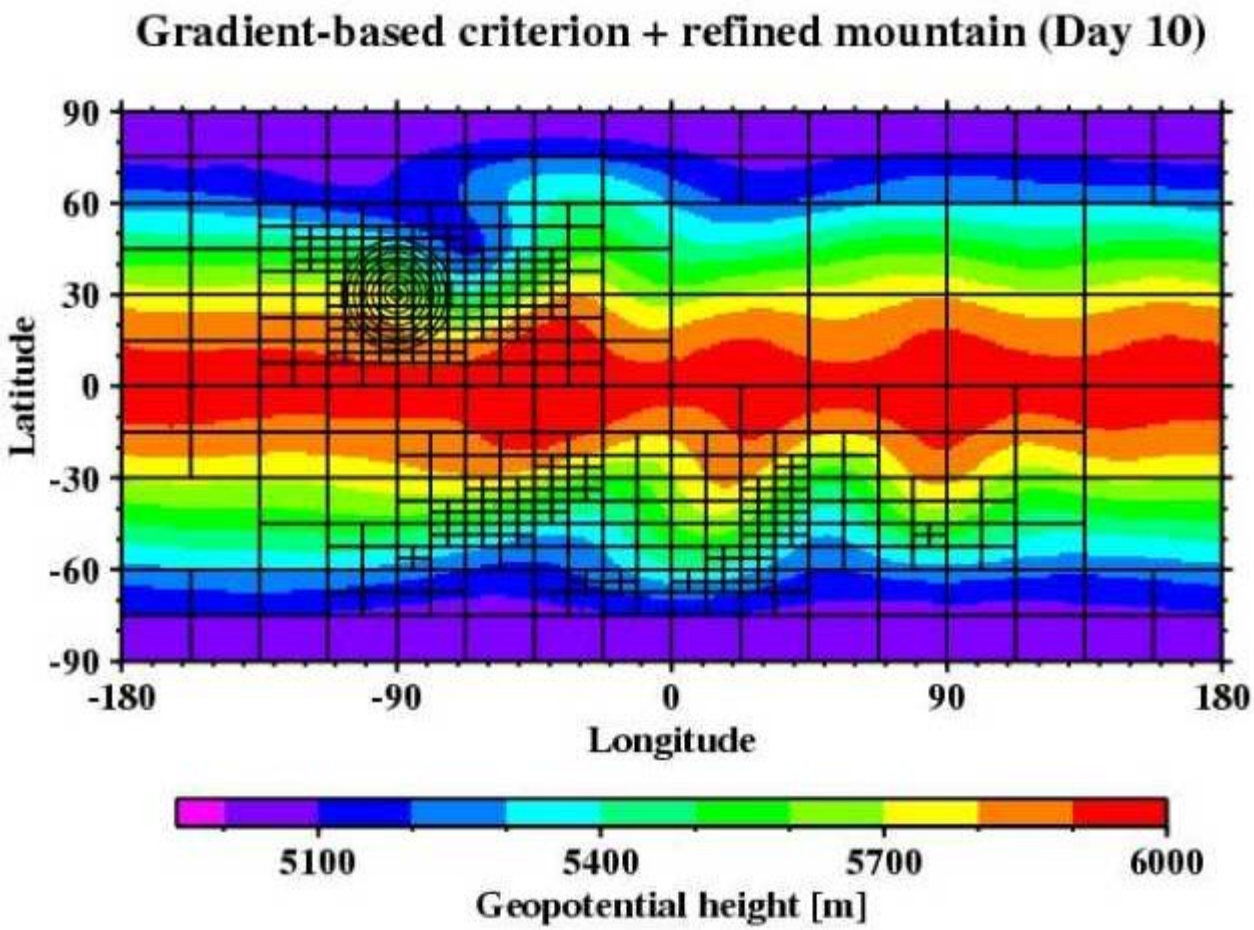
Atmospheric Chemistry

Water-soluble organic nitrogen in atmospheric aerosols: Kimberly Mace (ASP/ACD) monitored aerosols near a Colorado dairy by collecting size-resolved samples and analyzing them for water-soluble organic nitrogen compounds. She also set up an aerosol sampler in Puerto Rico for similar sampling, and she investigated lab techniques for detecting these compounds using gas chromatography with mass spectroscopy.

Numerical and Computational Techniques

Adaptive mesh refinement (AMR) techniques for modeling -- Christiane Jablonowski (ASP/SCD) developed an adaptive dynamical core for general circulation models (GCMs) that can statically and dynamically adapt its horizontal resolution based on user-defined refinement criteria. The block-structured AMR technique has been applied to a revised version of NCAR/NASA's Lin-Rood dynamical core. This hydrostatic dynamics package is based on a conservative finite volume discretization which can be run as a 2D shallow water model or 3D dynamical core. The figure below shows an example of a dynamically adapted shallow water experiment. It displays the flow over an idealized mountain at model day 10. The

adapted blocks were guided by a gradient-based refinement criterion (see also http://www.scd.ucar.edu/css/staff/cjablono/amr.html). The research is done in collaboration with Michael Herzog, Joyce Penner, Robert Oehmke, Quentin Stout, Bram van Leer (all of the University of Michigan).



2D flow over an isolated mountain with the dynamically adaptive finite volume dynamical core. The plot shows the geopotential height field at model day 10. The adapted blocks are guided by a gradient-based threshold. The adapted blocks are overlaid.

Education and Communication of Science

Improving scientific visualizations and educational material in digital libraries: Kirsten Butcher (ASP/SCD and DLESE/NSDL) studied the cognitive processes involved in learning with multimedia materials. This research has been targeted toward understanding learning with digital library materials, scientific diagrams and visualizations in addition to text. Through interactions with those designing digital libraries, she has helped guide such design in directions that will improve student learning with digital resources. She has also been studying how memory constraints, inference generation, and the interaction of visualization characteristics with learners' background knowledge affect learning through scientific visualizations and how such visualizations can be improved to communicate their messages more effectively.

Societal Implications

Topics addressing societal responses to stresses: Shui Bin (ESIG) studied several aspects of the ways in which societies respond to stresses, including those caused by emissions to the atmosphere:

- *Global Carbon Cycle and Trade.* The current system for accounting for carbon dioxide emissions is based on a within-border-measurement (WBM) rationale, and so does not represent the full global impact of a country's consumption-driven CO2 emissions. Shui Bin and Robert Harriss (ESIG) used a case study of carbon emissions as embodied in the trade of North American Free Trade Agreement (NAFTA) to suggest that a proposed within-border-consumption (WBC) accounting framework would provide a better estimate of a country's real contribution to global carbon emissions because such a measure would measure the global effect of domestic

consumption.

- *The Role of Embodied Carbon in Sino-US Trade.* The economic and political aspects of Sino-US trade have been discussed intensively, but the associated environmental impacts (including carbon dioxide emissions embodied in the Sino-US trade flows) have drawn little attention. Shui Bin and Harriss used 1997-2003 data and two analyses of scenarios to discuss the significant ways in which carbon emissions are associated with Sino-US trade.
- *Consumer responses to environmental impacts.* In collaboration with Hadi Dowlatabadi and others in ESIG, Shui has pursued several studies of the ways in which human consumption responds to environmental impacts. More than 60% of US energy use and CO2 emissions are a consequence of consumers' direct and indirect consumption activities, so an objective of this work is to help direct attention to the important role of the consumer in assessment of environmental impacts. Her work in this area has stressed that impact is not always represented well by income (as is sometimes assumed), that consumer choices on such matters as energy sources for water heaters can reduce energy consumption significantly (often with economic benefits to consumers), and that a consumer emissions inventory is a valuable tool when reduction strategies are considered.

Re-creation of Mann, Bradley, Hughes (MBH, 1998 & 1999) Reconstructions of N. Hemisphere Climate over the Last Millennium: In collaboration with Caspar Ammann (CGD), Doug Nychka (GSP) and Claudia Tebaldi (GSP), Eugene Wahl (ASP/ESIG) led an effort to replicate the MBH98 (1400-1980) reconstruction of the northern hemisphere annual average temperature. The 1400-1980 reconstruction has been replicated nearly exactly, showing it is highly robust to a number of simplifications purposefully developed in relation the original algorithm. This substantial replication is the first of its kind, which is important in that the MBH99 reconstruction for the entire period 1000-1980 has been featured prominently in the 3rd IPCC Report and elsewhere as key evidence concerning anomalous hemispheric warming in the 20th century.

Ethics of Generation and Use of Climate and Short-term Weather Forecasts – Eugene Wahl also worked with Rebecca Morss of (ESIG and MMM) to analyze assumptions, methods, limitations, and uses of weather and climate forecasts from an ethical perspective. Criteria and methods were drawn from modern applied ethics (in particular, the "Georgetown School" of analytical criteria and the method of iterative "reflective specification" developed by John Rawls), which have been developed into a framework specifically oriented to quandaries that arise in the preparation and provision of forecasts. A specific case was examined, the great flood of the Red River of the North in 1997, in which decisions made by forecasters had particularly important ethical dimensions.

Graduate Fellows

Matt Dunn 's PhD research project is the chemical characterization of newly formed atmospheric particles, which he is pursuing via thermal desorption chemical ionization mass spectrometry. An early result of this work has been the measurement of nanoparticle size distributions in Mexico City and the observation of new particle formation and particle growth in an urban setting. (Cf. Dunn et al, 2004.)

Katja Dzepina used measurements from the Mexico City Metropolitan Area 2003 (MCMA-2003) field campaign, which took place from March 29 to May 4 2003, so show that non-refractive aerosols larger than about 1 µm were about 2/3 organic carbon (both primary and secondary) and about 1/3 inorganic species (mainly nitrate, sulfate, and ammonium, with a smaller contribution by chloride). Organic aerosols dominated this aerosol concentration in Mexico City during this time period.

GTP graduate student Jonathan Graham is investigating turbulence in magnetohydrodynamic (MHD) fluids. He is currently investigating the so-called alpha model's capability to reproduce intermittency in the absence of direct-fully-resolved calculations. Intermittency can be temporal like the intermittency of solar flares or like an intermittent problem with your car that is never there when the mechanic looks at it. More rigorously, it is an enhancement of the likely-hood of rare events either temporally or spatially (as is the case for 2-dinensional MHD). This intermittency is a fundamental element of turbulence for which there is no theory, only empirical relations. It is therefore anticipated that this work will contribute an essential part in the attempt to develop a theory of turbulence.

Graduate research fellow Sara Lance (ASP/ACD) is investigating the effect of organic-containing aerosol on aerosol hygroscopicity and cloud droplet growth, both of which have important implications for climate change. Lance will be using a humidified tandem differential mobility analyzer to measure the hygroscopic growth of aerosols generated and sampled in an NCAR lab. A new continuous flow streamwise thermal gradient cloud condensation nuclei (CCN) counter will be used to observe the CCN activity of these aerosols. A thermal desorption chemical ionization mass spectrometer and possibly an aerosol mass spectrometer will also be used to concurrently measure the particle chemical composition. It is anticipated that these instruments will be deployed for the Megacities Impact on Regional And Global Environments (MIRAGE) campaign in Mexico City in 2006.

Justin Peter 's PhD research project, which he completed in FY2004 under the guidance of Steven Siems (Monash University) and Jorgen Jensen (ATD), examined the effects of clouds on the aerosol size distribution using measurements collected during the ACE-Asia field experiment. Two case studies were used to illustrate the effects, a cumulus cloud and an extratropical cyclone. For the cumulus study, mixing diagrams of conserved variables, wet equivalent potential temperature and total water mixing ratio, were used to identify the fraction of cloud base air that had combined with environmental air entrained into the cloud. By using aerosol size distributions measured below and around the cumulus cloud, Peter extended this classical approach to deduce the origins of detrained air. His approach was to predict the shape of the aerosol size distribution for different sources and then compare to observations to determine likely true sources. The measurements showed evidence of size-dependent scavenging of the aerosol, with up to 20% decrease in the concentration of ultra-fine and fine-mode particles and up to 40% decrease in the accumulation mode. The cloud not only caused a general reduction in aerosol concentration, but also substantially modified the aerosol size distribution in the lower free troposphere. This effect may significantly influence the properties of clouds subsequently formed on the detrained aerosol. In addition, it was observed that the concentration of ultra-fine particles in the detrained air was greater than that predicted by a simple model of in-cloud scavenging, as would be the case if ultra-fine particles are produced in cloud.

Senior Research Associates

Sources of mercury in the atmosphere: In the past year Hans Friedli (ASP) and Lawrence Radke (CGD) completed a study of mercury sources and transport from Southeast Asia that was conducted as part of the ACE-Asia field project. This and a related study demonstrate that Southeast Asia is the major contributor to anthropogenic mercury pollution. Other studies by Friedli and collaborators of mercury reservoirs in boreal forests have shown that 90+% of the mercury pools are located on the organic soil and so is likely to be fully or partly released during major wildfires. The pools are very large and parallel the carbon storage in the boreal areas .

Possible mitigation of global warming by modification of cloud albedo : John Latham (ASP) continued exploration of a novel idea for the amelioration of global warming by the advertent and controlled enhancement of the albedo A and longevity L of low-Level maritime clouds. Detailed calculations coupled with computer modeling with the UK Meteorological Office GCM support the quantitative validity of the proposed technique, which involves increasing the droplet concentration in such clouds, with a corresponding increase in both A and L and thus cooling. The idea involves the dissemination at the ocean surface of small seawater droplets in sufficient quantities to act as the dominant CCN on which cloud droplets form. Satellite control of the overall dissemination rate is envisaged. Latham's collaborators include Keith Bower and Tom Choularton (both of UMIST, Manchester, UK), Alan Blyth, Alan Gadian and Mike Smith (all of University of Leeds, UK), Stephen Salter, (University of Edinburgh, UK) and Andy Jones (Hadley Climate Centre, Meteorological Office, UK). If this technique were to prove workable on the scales required, it could be of great societal importance.

Deducing ice content in thunderstorms from satellite observations of lightning. Latham and collaborators, including Hugh Christian, Walt Petersen and Wiebke Deierling (all of NASA/MSFC), Alan Gadian and Alan Blyth, (both of University of Leeds, UK), Rumjana Mitzeva (University of Sofia, Bulgaria), Scott Ellis (ATD) and Jim Dye (MMM), are continuing their examination of the extent to which it is possible to determine thundercloud ice characteristics from satellite observations of lightning, which are now routinely made on a global scale, using NASA/MSFC devices. A specific goal is to ascertain whether measurements of lightning frequency f can yield estimates of precipitating and non-precipitating ice fluxes. Their computations, and particularly recent data analysis, support their hypothesis that f is roughly proportional to the product of the downward flux fg of graupel through the body of the thundercloud and the upward flux fi of ice crystals into its anvil. This raises the possibility of determining, on a global basis, values of fg and/or fi from the lightning measurements. Such information could have considerable climatological and nowcasting importance, particularly with respect to flooding.

Jerry Mahlman (ASP) provided expert testimony on global warming and served on several review panels and advisory panels during the year. In his role as science advisor for the National Geographic issue on global warming, he contributed advice and helped guide this story toward an accurate and clear representation of the science issues involved.

Geophysical Turbulence Program

The Geophysical Turbulence Program (GTP) hosted two workshops this year in addition to the regular seminar series and an active visitor program. These workshops are described in the Executive Summary.

Annick Pouquet (GTP) and postdoctoral fellow Pablo Mininni (ASP/GTP/University of Buenos Aires) and graduate fellow Jonathan Graham (GTP/University of Colorado) initiated a project to model MHD turbulence (link). A set of comparisons for 2D MHD has been made between the DNS code, which solves the primitive unmodified MHD equations, and the so-

called alpha model developed by Holm and his collaborators. The comparisons are favorable for the evolution of the long-wavelength parts of the spectra.

Dynamo action in the regime of low ratio of kinematic viscosity to magnetic diffusivity, or low magnetic Prandtl number PM as in the molten part of the interior of the earth is being presently investigated. The critical magnetic Reynolds number for dynamo action has an abrupt eightfold increase for lower values of PM when compared to PM=1, and then reaches a plateau. The problem is linked to turbulence which renders the dynamo difficult to start by blurring so to speak magnetic field lines.

In addition, a part-time graduate student Wilfred Thompson completed work on a server-client-based tool, GProbe, which provides a GASpAR user with on-the-fly diagnostics, enabling the user to monitor run performance. The monitor is written in Java with a MySQL database on the server enabling the client to perform playback and display. This student also modified the GBin I/O software within GASpAR to accommodate proper output synchronization on multiprocessors, when the number of finite elements on each processor may differ (even substantially).

The Turbulence Numerics Team within GTP, under the leadership of Annick Pouquet and Duane Rosenberg (GTP), has continued a multi-year project to develop an object-oriented Geophysical and Astrophysical Spectral element Adaptive Refinement (GASpAR) code for application to turbulent flows. Like most spectral-element codes, GASpAR combines the efficiency of finite-element methods with the accuracy of spectral methods, and it is designed to be flexible enough for a range of geophysics and astrophysics applications where turbulence or other complex multiscale problems arise. The computational core is based on spectral element operators, which are represented as objects. The formalism accommodates both conforming and nonconforming elements, and their associated data structures for handling inter-element communications in a parallel environment. Many aspects of this code are a synthesis of existing methods; however, GTP has focused on a new formulation of dynamic adaptive mesh (nonconforming h-type) refinement. This year has seen the addition of the adaptive algorithms and the associated connectivity algorithms and demonstrations of the effectiveness of the code on a number of test problems. It is anticipated that the 2-d code will enter production in calendar 2004 (early FY-2005).

Consequences of the “alpha model,” also called the “Lagrangian-averaged” model, for two-dimensional incompressible magnetohydrodynamic (MHD) turbulence were explored by Annick Pouquet. This model is an extension of the smoothing procedure in fluid dynamics which filters velocity fields locally while leaving their associated vorticities unsmoothed, and has proved useful for high Reynolds number turbulence computations. Several known effects (selective decay, dynamic alignment, inverse cascades, and the probability distribution functions of fluctuating turbulent quantities) in magnetofluid turbulence have been considered. Numerical solutions of the primitive MHD equations were compared to their alpha-model counterparts' performance for the same flows in regimes where available resolution is adequate to explore both. The hope is to justify the use of the alpha model in regimes that lie outside currently available resolution, as will be the case in particular in three-dimensional geometry or for magnetic Prandtl numbers differing significantly from unity. The investigation, using direct numerical simulations with a standard and fully parallelized pseudo-spectral method and periodic boundary conditions in two space dimensions, focused on the role that such a modeling of the small scales using the Lagrangian-averaged framework plays in the large-scale dynamics of MHD turbulence. Several flows were examined, and for all of them one can conclude that the statistical properties of the large-scale spectra were recovered, whereas small-scale detailed phase information (such as the location of structures) is lost.

A heuristic derivation of the power--law spectra that obtain in anisotropic magnetohydrodynamics (MHD) flows was given by Pouquet; it is applicable for both weak and strong turbulence. To that effect, the concept of critical balance introduced in Goldreich and Sridhar (1995) was generalized; it uses the existence for the energy spectrum of a relationship between the perpendicular and parallel wavenumber scaling exponents, the directions referring to that of an imposed uniform magnetic field. As a result of this analysis, it is possible to recover with the same phenomenological approach the three standard energy spectra for fluid and MHD turbulence, namely the Kolmogorov (1941), the Iroshnikov (1963) – Kraichnan (1965) and the weak Alfven wave turbulence constant-flux solutions derived in Galtier et al. (2000). Furthermore, in the latter case of weak MHD turbulence, the first heuristic derivation of the power-law spectrum for the precursor to the Kolmogorov constant-flux solution which was discovered numerically in Galtier et al. (2000) was given. Finally, similar relationships for other types of wave motions, such as whistler or inertial waves, were also outlined (paper submitted to Phys. Rev. Lett.).

The origin of magnetic fields in planets and stars is usually attributed to the dynamo effect, a magnetohydrodynamic instability governed by two parameters: the magnetic Reynolds number Rm (ratio of induction to Ohmic dissipation) and the magnetic Prandtl number Pm (ratio of fluid viscosity to magnetic diffusivity). Little is known for fluids with small Pm, although they are common in nature, the difficulty stemming from the turbulence associated with regimes where self-generation may develop. Here, Pouquet and collaborators consider numerically a flow that generates a dynamo at Pm=1. We measure the evolution of the dynamo threshold for fluids down to Pm=0.01, using a combination of numerical

and modeling schemes. They found that the development of turbulence induces a tenfold increase in the critical magnetic Reynolds number, and that Rmc remains roughly constant as Pm is further lowered. Thresholds predicted by kinematic simulations using time-averaged velocities yield correct estimates of Rmc.

Aimé Fournier (GTP) has developed new multi-resolution aspects of the spectral-element method, including error estimators and triadic interactions. The latter expresses the fundamental nonlinearity of fluid dynamics that accounts for possibly intermittent turbulent energy and enstrophy cascades across scales.

Jai Sukhatme's (ASP/GTP) research has been in the broad field of transport and mixing. On one hand his work has been devoted to abstract issues such as studying the asymptotic self-similar state of the advection diffusion equation in periodic domains. Whereas, another set of problems which are currently under investigation deal with transport and mixing in realistic tropospheric flows. The aim is to quantify tropospheric transport and to make contact with the available literature on transport in ideal turbulent fields. Details of some of these projects can be found at his webpage http://www.asp.ucar.edu/~jai

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Education and Outreach Activities

Seminar Series

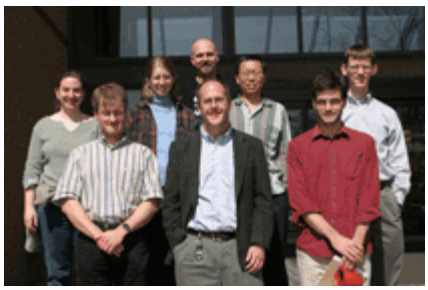
The ASP continued its series of seminar presentations. They are intended to promote greater understanding of the range of scientific activities underway at NCAR and the scientific community and to provide postdocs with an opportunity to schedule and arrange logistics for visiting scientists. During FY-04 ASP hosted eight seminars from NCAR scientists and one from Colorado State University.

The Geophysical Turbulence Program also had a full seminar series. Seminar lecturers are invited to stay around NCAR for a day or two to collaborate with NCAR turbulence researchers after their seminar. During FY-04 GTP hosted three seminars by NCAR scientists and 16 from outside institutions.

Thompson Lectures

In 1998 ASP established the "Thompson Lecture Series," named in honor of Phil Thompson who founded the Advanced Study Program and was NCAR's first associate director. Under this program, prominent scientists are brought to NCAR for short visits that promote interaction between them and the postdoctoral fellows and other junior scientists at NCAR. In addition to presenting formal lectures, the Thompson Lecturers listen to briefings on the research being conducted by ASP Fellows and comment and provide advice on those research projects. They also meet with groups of scientists to discuss some more general topics, provide career advice, and offer their perspectives on scientific trends and priorities. In FY-04, three Thompson Lecturers were brought to NCAR: Daniel Jacob (Harvard University), Dana Longcope (Montana State University) and David Battisti (University of Washington).

Daniel Jacob and Postdocs



Dana Longcope and Postdocs

David Battisti and Postdocs

Other Educational Activities

A few ASP Postdoctoral Fellows served as SOARS mentors during the summer months. SOARS is hosted through the Human Resources department of UCAR.

Postdoctoral fellows contributed expertise to many committees and seminar presentations at NCAR. Carrie Morrill presented a seminar at the NCAR Teacher's Workshop and Joshua Hacker participated in a University of Colorado

CIRES outreach program for curriculum development and teacher training in atmospheric sciences/meteorology in the St. Vrain Valley school district. Morrill was also a committee member of the UCAR DLESE Climate Change Collection for K-16 teachers and a contributor to the NOAA website on Abrupt Climate Change.

Postdoctoral fellows Christine Johnson and Jadwiga Beres organized a Girl Scouts' Day at NCAR in October with the assistance of Teresa Eastburn (UCAR Education and Outreach) and Linda Fuller (Mile High Girls Scouts Council). The 40 junior girl scouts visited NCAR for a day and met with female scientists to learn more about weather and climate while fulfilling the requirements for the science discovery badge. This activity was well received and documented as a template for future visits.

The Early Career Scientists Assembly (ECSA), through support of ASP, sponsored scientific travel for several NCAR early career scientists. During FY-04 the ECSA hosted a visit from Wallace Broecker (Lamont Doherty Earth Observatory of Columbia University) for the annual Scientific Leaders discussion and seminar presentations. Continued this year was the second annual Junior Faculty Forum for Future Scientific Directions in June 2004. The three-day forum consisted of 40 participants from 19 universities and institutions of the U.S., Switzerland, Canada and the United Kingdom and discussed the sun-climate connection and the role of coastal zones in global biogeochemistry.

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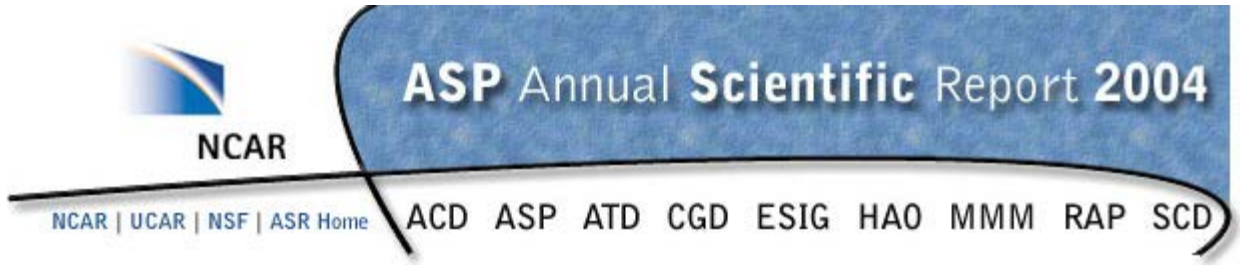

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Community Service

Annick Pouquet (GTP) served as editor for Journal of Computational Physics during the past fiscal year. She also served on the NSF review committee for one-year DOE multi-scale committee three times. Other ASP members served as reviewers for journals including Huaqing Cai who reviewed an article for Monthly Weather Review as did George Bryan who served as associate editor for Monthly Weather Review. Aimé Fournier refereed a manuscript for Monthly Weather Review, Nonlinear Processes in Geophysics and Physics Review Letters and refereed three manuscripts for Journal of Computational Physics. Duane Rosenberg peer reviewed scientific papers for Journal of Scientific Computing. David Gochis reviewed a journal article for Geophysical Research Letters and proposals for NSF and the NOAA Office of Global Programs.

Postdoctoral Fellows also served on advisory and ad hoc committees.
Kirsten Butcher served on the SCD Strategic Review Committee and was a SOARS mentor for protégé Braxton Edwards in the areas of writing and communications. David Gochis also served on the following committees: North American Monsoon Experiment Science working Group (NAME-SWG), NAME-International Project Support TEAM (NAME-INPST), NAME-Hydrometeorological Working Group (NAME-NHWG), the development of a Ten Year Vision Strategy for the National Science foundation Sponsored Consortium for the Advancement of Hydrological Sciences, Inc. (CUAHSI), and as co-chair for the planning committee on World Weather Research Programme (WWRP) 2 nd Conference on Quantitative Precipitation Forecasting.

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Awards

Three postdoctoral fellows received special honors and awards during FY-04.

Christiane Jablonowski received the Distinguished Achievement Award from the University of Michigan, College of Engineering, for her academic and personal excellence.

Christine Johnson was appointed as an Associate Fellow of the Royal Astronomical Society in the United Kingdom (UK).

Riwal Plougonven was awarded two travel grants: AGU's to attend the Chapman Conference on Gravity Wave Processes and their Parameterizations and the Young Scientist Travel Award for the E.G.U. General Assembly, April 2004.

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Staff, Visitors & Collaborators

Staff

William A. Cooper (on leave to NSF 1 October 2003 to 30 September 2004)
Thomas Bogdan (7 October 2003 to 5 July 2004)
Maura Hagan (from 18 July 2004)
Scott Briggs
Garth D'Attilo (25%)
Aime Fournier (GTP)
Barbara Hansford
Judy Miller (to 31 October 2003)
Barbara Petruzzi (from 18 November 2003)
Annick Pouquet (GTP)
Duane Rosenberg (GTP)
Wilfred Thompson (GTP)

Senior Research Associates

Guy Brasseur (ACD)
Hans Friedli (ACD)
John Latham (MMM)
Jerry Mahlman (DIR/ESIG)
Lawrence Radke (ACD)

NCAR Graduate Fellows

Matthew Dunn (ACD); *University of Colorado;* measurements of chemical composition of ultra-fine aerosols.
Katja Dzepina (ACD); *University of Colorado;* aerosol size and composition measurements and data analysis; aerosol modeling.
Jonathan Graham (GTP/CMG Grant); *University of Colorado;* turbulence in magnetohydrodynamics.
Sara Lance (ACD); *Georgia Institute of Technology;* organic containing aerosols effect in climate.
Justin Peter (ATD); *Monash University, Australia;* observations of thermodynamics, dynamics, aerosols and clouds from ACE-Asia 2001.

Postdoctoral Fellows

Caspar Ammann (CGD); *University of Massachusetts*; paleoclimatology; climate reconstruction; climate modeling; external forcing; climate change.
Jadwiga Beres (ACD/CGD/HAO); *University of Washington;* gravity waves, educational outreach.
Judith Berner (CGD); *University of Bonn;* Stochastic parameterization of subgrid-scale processes.
George Bryan (MMM); *Pennsylvania State University;* Storm and cloud dynamics.
Kirsten Butcher (DLESE); *University of Colorado;* scientific visualization/multimedia learning.
Huaqing Cai (ATD); *University of California, Los Angeles;* convection initiation.

Richard Cullather (CGD); *University of Colorado;* climate variability.
David Gochis (RAP); *University of Arizona*; Topographic circulations; hydrometeorological modeling; regional climate dynamics: water law.
Joshua Hacker (MMM/CGD); *University of British Columbia*; Mesoscale predictability and regional modeling.
Christiane Jablonowski; *University of Michigan, Ann Arbor;* adaptive mesh refinement for weather and climate models, test cases for dynamical cores of GCMs, QBO simulations and numerical methods for GCMs.
Jan Kazil (HAO); *University of Bern;* atmospheric ions and ion-induced nucleation.
Benjamin Johnson (CGD); *University of Reading, U.K.;* cloud parameterizations in climate models.
Christine Johnson (CGD); *University of Reading, U.K.;* data assimilation and adaptive observations.
Kimberly Mace (ACD); *Texas A & M University*; atmospheric organic nitrogen in aerosols & rainwater; nitrogen flux; anthropogenic influence on the global nitrogen cycle; relationships of biochemical nitrogen cycling & climate.
Katharine Moore (ACD); *Colorado State University*; laboratory and field investigations of heterogeneous and multi-phase atmospheric chemistry (particularly cloud and nanoparticle composition).
Carrie Morrill (CGD); *University of Arizona*; Holocene climate variability, paleoclimate modeling.
Rafael Manso-Sainz (HAO); *University of La Laguna, Spain;* solar magnetism.
Pablo Mininni (GTP/CMG Grant); *University of Buenos Aires, Argentina*; MHD turbulence and dynamo theory.
Sreela Nandi (ACD); *University of Colorado*; modeling of air quality, wildfire studies and atmospheric chemistry; public policy.
Sungsu Park (CGD); *University of Washington;* Marine Boundary Layer clouds.
Gabrielle Petron (ACD); *University Paris 6, France;* inverse modeling and data assimilation in the context of tropospheric chemistry.
Riwal Plougonven (MMM); *University of Pierre and Marie Curie, Paris, France;* wave-vortex interactions.
Mark Potosnak (ACD); *Columbia University*; biogenic hydrocarbon emissions and the atmosphere.
Matthias Rempel (HAO); *Max Planck Institute for Aeronomy*; convective overshoot and stability of toroidal magnetic field at the base of the solar convection zone.
Axel Seifert (MMM); *University of Karlsruhe;* cloud modeling and cloud microphysics.
Hatim Sharif (RAP); *University of Connecticut*; precipitation observation and estimation, runoff modeling, land surface modeling.
Shui Bin (ESIG); *Carnegie Mellon University;* consumer environmental impact assessment
Craig Stroud (ACD); *University of Colorado*; tropospheric photochemistry: understanding the formation of ozone and organic aerosol.
Jai Sukhatme (GTP); *University of Chicago;* passive scalar mixing.
Wen-Wen Tung (MMM); *UCLA*; cloud systems and clouds in climate diagnosis.
Eugene Wahl (ESIG); *University of Minnesota*; climate data/model comparisons; reconstruction of past environmental change; environmental ethics.
Emma Woodfield (HAO); *Leicester University, UK,* the solar-terrestrial interaction; magnetosphere-ionosphere coupling.

ASP Visitors and Collaborators

David Battisti, *University of Washington*
Wallace Broecker, *Columbia University*
Daniel Jacob, *Harvard University*
Dana Longcope, *Montana State University*
Edward Lu, *NASA*

GTP Visitors and Collaborators

Rafail Abramov, *New York University*
B. J. Balakumar, *University of Illinois, Urbana-Champaign*
Steve Belcher, *University of Reading, UK*
Marie Farge, *CNRS Ecole Normale Superieure, Paris*
Toshiyuki Gotoh, *Nagoya Institute of Technology, Japan*
David Gurarie, *Case Western Reserve University*
Darryl Holm, *Los Alamos National Laboratory*
Dana Knoll, *Los Alamos National Laboratory*
Alessandra Lanotte, *National Research Council, Italy*
Szymon Malinowski, *University of Warsaw, Poland*
William Matthaeus, *University of Delaware*
W. Kendall Melville, *University of California, San Diego*
Kamran Mohseni, *University of Colorado, Boulder*
David Montgomery, *Dartmouth University*

Alain Noullez, *Observatoire de la Côte d'Azur, Nice*
Jean-Francois Pinton *, Ecole Normale Superieure de Lyon of CNRS*
Helene Politano, *Observatoire de la Côte d'Azur, Nice*
Yannick Ponty, *Observatoire de la Côte d'Azur, Nice*
Robert Kerr, *University of Warwick, UK*
Kai Schneider *, University of Provence, Marseille*
Wilfred Thompson, *University of Colorado*
Yue-Kin Tsang, *University of Maryland*
Oleg Vasilyev *, University of Colorado, Boulder*
Vladimir Zakharov, *University of Arizona*

ASP Summer Colloquia (2)

Atmospheric Remote Sensing Using the Global Positioning System

Coordinators:
Ying-Hwa Kuo; *NCAR/UCAR*
Chris Rocken; *UCAR*
Sergey Sokolovskiy; *U OP/COSMIC*
Robert Kursinski; *University of Arizona*
George Hajj; *Jet Propulsion Laboratory, NASA*

Lecturers:
Yuichi Aoyama, *Kyoto University, Japan*
John Braun, *UOP/COSMIC*
Lidia Cucurull, *NCEP/UCAR*
John Dykema, *Harvard University*
Keith Groves, *Hanscom Air Force Base*
George Hajj, *Jet Propulsion Lab, NASA*
Sean Healey, *ECMWF*
Manuel Hernandez-Pajares, *Technical University of Catalonia, Spain*
Ching-Yuang Huang, *North Central University, Taiwan*
Doug Hunt, *UOP/COSMIC*
Ted Iwabutchi, *UOP/COSMIC*
Rob Kursinski, *University of Arizona*
Bill Kuo, *UOP/COSMIC*
Stephen Leroy, *Harvard University*
Martin Lohmann, *COSMIC/NESDIS*
Tony Mannucci, *Jet Propulsion Lab, NASA*
William Randel, *ACD*
Christian Rocken, *UOP/COSMIC*
M. Rothacher, *University of Munich, Germany*
William Schreiner, *UOP/COSMIC*
Chris Snyder *, UOP/COSMIC*
Sergey Sokolovskiy, *UOP/COSMIC*
Paul Straus, *Aerospace Corporation*
Stig Syndergaard, *UOP/COSMIC*
Lung-Chih Tsai, *North Central University, Taiwan*
Stick Ware, *UOP/COSMIC*
Tae-Kwon Wee, *UOP/COSMIC*
Jens Wickert, *GFZ, Germany*
Larry Young, *Jet Propulsion Lab, NASA*
Tom Yunck, *Jet Propulsion Lab, NASA*
Cinzia Zuffada, *Jet Propulsion Lab, NASA*

Participants:
Jennifer Abernethy, *University of Colorado*
Erick Adame, *SUNY Oneonta*
Kelly Amundsen, *Ohio State University*
Yunchang Cao, *Chinese Meteorological Administration*
Jen-Cheng Chang, *Chinese Culture University*
Jan-Huey Chen, *National Taiwan University*

Shu-Ya Chen, *North Central University, Taiwan*
Chihan Cheng, *North Central University, Taiwan*
Suk-Jin Choi, *Seoul National University, Korea*
Sung-Rae Chung, *Korea Meteorological Administration*
Joaquim de Alencar Filho, *Instituto Nacional de Pesquisas Espaciais*
Michael Duda, *University of Colorado*
Shengjie Ge, *Ohio State University*
John George, *National Centre for Medium Range Weather Forecasting*
Laura Hinkelman *, NASA, Langley*
Wallace Hogsett, *University of Maryland*
Victoria Hoyle, *University of Calgary, Canada*
Cheng-Yung Huang, *North Central University, Taiwan*
Wei-Peng Huang, *Central Weather Bureau, Taiwan*
Meng-Pai Hung, *University of Maryland*
Masayuke Kanzaki, *Japan*
Ha-Taek Kwon, *Seoul National University, Korea*
Brent Laabs, *University of California, Davis*
Haixia Liu, *University of Oklahoma*
Johnny Lo, *Curtin University of Technology, Australia*
Ronald Mastaler, *University of Arizona*
Chris McCormick, *Broad Reach Engineering*
Boksoon Myoung, *Texas A&M University*
Natalya Nicholson *, University of Calgary, Canada*
Matthew Nielsen, *Colorado State University*
Laust Olsen *, Aalborg University, Denmark*
Grace Peng, *The Aerospace Corporation*
Marcello Petitta, *University of Rome "La Sapiena," Italy*
Dione Rossiter, *University of California, Berkeley*
Lie-Chung Shen, *North Cheng-Kung University*
Hyun-Cheol Shin, *Korean Meteorological Administration, Korea*
Dan Smith, *Broad Reach Engineering*
Andrew Snyder *, Purdue University*
Claudia Stolle, *University of Leipzig, Germany*
Ho-Fang Tsai, *National Space Program Office, Taiwan*
Chun-Erh Tseng, *Central Weather Bureau, Taiwan*
Chao-Chao Wang, *University of New Brunswick, Canada*
Chien-Ya Wang, *Chinese Culture University, Taiwan*
Sung-Ho Woo, *Seoul National University, Korea*
Cristiano Max Wrasse *, Instituto Nacional de Pesquisas Espaciais*
Bor-Han Wu, *National Space Program Office, Taiwan*
Jolie Wu, *AFRL/VSBXI (Hanscom air force base)*
Feiqin Xie, *University of Arizona*
Mei Xu *, RAP*
Kuo-Feng Yang, *North Central University, Taiwan*
Liangying Zhang, *NCAR*

Climate and Health Summer Colloquium

Coordinators:
Linda Mearns; NCAR
Doug Nychka; NCAR
Jonathan Patz; Johns Hopkins Bloomberg School of Public Health

Lecturers:
Peter Backlund, *NCAR*
Russell Barbour, *Yale School of Medicine*
Sam Batzli, *University of Wisconsin, Madison*
Michelle Bell, *Yale University*
William Collins, *CGD*
Kristie Ebi, *EXPONENT Consulting*
Paul Epstein, *Harvard Medical School*

Eric Gilleland, *RAP*
Mary Hayden, *University of Colorado*
Roberta Johnson, *E&O/UCAR*
Richard Katz, *ESIG*
Sari Kovats, *London School of Hygiene and Tropical Medicine*
Adrienne LeBaily, *Center for Disease Control*
Sasha Madronich, *ACD*
Linda Mearns, *ESIG*
Jonathan Mayer *, University of Washington*
Chester Moore, *Colorado State University*
Susi Moser, *ESIG*
Doug Nychka, *CGD*
Jonathan Patz, *Johns Hopkins University*
Roger Pulwarty, *Climate Diagnostics Center/NOAA*
Emi Saito, *USGS National Wildlife Health Center*
Claudia Tebaldi, *ESIG*
Madeleine Thomson, *International Research Institute for Climate Prediction*
Kevin Trenberth, *CGD*
Mark Wilson, *University of Michigan*
Rob Wilby, *Environment Agency, UK*
Tom Wigley, *CGD*
Paul Wilkinson, *London School of Hygiene & Tropical Medicine*
Eric Wood, *US Geological Survey, EROS Data Center*
Emily Zielinski-Gutierrez, *Center for Disease Control and Prevention*

Participants:
Anatta, *UCAR*
Richard Anyah, *North Carolina State University*
Alan Belensz, *Environmental Protection Bureau, NY*
Terri Bettencourt, *RAP*
Erik Bowles, *Kansas State University*
Joan Brunkard, *University of California, Santa Cruz*
Jill Coleman, *Ohio State University*
Heather Conley, *Kansas State University*
Dan Cooley, *CGD*
Durin Dregner, *CGD*
Kevin Durand, *University of Colorado*
Robert Field, *Canadian Forest Service*
Reinhart Furr, *CGD*
Zhena Gallan, *UCAR*
Samson Gebrab, *Utah State University*
David Grass, *Columbia University*
Maura Hagan, *ASP*
Alexandra Henneberger, *University of Munich, Germany*
Robert Henson, *UCAR*
David Hosansky, *UCAR*
Katja Huber, *University of Natural Resources and Applied Sciences, Austria*
Chandy John, *Case Western Reserve University*
Carrie Kaufman, *CGD*
Kim Knowlton, *Columbia University*
Korine Kolivras, *Virginia Tech*
Zhuobin Li, *Case Western Reserve University*
Michael Marshall, *Clark University, Kenya*
Marcelo Mena, *Center for Global & Regional Environmental Research*
Ernesto Munoz, *University of Maryland*
Sarah Olson, *University of Wisconsin, Madison*
Shlomit Paz, *University of Haifa, Israel*
Angela Pignotti, *CGD*
James Rattling Leaf *, ESIG*
Aisha Reed, *Purdue University*
Carla Rodriguez, *NYC Dept. of Health & Mental Hygiene*

Miguel Angel Rodriguez Arias , *Lab for Research of Climate, Barcelona, Spain*
ShuiBin, *ESIG/ASP*
Scott Spak, *University of Wisconsin*
Roxann Stennet, *Univ. of the West Indies, Mona*
Sabine Thaler, *University of Birmingham, UK*
Catherine Tuglus, *Columbia University*
Jun Wang, *University of Alabama*
Erika Wise, *University of Arizona*

Junior Faculty Forum hosted by the NCAR Early Career Scientists Assembly

Participants:
Tom Bogdan, *NCAR*
Caspar Ammann, *NCAR*
Doug Capone, *University of Southern California*
Phillip Chamberlain, *University of Colorado*
Adele Chuck, *University of East Anglia, UK*
Katie Coughlin, *University of Washington*
Richard Cullather, *NCAR*
Aiguo Dai, *NCAR*
Douglas Day, *University of California, Davis*
Ian Faloona, *University of California, Davis*
V. Lynn Harvey, *University of Colorado*
Jan Kazil, *NCAR*
Daniel Kirk-Davidoff, *University of Maryland*
Joanie Kleypas, *NCAR*
Tim Leuker, *Scripps Institution of Oceanography*
Keith Lindsay, *NCAR*
Hanli Liu, *NCAR*
Monica Madronich, *NCAR*
Natalie Mahowald, *NCAR*
Daniel Marsh, *NCAR*
Katja Matthes, *NCAR*
Galen McKinley, *University of Wisconsin*
Katharine Moore, *NCAR*
Raimund Muscheler, *Geobiosphere Science Center, Switzerland*
Sreela Nandi, *NCAR*
Cyndy Nevison, *NCAR*
Gian Kasper Plattner, *University of California, Los Angeles*
Mark Potosnak, *Desert Research Institute*
Rob Rhew, *University of California, Berkeley*
Sybil Seitzinger, *Rutgers*
Drew Shindell, *Columbia University*
Rebecca Shipe, *University of California, Los Angeles*
Ron Siefert, *University of Maryland*
Craig Stroud, *NCAR*
Ajit Subramanian, *Lamont Doherty*
Sachida Tripathi, *NOAA*
Diana Varela, *University of Victoria, Canada*
Leah May Ver, *University of British Columbia, Canada*
John White, *University of Florida*
Christine Wiedinmyer, *NCAR*

Geophysical Turbulence Program Workshops (2)

The Cumulus Parameterization Problem in the Context of Turbulence Studies

Organizers:
Leo Donner, *NOAA, Geophysical Fluid Dynamics Laboratory*
Wojciech Grabowski, *NCAR*
Mitch Moncrieff, *NCAR*
Joseph Tribbia, *NCAR*

Jun-Ichi Yano, *Meteo France*

Participants:
Akio Arakawa, *University of California, Los Angeles*
Mary Barth, *NCAR/MMM*
Peter Bechtold, *ECMWF, England*
Jadwiga Beres, *NCAR/ASP*
Judith Berner, *NCAR/ASP*
Jean-Louis Brenguier *, Meteo France*
George Craig *, Institute for Atmospheric Physics, Germany*
Kerry Emanuel, *Massachusetts Institute of Technology*
Aimé Fournier, *NCAR/GTP*
Alan Grant, *University of Reading, England*
Ross Griffiths, *The Australian National University*
Francoise Guichard, *Centre National de Recherches Meteorologiques-Groupe Atmosphere Meteorologique et Environnement, France*
Joshua Hacker *, NCAR/MMM*
William Hall, *NCAR/MMM*
Hsiao-Ming Hsu, *NCAR/RAP*
Christine Johnson, *NCAR/ASP*
Marat Khairoutdinov, *Colorado State University*
Steve Krueger, *University of Utah*
Donald Lenschow, *NCAR/MMM*
Hanli Liu, *NCAR/HAO*
Brian Mapes, *National Oceanic and Atmospheric Administration-Climate Diagnostics*
John Marshall, *Massachusetts Institute of Technology*
Charles Meneveau, *Johns Hopkins University*
Chin-Hoh Moeng, *NCAR/MMM*
Richard Neale, *NOAA*
Riwal Plougonven, *NCAR/ASP*
Annick Pouquet, *NCAR/GTP*
David Randall, *Colorado State University*
Rod Schmidt, *Sandia National Laboratory*
Axel Seifert, *NCAR/ASP*
Joel Sommeria, *Laboratoire des Ecoulements Geophysiques et Industriels-Coriolis, France*
Bjorn Stevens, *University of California, Los Angeles*
Craig Stroud, *NCAR/ACD*
Jai Sukhatme, *NCAR/ASP*
Peter Sullivan *, NCAR/MMM*
Jielun Sun, *NCAR/MMM*
Wen-Wen Tung, *NCAR/MMM*
Sonja Weinbrecht, *University of Reading, England*
Xiaoqing Wu, *Iowa State University*

Atmospheric Turbulence and Mesoscale Meteorology: A Symposium in Honor of Douglas K. Lilly

Organizers:
Evgeni Fedorovich, *University of Oklahoma*
Katharine Kanak, *University of Oklahoma*
Donald Lenschow, *NCAR/MMM*
Chin-Hoh Moeng, *NCAR/MMM*
Richard Rotunno, *NCAR/MMM*
Bjorn Stevens, *University of California, Los Angeles*

Participants:
Steve Albers, *Colorado State University*
Rick Anthes, *UCAR*
Marta Antonelli, *NCAR visitor*
Stan Barnes, *National Oceanic and Atmospheric Administration*
Howard Bluestein, *University of Oklahoma*
Tom Bogdan, *NCAR/ASP*

Elie Bou-Zeid, *Colorado State University*
Greg Byrd, *UCAR/COMET*
Bob Conzemius, *University of Oklahoma*
Matteo Corazza, *NCAR visitor*
Karl Danninger, *NCAR*
Jim Deardorff, *unaffiliated*
Kelvin Droegemeier *, University of Oklahoma*
Kerry Emanuel, *Massachusetts Institute of Technology*
Evgeni Fedorovich, *University of Oklahoma*
Aime Fournier, *NCAR/GTP*
Ken Gage, *NOAA*
Peter Gilman, *NCAR/HAO*
David Gurarie, *Case Western Reserve University*
Jack Herring, *NCAR*
Chad Higgins, *Johns Hopkins University*
Hsiao-Ming Hsu, *NCAR/RAP*
Katharine Kanak, *University of Oklahoma*
Akira Kasahara, *NCAR/CGD*
Petra Kastner-Klein, *University of Oklahoma*
Marat Khairoutdinov, *Colorado State University*
Joseph Klemp, *NCAR/MMM*
Si-Wan Kim, *NCAR*
Jeff Kimpel, *National Oceanic and Atmospheric Administration*
Yoshifumi Kimura, *Nagoya University, Japan*
Charles Knight, *NCAR/MMM*
Yefim Kogan, *University of Oklahoma*
Zena Kogan, *University of Oklahoma*
Peter Lamb, *University of Oklahoma*
Cara-Lyn Lappen, *Colorado State University*
Donald Lenschow, *NCAR/MMM*
David Lewellen, *West Virginia University*
Doug Lilly, *University of Oklahoma*
Marie Lothan, *NCAR/MMM*
Roland Madden, *NCAR/CGD*
Jerry Mahlman, *NCAR/ASP*
Jim McWilliams, *University of California, Los Angeles*
Charles Meneveau, *Johns Hopkins University*
Phil Merilees, *NCAR/CGD*
Dmitrii Mironov, *Deutscher Wetterdienst, Germany*
Chin-Hoh Moeng, *NCAR/MMM*
Michael Montgomery, *Colorado State University*
Rebecca Morss, *NCAR/MMM*
Ned Patton, *NCAR/MMM*
Annick Pouquet, *NCAR/GTP*
Paul Quelet, *Colorado State University*
David Randall, *Colorado State University*
Duane Rosenberg, *NCAR/GTP*
Richard Rotunno, *NCAR/MMM*
David Schecter, *Colorado State University*
Wayne Schubert, *Colorado State University*
Axel Seifert, *NCAR/ASP*
William Skamarock, *NCAR/MMM*
Ron Smith, *Yale University*
Boba Stankov, *National Oceanic and Atmospheric Administration*
Bjorn Stevens, *University of California, Los Angeles*
Jerry Straka, *University of Oklahoma*
Peter Sullivan, *NCAR/MMM*
Jielun Sun, *NCAR/MMM*
Juanzhen Sun, *NCAR/MMM*
Ignaz Vergeiner, *Deutsher Wetterdienst, Austria*

Jordi Vila-Guerau de Arellano, *Wageningen University, The Netherlands*
Morris Weisman, *NCAR/MMM*
John Wyngaard, *Pennsylvania State University*
Mei Xu *, NCAR/RAP*
Tak Yamaguchi, *Colorado State University*

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Director's Message

A Year of Transitions

It is my pleasure to introduce the 2004 Annual Scientific Report for the Atmospheric Technology Division (ATD). The year began with development of a strategic plan. Not a routine 5-year renewal of mission and program, this plan sought to reposition ATD for a transition "Toward an Earth Observing Laboratory". The process was inclusive, beginning with a detailed examination of science and technology drivers. Approximately 80 staff participated with important contributions having been realized from nearly every employee group. We then employed the services of a blue ribbon External Advisory Committee, which provided technical feedback and novel programmatic concepts. The first draft elicited some unusual reactions such as "It's too scientific…", testimony to ATD's commitment, which is grounded in and driven by scientific disciplines we serve.

Technical achievements were numerous. For starters, "get REAL", a Raman-shifted Eye-safe Aerosol Lidar, which points the way toward extension of this technology to constituent-detecting differential absorption lidars as well as Doppler air motion sensing. Want to dance? Then try the S-POLKa, featuring the latest in a Ka-band craze for multi-parameter radar investigations of precipitation. You may also wish to visit the piece on CME (Carbon in the Mountains Experiment), an early foray into adaptive array sensing with wireless communications in support of the biogeosciences. Novel twists in APOL's tunable diode laser sensors have renewed our attempts to further quantify constituent concentrations by our joint photonics - optoelectronics lab with the Atmospheric Chemistry Division. And, ohmygosh, don't forget the blizzard of cloud physics data produced by new sensors on the C-130 in the AIRS-II experiment.

Nothing surpassed the rising expectations for HIAPER, our nascent Gulfstream V stratospheric jet with a truly global reach. All corners of the Division were involved in the design and development of infrastructure such as the huge new hangar, data and display systems, communication systems, instruments, ports, inlets, and the hiring of operational staff. Scheduled for arrival in December 2004, this platform truly takes ATD into the "earth observing" arena and the "golden age" of research aviation at NCAR.

Don't forget to visit the successes of all our field programs each of which resulted in a high degree of success, receiving the plaudits of numerous investigators. It was a busy year for S-POL, including the halting but successful transition to S-POLKa during WISP and NAME. The C-130 got a workout in Ocean Waves, and the sounding/profiling systems hit the atmospheric surf with braking waves of the gaseous ilk in Sierra Rotors.

At year end ATD began its transition to a new and more "extensible" organization. Exploration of emerging technologies; conduct of inter-disciplinary science discovery; stimulation of new collaborative and strategic partnerships; and establishment of a sharply focused presence in education and outreach all present new challenges and opportunities. The prospect of five new Development Laboratories will facilitate both leadership and career opportunities in optical sensing, radio remote sensing, global monitoring systems, surface arrays, and airborne flight level sensing. So enjoy the tour. We are proud to present it….and get ready for emergence of the Earth Observing Laboratory in 2005!

– Rit Carbone, Interim Director

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Executive Summary

Select From:

For the past 35 years, ATD has served the atmospheric research community by providing state-of-the-art atmospheric observing systems, as well as technical and data support services for field projects. In addition to that mission, in FY 04, ATD has contributed in a number of NCAR Strategic Initiatives, including the Biogeosciences Initiative and Water Cycle Across Scales, in a way that forges a path towards an interdisciplinary and collaborative approach to understanding and solving some of the most pressing weather and atmospheric challenges facing us today.

FY04 has also been a time of excitement for ATD as the High-performance Instrumented Airborne Platform for Environmental Research (HIAPER) underwent final preparations and modifications to 'take to the skies' in 2005. ATD's Raman-Shifted Eye-save Aerosol Lidar (REAL) team carried out the system's first field demonstration at the Pentagon in Washington, D.C., and a prototype of the Adaptive Sensor Array (ASA) was deployed in support of the Carbon in the Mountains Experiment (CME), which is part of the Biogeosciences Initiative. ATD also participated in 12 Field Projects throughout North America utilizing 12 of our facilities as well as the C-130.

Cross-Cutting Interdisciplinary Programs

Biogeosciences Initiative

The overarching objective of NCAR's Biogeosciences Initiative is to incorporate relevant aspects of the biological sciences into geophysics and atmospheric research. In FY04, ATD has contributed in a number of ways to the objectives outlined in the Initiative, which is a 5-year NSF-funded collaborative project involving the University of Colorado, Colorado State University, University of Miami as well as NCAR's ATD, Atmospheric Chemistry Division (ACD) and MMM.

In FY04, ATD participated in the Carbon in the Mountains Experiment (CME), conducted at the Niwot Ridge Research Site, ATD deployed instrumentation to investigate the local forest CO2 exchange. These observations will be used to resolve the atmospheric transport of CO2 in order to accurately measure the net ecosystem carbon exchange, and as input to a regional-scale data-assimilation model to improve our understanding of the processes controlling carbon cycling by mountain forests.

ATD developed an autonomous, inexpensive, and robust CO2 analyzer [AIRCOA]. RAF's Britt Stephens constructed 4 AIRCOA units after our initial design testing and deployed three of these in the field during the CME campaign. Diagnostics and Results. A key

component in the robustness of these analyzers is near real-time data processing with extensive automated diagnostic tests to verify normal operation, with new results available from a web interface every day.

ATD conducted the first Airborne Carbon in the Mountains Experiment (ACME I) in May and July of this year to explore methods for constraining regional-scale CO2 fluxes over complex terrain and to collect measurements useful for devising and testing strategies for long-term monitoring of these fluxes.

In an international collaboration, ATD worked with Colorado State University, NOAA CMDL, LSCE (France), University of. Heidelberg (Germany), Max Planck Institute for Biogeochemistry (Germany), Tohoku University (Japan), NIES (Japan), and CSIRO (Australia) to complete a synthesis of vertical profile CO2 data from 20 sites around the world to define the vertical distribution of CO2 in the atmosphere. RAF's Britt Stephens presented an invited seminar on this project at NOAA CMDL and a publication based on this work is in preparation.

Analytical Photonics & Optoelectronics Laboratory (APOL) (top)

APOL group has had a busy year supporting both NCAR Biogeoscience Initiative as well as ATD's mission of advancing observing technology. A few of the activities include 1) continued development of a high precision CO2 isotopic ratio instrument based upon difference frequency generation (DFG); 2) continued development of a rugged, light-weight, high performance DFG instrument for airborne measurements of formaldehyde (CH2O); 3) continued improvements (both hardware and software) to a liquid-nitrogen cooled lead-salt tunable diode laser absorption spectrometer (TDLAS) for airborne measurements of CH2O; 4) participation in the 2004 INTEX-NA study using the TDLAS instrument for airborne measurements of CH2O; and 5) initiation of a preliminary first look at the data to identify unique photochemical events.

Water Cycle Across Scales

The NCAR Water Cycle Across Scales initiative has as its primary goal to understand how water vapor, precipitation, and land-surface hydrology interact across scales to define the hydrological cycle, and to use this information to improve both large and small scale weather prediction and climate models. ATD continued its collaborative efforts with RAP in 2004 with a combined approach of scientific research and development addressed the following issues:

IHOP diurnal cycle studies (in collaboration with Dave Parsons, Jim Hack, Aiguo Dai and Kevin Trenberth)

The goal of this work was to prepare an hourly, gridded IHOP database to study the diurnal variations of different processes, to compare different datasets and for modelers to use it to validate performances of their models in simulating the diurnal cycle. ATD began with 3-hourly radiosonde data at 5 ARM sites for 21 days, then studied diurnal cycle of precipitation by doing and comparison of hourly, NCEP/CPC gridded multi-sensor and NWS ABRFC stage III precipitation.

Study diurnal variations of water vapor using global GPS data (collaborating with Aiguo Dai, Stick Ware and Teresa Van Hove)

This Opportunity Fund project sought to develop an analysis technique to derive and continuously update a near real-time, global, 2-hourly data set of atmospheric precipitable water (PW) using ground-based Global GPS measurements of the zenith path delay (ZPD).

Community Observing Systems (top)

HIAPER

In FY04, modifications to the GV were completed by Gulfstream and Lockheed. These modifications included the installation of three under wing hard points on each wing, three 20.5-inch diameter view ports (two up-looking and one down-looking), several fuselage hard points and aperture plates, cabin attachment points (seat rails), and research power and signal wiring. High pressure testing of the modified fuselage was successfully conducted in September and preparations were made for ferrying of the aircraft from Greenville, SC to Savannah, GA for interior and exterior completion at the Savannah Air Center. The figure to the left shows the newly-modified GV receiving final placement of the NSF and NCAR logo templates on the fuselage.

Over the past year, the various HIAPER infrastructure subgroups made significant progress toward the development of critical research systems for the aircraft. The data acquisition system development group – headed by Mike Spowart and Dick Friesen of the HPO – has led the effort to develop a next generation data system that is faster, smaller, lighter, and consumes less power than the current NSF/NCAR C-130 system. The new GV data system is built around a PC-104 (ISA bus) architecture and will continue to provide all of the standard digital interfaces supported by the C-130 system. Older, non-standard digital interfaces (e.g., the PMS probe 2D interface) will be discontinued and replaced by a new USB interface. Construction of the data sampling modules (DSMs) to be used to acquire data from instrumentation mounted on the aircraft was completed in FY04, as was environmental testing of the DSM prototype. Chris Webster and Mike Daniels continued to oversee the effort to develop new data visualization and access software for the GV. Software engineers from throughout ATD contributed time and expertise to this software development effort, resulting in the creation of several prototype display packages by the conclusion of FY04.

Other HIAPER infrastructure preparation efforts undertaken during FY04 included the award of subcontracts for installation of the intercommunication system (ICS) and SATCOM systems and an Airborne Flight Information System (AFIS) on the GV. The ICS installation will be performed by Garrett Aviation and Savannah Air Center personnel during the aircraft interior and exterior completion time period, and Atlas Telecom will undertake installation of the SATCOM systems and the AFIS following the delivery of the GV to UCAR/NCAR.

In July, two of the ATD pilots – Henry Boynton and Lowell Genzlinger – completed an intensive flight simulator training course in Savannah, GA to receive their credentials to pilot the GV. Additionally, a number of ATD personnel traveled to July during this same month to participate in an “all hands” training program for the aircraft. This latter series of classes provided the participants with the opportunity to learn about emergency and safety procedures for the aircraft and to take part in a drill involving the evacuation of the smoke-filled cabin of a life-size GV cabin model into water. ATD maintenance team members Bob Beasley, Brent Kidd, and Jim Nolan began the GV maintenance training program in September and will complete the course in early October.

Raman-shifted Eye-safe Aerosol Lidar (REAL)

FY04 saw exceptional advances for REAL. The ATD lidar team migrated

the laboratory prototype to a seatainer, designed & fabricated a beam-steering-unit to enable rapid scanning, and carried out the system's first field demonstration at the Pentagon in Washington, D.C. The DARPA sponsors were sufficiently impressed with the performance of REAL that they have partnered with NCAR to contract a large commercial firm (ITT Industries) to fabricate a continuously operating and unattended REAL for permanent operation at the Pentagon. UCAR has filed patent applications on REAL and some of its components and hopes to license the technology for commercialization.

Adaptive Sensor Array (ASA)

Progress on ASA (formerly ISA) continued this year with the deployment of a prototype system. CME04 investigators for the Biogeosciences Initiative requested over 50 temperature soil probes to be deployed in an extensive spatial array. This provided the opportunity to design a prototype of the lowest level of the ASA system, the microscale array. A single prototype unit, referred to as a mote, included 6 temperature probes, sufficient data processing capability to provide calibrated data, an RF communication link, and a small solar-charged battery for power. Each mote was in communication with the new data system and had built-in command control capability to permit critical operating parameters to be adjusted in real-time. All temperature probes were individually calibrated to achieve accuracies better than 0.10 C. The use of stand-alone power sources and RF data communication allowed extensive site selection flexibility. A total of 12 motes supporting 72 temperature probes were deployed. Future plans are to expand the design to allow other ISFF sensors to be fully autonomous and networkable using wireless communication techniques incorporating dynamic routing algorithms. Additional upgrades to the new data system are planned to permit independent adaptation of sampling and response in addition to manual control.

Community Service (top)

ATD exemplifies NCAR's community service function. ATD's activities advance the community's observational capabilities through the deployment of existing facilities and the development, sometimes over many years, of new instrumentation and platforms. Two thirds of all ATD support activities serve university users and most involve users from several universities. Many university and NCAR scientists regard ATD's capabilities and services as the primary justification for a national center. In FY04, ATD participated in 12 Field Projects throughout North America utilizing 12 of our facilities as well as the C-130. For more information on our Field Projects, visit our ATD Accomplishments Page.

ATD plays a strong role in traditional graduate

student education by offering opportunities for participation in field projects as mission coordinators, flight scientists, daily operations managers, etc., and their use of ATD data sets in their research and Theses. The successful NSF Biocomplexity proposal for an isotope-resolving CO2 instrument, led by ATD, had an explicit and well-reviewed education component developed in partnership with UCAR E&O.

As in the previous year, the APOL group worked in close collaboration with NCAR's Education and Outreach Program to host two teachers and students from local area high schools to help with all phases of this project. This link not only further describes the full project but also shows one important aspect of the teacher and student involvement: organization and dissemination of the material to the broader public.

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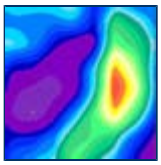
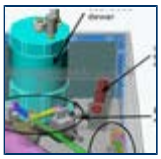
ATD Achievements



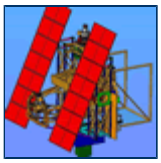
Research

Field Programs



Facilities Development

Data and Network Services



Design and Fabrication

Education and Outreach

ATD Achievements - Research

Select from:

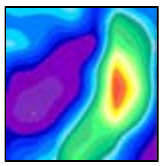
Strategic Initiatives - Select From:

In an effort to bridge science disciplines and gather the highest quality teams to pursue scientific knowledge our society needs, NCAR has launched a set of integrative initiatives (Strategic Initiatives) that explore a variety of earth systems from a 21st-century vantage point. ATD is currently participating with other NCAR divisions in a number of these cross-cutting interdisciplinary studies, including Water Cycle Across Scales (which studies the hydrological cycle), the Biogeoscience Initiative (which bridges the biological sciences with the geological and atmospheric sciences), Wildfire, and Upper Troposphere/Lower Stratosphere (to understand long-term climate change).

Water Cycle Across Scales

The NCAR Water Cycle Across Scales initiative has as its primary goal to understand how water vapor, precipitation, and land-surface hydrology interact across scales to define the hydrological cycle, and to use this information to improve both large and small scale weather prediction and climate models. For more information on the initiative, visit NCAR's Water Cycle webpage.

IHOP Research



Utilizing funding from the NCAR USWRP, NCAR Watercycle Across Scales program and base ATD NSF funding ATD Scientist Jim Wilson conducted the research and submitted a paper to a special IHOP issue of Monthly Weather Review. The paper is entitled Summary of Convective Storm Initiation and Evolution During IHOP: Observational and Modeling Perspective. Please see the RAP IHOP research section for a discussion of this research.

The dropsonde humidity data have not been fully utilized due to lack of knowledge of performance of the dropsonde humidity sensor. The performance of dropsonde humidity sensor is evaluated by using dropsonde data collected from DYCOMS-II and IHOP_2002. The evaluation found no systematic dry bias in dropsonde humidity data as suggested by previous studies.

ATD scientists Dave Parsons and June Wang worked with other investigators in NCAR's Climate & Global Dynamics Division (CGD) to compare these detailed observations taken during IHOP_2002 against similar simulations of the region conducted with the Community Climate System Model. A particular point of interest is to understand why the diurnal cycle in the climate model has an afternoon rainfall maximum instead of the region's well known nocturnal maximum in order to improve the performance of the climate model. The observed and simulated diurnal cycles in humidity are also quite different. The model performance on the wind and temperature appears much more promising.

Parsons and Wang are also working on understanding why nocturnal convective systems can occur over the arid western portions of the Southern Great Plains despite a stability profile that is not conducive to the presence of deep

convection. The work is focusing on undular bores showing that such features are quite common over this region and appear to work to maintain nocturnal convective systems by creating a more favorable environment through widespread lifting ahead of these systems.

The S-Pol radar refractivity retrieval uses return from ground targets to provide a map of low-level refractivity, a proxy for low-level moisture. ATD scientists Jim Wilson, Tammy Weckwerth, Crystal Pettet worked to validate the S-Pol radar refractivity retrieval using a variety of diverse measurements from IHOP. Comparisons convincingly show that the retrieval provides an accurate representation of low-level atmospheric refractivity. Under most daytime summertime conditions, radar refractivity measurements are representative of a ~250-m deep layer. Wilson, Weckwerth and Pettet also performed analysis on the utility of refractivity for short-term forecasting applications. They found that the refractivity field may detect low-level boundaries prior to the more traditional radar reflectivity and Doppler velocity fields showing their existence. Data from two days in which convection initiated within S-Pol refractivity range suggest that the refractivity field may exhibit some potential utility in forecasting convection initiation. This study suggests that unprecedented advances in mapping near-surface water vapor and subsequent improvements in predicting convective storms could result from implementing the radar refractivity retrieval on the national network of operational radars.

Other Water Cycle research includes:

Using S-Pol and mobile Doppler radar, radiosonde, TAOS, mobile mesonet, fixed surface station, and airborne water vapor DIAL data from IHOP to understand details and evolution of horizontal and vertical distributions of water vapor in the quiescent boundary layer;

- Using serial radiosonde ascents from many sites to assess the representativeness and evolution of soundings which are typically used to forecast daily convective potential
- Evaluating a convection initiation case study of low-level internal gravity waves intersecting an outflow boundary.

Wang, working with new ATD scientist Liz Zhang, hypothesized that the intersection regions result in increased boundary layer moisture and stronger updrafts and thus a greater likelihood of convection initiation at those locations. A project, entitled “Deriving a Global, 2-Hourly Atmospheric Precipitable Water Dataset from GPS Measurements and its Scientific Applications”, is supported by NCAR Director Office Opportunity fund. The goals of the project are to develop an analysis technique for deriving a near real-time, global, 2-hourly data set of atmospheric precipitable water (PW) using existing ground-based GPS measurements of zenith path delay (ZPD) and to use the PW data to study global PW diurnal variations and quantify errors/biases in global radiosonde humidity data.The development of the analysis technique is nearly complete.The preliminary analysis of one-year PW data shows the potentials for using the dataset to monitor the quality of global radiosonde humidity data, which has always been a challenge.

Biogeosciences (top)

The overarching objective of NCAR’s Biogeosciences Initiative is to incorporate relevant aspects of the biological sciences into geophysics and atmospheric research. In FY04, ATD has contributed in a number of ways to the objectives outlined in the Initiative, which is a 5-year NSF-funded collaborative project involving the University of Colorado, Colorado State University, University of Miami as well as NCAR’s ATD, Atmospheric Chemistry Division (ACD) and MMM.

Airborne Carbon Dioxide and Carbon Monoxide Measurements

Collaboration between ATD, CGD, and the Biogeosciences Initiative has been in place for several years to fund development and field support of airborne facility in situ trace gas instruments. Supported developments include water vapor and fast-response ozone measurements in addition to carbon dioxide and carbon monoxide. The activities have been successful on several fronts in maintaining and improving the quality of requestable instrumentation and data sets.

The airborne CO2 instrument was modified to enable flux measurements by the eddy covariance method. Performance during the Gulf of Tehuantepec (Ocean Waves - also see GOTEX) and Airborne Carbon in the Mountains (ACME) experiments allowed assessment of measurement capabilities. Spectral analysis of Ocean Waves marine boundary layer data imply an instrument frequency response of 4-Hz, and time series analysis implied a mixing ratio measurement precision of 0.2 - 0.3 ppmv (1-? for a 1-second average). The flux artifact of this sensor due to air motion sensitivity was quantified in both marine and terrestrial boundary layer environments during both missions by introduction of calibration gas into the sample cell during a portion of a boundary layer transect. A small artifact due to correlated air motion sensitivity was observed in Ocean Waves data at frequencies lower than 2 Hz, however, the amplitude of these fluctuations is a factor of 50 smaller than the equivalent power spectral content of ambient data obtained in the marine boundary layer at the same altitude. Preliminary ACME results from intercomparison to analyses of flask samples (H.

Graham, R. Keeling, Scripps Institute of Oceanography) imply an accuracy of ± 0.2 ppmv. This result has been reproduced by intercomparison to CME ground network working standards provided and analyzed by the CO2 calibration facility (B. Stephens, ATD).

Airborne Water Vapor Measurements

The commercial NCAR open path diode laser absorption hygrometer was modified to improve accuracy of lower tropospheric water vapor mixing ratio observations and to increase the time response of the instrument from an 8-Hz sampling rate to 18-Hz. The modified laser hygrometer performed well as an experimental measurement on the second Alliance Icing Research Study (AIRS-II) and Ocean Waves experiments. Results from the AIRS-II mission established confidence in the accuracy of clear sky water vapor measurements to be +/- 5%, relative to chilled mirror sensors on the same platform. Preliminary results from the Ocean Waves data have confirmed the capability of this sensor to measure vertical fluxes by the eddy covariance method. Spectral analysis of 18-Hz data from boundary layer transects agree well with lyman alpha hygrometer data.

To increase confidence in the absolute accuracy of all NCAR facility water vapor measurements, an accurate, large dynamic range water vapor calibration system was purchased. This commercial system includes a humidity generation system and a certified reference sensor with traceability to both the US and UK standards organizations. Both cover a dew point range of -80º to +20º C, and the reference sensor accuracy is ± 0.1º C in the -60º to +20º C range and ± 0.2º C in the -80º to -60º C region. These efforts are co-sponsored by NCAR's ACD, the Biogeosciences Strategic Initiative, and NCAR Directorate.

Wisconsin Tall-Tower Atmospheric O2 Measurements

ATD concluded three and half years of atmospheric O2 measurements at the WLEF tall tower research site, and returned equipment to the lab for reconditioning while future deployments are considered. Britt Stephens presented an invited seminar on these measurements at the APO Conference in Jena, Germany (poster) and several publications based on this work are in preparation.

Synthesis of Global Light Aircraft CO2 Data

In collaboration with Colorado State University, NOAA Climate Monitoring and Diagnostics Laboratory (CMDL), Le Laboratoire des Sciences du Climat et l'Environnement (LSCE - France), University of Heidelberg (Germany), Max Planck Institute for Biogeochemistry (Germany), Tohoku University (Japan), National Institute for Environmental Studies (NIES - Japan), and Commonwealth Scientific and Industrial Research Organisation (CSIRO - Australia), ATD has completed a synthesis of vertical profile CO2 data from 20 sites around the world to define the vertical distribution of CO2 in the atmosphere. These results have been compared to output from the 16 TransCom 3 Project models to test their representation of vertical tracer transport. B. Stephens presented an invited seminar on this project at NOAA CMDL and a publication based on this work is in preparation.

Wildfire (top)

A long term objective of the NCAR Wildland Fire Initiative is to acquire a research quality data set that will address outstanding scientific questions being investigated by fire researchers. In FY04, ATD's Julie Haggerty, NCAR's Mesoscale & Microscale Meteorology Division's (MMM) Janice Coen, and NCAR's Research Application Program's (RAP) Jeff Cole began development of a preliminary experimental plan and logistical strategy. Motivation for conducting such an experiment includes:

1. acquisition of a comprehensive data set with appropriate spatial and temporal resolutions to be used as input for and verification of fire behavior models;
2. corroboration of previous data sets;
3. better characterization of atmospheric conditions than is available from previous experiments.

The experimental plan lists desired measurements (e.g., fuel inventories, emissions, and atmospheric conditions) and proposes types of platforms and sensors that should be used to acquire the necessary measurements. Required spatial and temporal resolutions are also defined. The major challenges involved in deploying sensors in a burning environment are considered. Discussions continue with interested scientists in the Wildland Fire Initiative and in the larger Wildland Fire Collaboratory; refinements to the experimental plan will continue in FY05.

Upper Troposphere-Lower Stratosphere Strategic Initiative (top)

The Upper Troposphere and Lower Stratosphere (UT/LS) region is of critical importance for understanding long-term climate change. Here ozone is an effective greenhouse gas, and water vapor, cirrus clouds, and aerosols have a strong influence on radiation balance. It is also a region where transport processes that couple the stratosphere and troposphere occur on a multitude of scales and where multiphase chemistry and cloud microphysical processes influence the variability of ozone and water vapor, and hence affect long term climate change. The joint ATD/ACD Analytical Photonics & Optoelectronics Laboratory (APOL) addresses the development and employ of new advanced technologies, instruments, and advanced algorithms for improved ground-based and airborne measurements of various trace gases, which supports the UT/LS Initiative. For more detail on this effort, visit APOL.

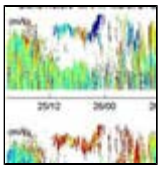
Community Collaborations/Ongoing Research -

Select From:

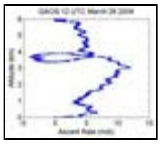
In addition to our state-of-the-art observing facilities, field support and data services, ATD plays another important role in the atmospheric research community - that of collaborative scientific research and analysis of data gathered from field projects. In FY 04, ATD collaborated with scientists from all over the globe to further understand such atmospheric phenomena as terrain-induced waves and rotors, airflow across rugged terrain, turbulence and fluxes in the boundary layer, ambient formaldehyde, and ice propagation.

Remote Sensing of Terrain-Induced Waves and Rotors (top)

Terrain -Induced Waves and Rotors can pose severe aeronautical hazards and have been cited as contributing to numerous aircraft upsets and accidents involving commercial, military and civilian aviation. Rotors can pose severe aeronautical hazards and have been cited as contributing to numerous aircraft upsets and accidents involving commercial, military and civilian aviation. To aid in our understanding of this sometimes costly and dangerous phenomena, ATD scientists Steve Cohn and Bill Brown collaborated with investigator Dr. Vanda Grubisic from the Desert Research Institute (DRI) as well as the Naval Postgraduate School (NPS) in the Terrain-Induced Rotors experiment (T-REX), of which the Sierra Rotors project is a part. ATD's research focused on studying the ability of remote sensors to diagnose wave and rotor motions. Continuous periods of upward or downward motion seen in the vertical beam of a wind profiler are indicative of a mountain (stationary) wave. Broad spectral widths, observed as the second moment of a clear air Doppler spectrum or as the fading time of a spaced antenna measurement, indicate large velocity variance with the radar integration volume. This large variance can be due to turbulence associated with rotors.



The figure to the left (click for full-sized image) shows vertical wind speed and spectral width measured with MAPR on a 3 day period of the Sierra Rotors project when mountain waves were forecast. Velocities shown in the upper frame are colored red for strong upward motion and blue for strong downward motion. These strong motions indicate waves. The lower frame shows the spectral width during the same period. Most broad widths (red) correspond to times and altitudes where wave motion is also seen. The presence of vertical motion without broad widths may indicate weaker waves that are not generating a rotor circulation. Periods of broad width with little vertical motion may indicate that the stationary wave above the profiler has a near zero phase.

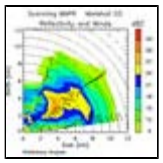


Although there is some ambiguity in interpreting profiler data alone, rawinsonde measurements are available to show gross vertical motion, an array of surface meteorological stations show flow reversal from rotors, and modeling studies will assist in interpretation of this data. The figure to the left (click for full-size) shows the ascent rate of a rawinsonde released from the MAPR site. The typical ascent rate of about 4 ms-1 is drastically modified as the balloon is carried first up at more than 10 ms-1 and then down at more than 4 ms-1 by wave motions. A mobile ISS (MISS) was also deployed to make measurements from alternate locations around the valley.

Scanning Radar Wind Field Measurements (top)

A series of experiments involving scanning a radar with multiple receiving antennas was completed in FY2004. A normal scanning radar with a single receiver can only make direct wind measurements along the beam of the radar (using the Doppler effect), and can only make a full 3-D wind measurement using derived techniques such as target tracking or dual-Doppler (requiring two radars). This

experiment used the ISS group's MAPR wind profiler to investigate techniques to make direct full 3-D wind measurements using multiple receivers. MAPR uses spaced antenna techniques to make a cross beam wind measurement, as well as along beam wind measurement using Doppler shift. Normally MAPR just points vertically; for this experiment it was mounted on a pedestal, tilted and slowly scanned in the azimuth direction to produce a simple scanning radar. The beam width of MAPR is about 10 degrees, much broader than a traditional scanning radar, and the range was limited to about 20 km, however the radar did prove to be a useful platform for testing wind measuring techniques.

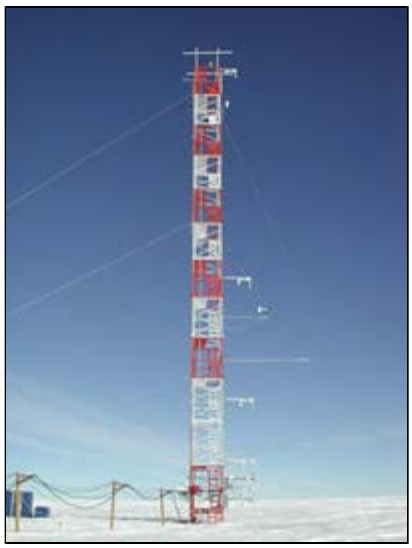


An example of preliminary results from the radar is shown at the left (click image for full size.) In this case the radar was scanning through a nearby rain shower, stopping to dwell along selected beam directions to obtain wind measurements (left panel). Wind measurements from the dwell direction with the strongest reflectivity are shown as a elevation cross-section in the center panel and compare well with a sounding taken in nearby Denver about half an hour previously (right panel). Analysis of the observations is continuing.

Boundary Layer Turbulence and Fluxes (top)

A recent field project in support of the Advanced Technology Solar Telescope, DASH04, revealed the existence of errors in the measurement of inertial range turbulence by sonic anemometers. The errors are caused by the finite time intervals between the pulses emitted sequentially by the three measurement axes of a sonic anemometer. ATD scientist Tom Horst has investigated and quantified these pulse sequence delay errors, as well as path averaging errors, for the non-orthogonal sonic path geometries used by the CSAT3 and Solent sonic anemometers.

Investigation of Sulfur Chemistry in the Antarctic Troposphere (ISCAT)



Analysis of ISFF measurements taken at the South Pole in the Antarctic summer of 2000 show that NO fluxes emitted from the ice pack are significantly larger than those in the Greenland ice pack, though not by enough to explain the much higher ambient levels of NO at the South Pole. Here, NO is thought to control OH, which determines the rate of oxidation of sulfur that is used to document climatic events. To interpret these results, a method was developed to compute the height of the atmospheric boundary-layer (which contains much of the NO) from tower-based measurements of turbulent velocity spectra. A clear anticorrelation between the NO levels and the boundary-layer height was seen, indicating that boundary-layer structure is critical in controlling NO concentrations.

Left: The vertical Profile and Turbulence Sensors used to calculate fluxes of NO.

Energy Balance Experiment (EBEX)

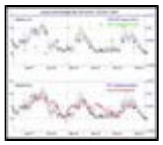
An international team led by scientists from the University of Bayreuth, Germany, University of Basel, Switzerland, KNMI, the Netherlands, and NCAR/ATD continues to analyze data collected during the surface EBEX in August

2000. This study aims to understand why energy balance closure is difficult, especially over vegetative canopies that also could explain closure problems that have been found for carbon budget studies. Sensor and data handling comparisons have found good agreement between most data subsets and spatial composites have been able to mitigate sampling problems. However, a daytime imbalance of about 15% is still observed. There is some evidence that this could be due to mesoscale heat advection.

Left: The central EBEX tower site during the sensor intercomparison period.

Airflow in Complex Terrain (top)

ATD Scientist Steve Cohn, in association with NCAR's Research Applications Program (RAP), is conducting research into air flows measured around the rugged terrain of Juneau, Alaska. While the eventual goal of this project is development of a turbulence and wind shear alert system for aviation around Juneau, the data collected is also being examined to understand flows in the long, narrow Gastineau Channel (GC) and the high-latitude mountain-valley flow systems of Juneau. The photograph to the left shows the GC, looking to the southeast. One investigation is into the forcing of strong flows in the GC. Analogous to valley flows, candidate forcing mechanisms are due to thermal gradients, downward momentum transport from the overlying synoptic flow, forced channeling, and pressure driven channeling.



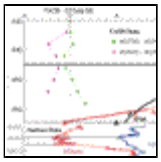
The figure to the left (click for full size) (top frame) shows the wind speed measured at the South Douglas pier within the GC with 1-minute resolution. This is during a 6-day case study period which includes three strong channeled flow events. The overlying synoptic pressure gradient has been found from synoptic analysis maps (every 12 hours). In the upper plot blue dots are the along-channel pressure gradient component, and green dots are the along channel component of the geostrophic wind. It is clear that, at least during this period, winds in the GC are driven by the overlying pressure gradient. They are not well correlated to direct forcing represented by the geostrophic wind component.

Vertical Transport and MiXing (VTMX) Data Analysis (top)

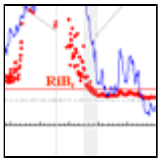
The analysis of VTMX data sets during FY04 has focused on understanding the link between mixing and orographic flows within the stable nocturnal boundary layer. To this end ATD scientists Bill Brown and James Pinto have collaborated with NOAA/ETL and DOE/Pacific Northwest National Laboratories (PNNL) on understanding how nocturnal flow evolves across the Great Salt Lake Basin and how it influences local stability (in press). Analysis of data collected

with ATD (sodar, SABL, TAOS, and radiosondes) and PNNL (sonic anemometer) instrumentation revealed that a low-level downvalley jet formed at night about 50% of the time during the VTMX field experiment, which took place in October 2000. The vertical extent and dynamical characteristics (jet max speed, amplitude of wind speed oscillations) of the flow varied substantially from day to day. It was found that several downvalley jet events were characterized by large amplitude / low frequency variations or pulses in the jet strength. These cases were found to have an important feature in common – they all had surface energy budgets that were strongly negative allowing the surface to continue cooling and strengthen the surface-based inversion which often decoupled the surface from the flow aloft, particularly in sheltered areas such as those characterized by the data.

Pulses in the jet strength patterned mixing throughout the basin. At the leading edge of the jet, warm inversion-layer air is turbulently mixed down toward the surface. Behind the jet, mesoscale advection of cold air results in cooling throughout the jet.



Data from a number of sensors characterize the thermodynamic effects of the downvalley jet. Successive soundings obtained before (0427 UTC) and after (0702 UTC) the jet ensued indicate the strong warming in a shallow layer adjacent to the surface and cooling aloft. TAOS data reveal that the warming occurred briefly over a much deeper layer below the jet max in the region where one would expect a significant amount of shear driven turbulence. Data from two surface meteorological stations at different elevations indicate that mixing is delayed at the lower, more sheltered site.

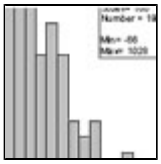


Analysis of the bulk Richardson number and turbulence data from the sonic and sodar reveal that turbulent mixing of warm air down to the lower terrain sites is delayed until the local bulk Richardson number approached the theoretical critical number for the production of turbulence (0.25). That is, the production of turbulence via vertical shear must overcome the strong static stability of the surface-based inversion layer before mixing penetrates down to the surface. Increases in sodar vertical velocity variance prior to reaching the RiB and evidence in the SABL data reveal that waves may precede the vertical mixing by turbulence.

Analysis of research aircraft cloud measurements for assessment of satellite icing retrievals (top)

In conjunction with in-flight icing programs funded by the FAA and NASA, ATD scientists Julie Haggerty and Jothiram Vivekanandan analyzed research aircraft data for assessment of satellite-based cloud retrieval algorithms. Case studies with a variety of icing and non-icing cloud conditions were selected from various field experiments including AIRS-II and WISP04. Results thus far indicate some skill in satellite-based phase retrieval algorithms. Difficulties arise in situations where an overlying cirrus layer obscures supercooled liquid clouds. Partial results are described by Haggerty et al. (2004); additional cases are being examined as appropriate aircraft data are acquired.

Advances in Tropospheric Photochemistry Employing Airborne CH2O Measurements



The APOL group has been actively involved in efforts to advance our understanding of tropospheric photochemistry based upon our high quality ambient formaldehyde (CH2O) measurements acquired during various field campaigns. Last year's ASR describes one aspect of this activity involving TRACE-P data. APOL is continuing with this endeavor this year with INTEX-NA data. Although it is far too early to formulate a comprehensive story, a preliminary first look at our data reveals a very important finding: namely, the persistence of elevated CH2O mixing ratios at high altitudes during the summer time over the continental United States. Persistent continental thunderstorm activity during the summer months vertically convects polluted boundary layer air to high altitudes where it eventually mixes with cleaner background air in the outflow of clouds. Although this process has been well established, vertical convection of soluble and reactive gases like CH2O has not been well characterized during such events. The flight tracks during the INTEX-NA study, which passed over natural and anthropogenic source regions of the south and mid-west United States, provided an excellent opportunity to study cloud outflow and cloud processing events.

ICE

Ice processes in clouds are poorly understood, especially processes that affect the initial formation and propagation of ice. This lack of understanding results in large uncertainties in numerical modeling work over a wide scope of atmospheric size and time scales, such as the production of precipitation and predicting climate changes. Recent advances in observational tools, laboratory cloud simulation chambers, numerical models, and computer hardware are

providing new capabilities to understand and model ice initiation processes.

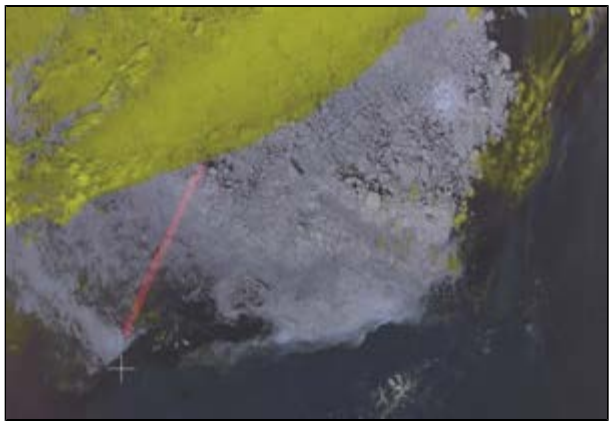
With support from the NCAR Opportunity Fund, scientists from ATD and MMM organized a community effort to address ice processes in clouds. This past year, a steering committee was formed, and the Ice Initiation Workshop was held in June at NCAR's Foothills Lab. The workshop ran two days and had invited talks plus presentations by participants. There were 64 attendees from 32 institutions and 5 countries. The ultimate goal of this activity is to develop an NCAR strategic initiative, with NCAR providing scientific leadership to help organize field observations, lab, and modeling studies. Strong participation of the university community is expected, including graduate students. A Scientific Overview Document is being written to supplement proposals by university investigators. The scientific scope, participants, and activities of this project are summarized on the web. Another web page (MMM) summarizes the workshop and has presentations of the talks.

Melt Pond Coverage on Arctic Sea Ice (top)

In a collaborative effort between NCAR, the University of Colorado, and the US Army Cold Regions Research and Engineering Lab, and led by ATD's Mark Tshudi, photo mapping of melt pond coverage on sea ice was undertaken in the Arctic during the summer of 2004 using Aerosondes. Aerosondes are small, long endurance, unmanned aerial vehicles (UAV) that have a 3 m wingspan and can carry a 2.5 kg payload. They are designed to undertake a wide range of operations in a highly flexible and inexpensive mode. The aircraft, developed by a US-Australian consortium, are operated and are undergoing further development by Aerosonde Robotic Aircraft and Aerosonde North America.

Melt ponds have been identified as a key feature in determining the amount of solar insolation absorbed by sea ice, and hence is a primary controller of the melt rate of the ice through the summer. Sea ice models have, to date, crudely parameterized ponds, due in part to a lack of large-scale observations of their temporal and spatial evolution. This NASA-funded study uses observations from the EOS sensor MODIS to estimate pond fraction over a large portion of the Beaufort and Chukchi, by examining several spectral (visible and near-infrared) MODIS bands and deducing melt pond coverage from the known spectral properties of ponds.

The Aerosonde flights dedicated to the melt pond study were necessary to test the validity of the pond coverage estimated using the MODIS data. These flights utilized a downward-looking Olympus C-3030 digital camera, mounted within the Aerosonde, to photograph the sea ice. The digital photos are to be analyzed by the investigators to classify each photo according to the percentage cover of melt ponds, unponded ice, and open water. These estimates are compared to the values retrieved using MODIS for the same area of coverage. To enhance these comparisons, missions were flown with 10 km x 10 km grid patterns, with overlapping (along-track and cross-track) digital photos, which allow for comparison with 400 MODIS pixels (500 m resolution).



The image to the left is a MODIS image of sea ice (white), clouds (shaded in yellow), with an Aerosonde track flown (in red) the same day. Land is dark, with Barrow indicated by the "+".

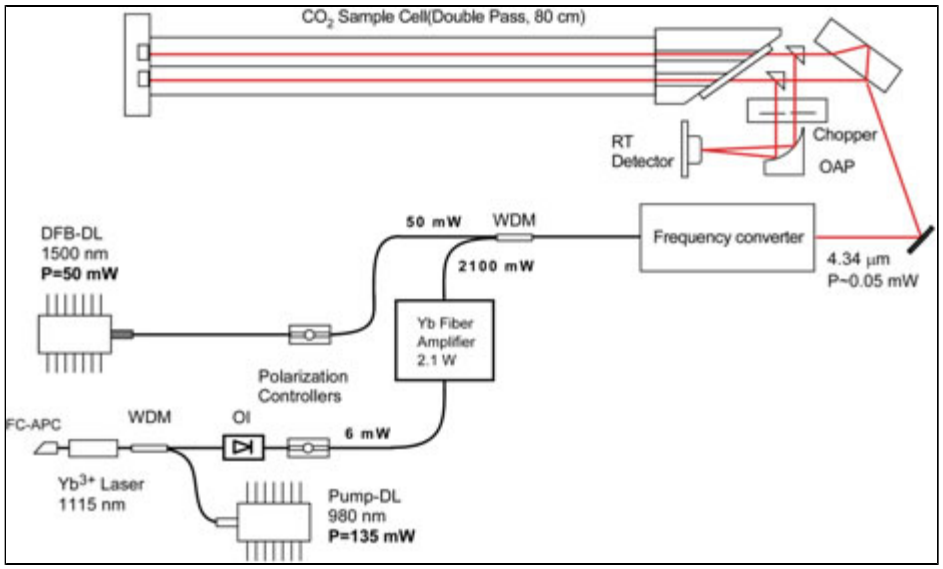
Additional missions were designed to examine the evolution of pond coverage over sea ice off the coast of Point Barrow, Alaska. The sea ice in this area of interest was fast ice (i.e. not drifting ice) and served as an area where melt ponds can be observed during formation and their evolution through the summer. The Aerosonde team flew several flights paralleling Point Barrow and overlapping in a pattern that provided contiguous digital camera images of the fast ice from shore to a few km off the coast. These flights were repeated several times during June, providing imagery that will assist investigators in determining how pond fraction changes over this period.

The joint ATD/ACD Analytical Photonics & Optoelectronics Laboratory (APOL) addresses the development and employ of new advanced technologies, instruments, and advanced algorithms for improved ground-based and airborne measurements of various trace gases, which supports NCAR's Upper Troposphere/Lower Stratosphere Initiative. Specific achievements of APOL this past year include:

1. continued development of a high precision CO2 isotopic ratio instrument based upon difference frequency generation (DFG);
2. continued development of a rugged, light-weight, high performance DFG instrument for airborne measurements of formaldehyde (CH2O); and
3. continued improvements (both hardware and software) to a liquid-nitrogen cooled lead-salt tunable diode laser absorption spectrometer (TDLAS) for airborne measurements of CH2O

CO2 isotopic ratio instrument based upon difference frequency generation (DFG)

Figure 1(left) illustrates a modified version of the optical setup shown last year, has been constructed and a number of tests have been carried out. This new setup allows the sample and reference beams to make two traversals of the absorption cells for improved measurement precision. As discussed in our previous ASR, the absorption signals from the two cells containing the sample gas and an isotopic reference standard are



rapidly compared using on-line fitting analysis. The fitting procedures have been developed and wait further testing on CO2 absorption features.

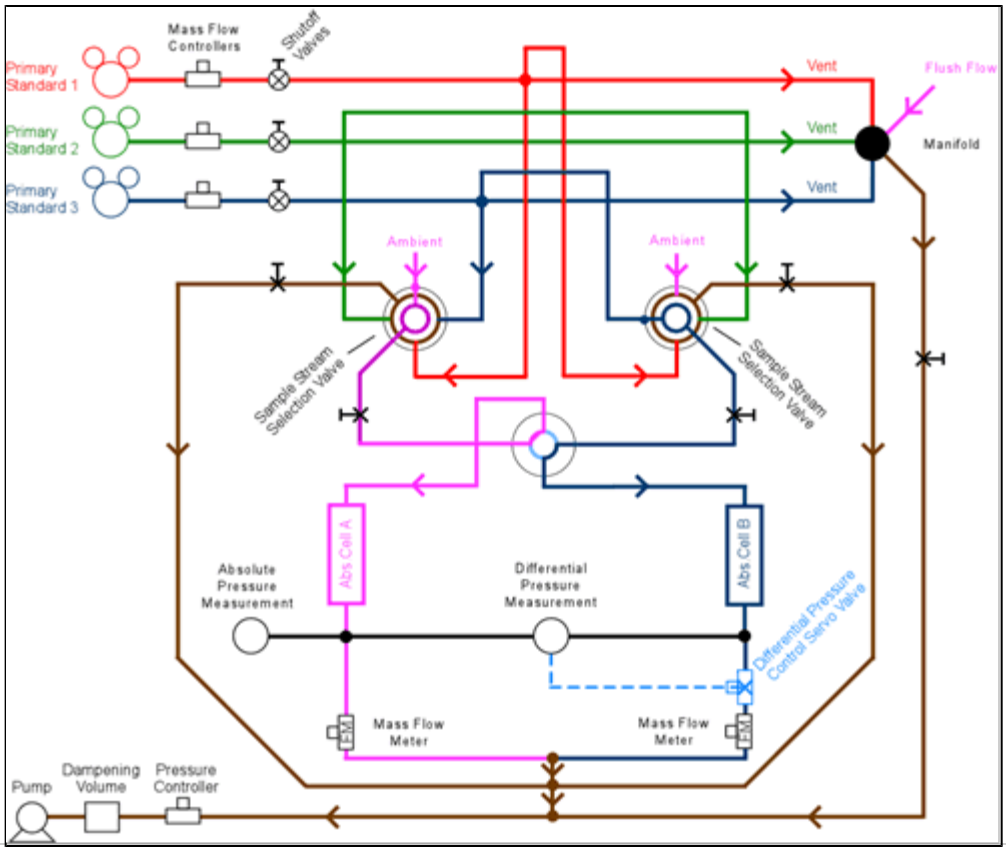
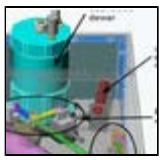


Figure 2 shows the design of the inlet system, which represents the second major task associated with high precision CO2 measurements. This system, which is in the testing phase, allows us to introduce various combinations of reference standards and ambient samples to the absorption cells under closely matched conditions of pressure and flow. Other studies frequently do not take such precautions.

Airborne DFG Instrument for the Measurement of CH2O (formaldehyde)



The APOL group has been actively involved in a long-term effort to carry out ever more accurate and precise measurements of CH2O (formaldehyde) throughout the troposphere and lower stratosphere. The present instrument sensitivity needs to be further improved for routine CH2O measurements in the background atmosphere, particularly in the upper troposphere/lower stratosphere where CH2O decomposition becomes a major source of reactive hydrogen radicals. In addition, the instrument is large and requires periodic operator intervention. To address this critical need as well as the need to develop smaller, lighter, and autonomous-operation instruments for future HIAPER campaigns, the APOL group has been developing a new high performance airborne CH2O instrument based upon difference frequency generation (DFG). However, for size comparison purposes, we show in Figures 3 (above left, click for larger image) and 4 (left - click for larger image) our present airborne TDLAS system and the compact new DFG system. The Herriott absorption cells in both systems are approximately the same size. With this in mind, a comparison of these two figures immediately reveals that the DFG system is significantly

smaller than the TDLAS system; the DFG-Herriott cell configuration in Fig. 4 has replaced the entire optical setup of the TDLAS system in Fig. 3. A further advantage of the DFG system is that no liquid cryogens are required, in stark contrast to our present TDLAS system. Although laboratory tests with the new DFG system are not yet complete, evidence strongly indicates that this new system will ultimately achieve higher performance than our TDLAS system for CH2O and other molecules.

Airborne TDLAS System Hardware and Software

Despite the significant progress achieved in the DFG development, the laboratory prototype system has not yet been tested on airborne platforms. Rather than risk flying such a system for the first time during a critical field mission, we decided to pursue the more prudent course of action by employing the TDLAS system during the 2004 summer INTEX-NA study. However, numerous small modifications were implemented to this system this past year to further improve the system robustness, reliability, and performance. Many of these modifications, which are too numerous to list here, focused on improving the optical-mechanical stability of the system. In addition, numerous software changes were also implemented for improved performance, reliability, and enhanced data quality assurance.

(top)

Ground-Based Observing Systems - Select From:

Remote Sensing -
REAL | S-Pol | Rapid DOW | NEXRAD

REAL (Raman-shifted Eyesafe Aerosol Lidar)

REAL had its first prototype demonstration last spring at the Pentagon in Washington DC. ATD collected eye-safe scanning backscatter data (at 1.5 microns) over a wide variety of weather conditions on 9 days, from pouring down rain to severe clear. Much time was spent making sector Plan-Position Indicator (PPI) scans over the Pentagon and surrounding region and Range Height Indicator (RHI) were also collected to show the vertical structure. In all, ATD over 10,000 quick-look images on 9 CDs and half dozen DLTs containing the raw data. The images are rich with fascinating features--things that are almost never visible to the naked eye. The animations of the images, which are available online, are even more powerful because they reveal the advection and dispersion of the features--and promise the ability someday to obtain the vector wind field by tracking methods. Similar data taken from the Foothills Lab site is available for viewing.

S-Pol (S-band Dual Polarization Doppler Radar)

S-Pol has seen some major modifications during FY04 and has been deployed on two major field projects: Winter Icing Storms Project 2004 (WISP04) and North American Monsoon Experiment (NAME). FY04 development activities for the S-Pol have been highlighted here.

Rapid DOW

This year ATD continued collaborations with Center for Severe Weather Research (CSWR) for the completion of the Rapid Dow truck-mounted radar operated by CSWR the under a collaborative agreement with NCAR. This radar is unique because of its use of six, frequency-steered beams utilizing a flat plate antenna. The multiple beams allow volume data acquisition of short lifetime phenomenon, such as tornados and detailed hurricane eyewall structures. Work did not proceed as well as hoped because of staffing and field project conflicts. Plans continue to be made for the completion of this radar.

(top)

NEXRAD (NEXt Generation RADar)

The NEXRAD data quality project is funded by the Radar Operations Center (ROC) of Norman OK. The purpose of the project is to increase the data quality of the National Weather Service's NEXRAD radars. The work at NCAR has primarily focused on two areas:

1. range-velocity (RV) ambiguity mitigation
2. radar echo classification (e.g., anomalous propagation (AP) clutter and precipitation).

During FY04, ATD continued to develop new and improved software tools for the analysis and verification of a RV and AP mitigation algorithms

The RV mitigation technique involves the phase coding of the transmit pulses and the subsequent recohering of the received echoes. Phase coding the transmit pulses of weather radar makes possible the separation of multi trip echoes, thereby extending the unambiguous range of the radar while not compromising the unambiguous velocity. To accomplish this in real time, a SIGMET RVP8 processor was installed in S-Pol in May of 2003. Data has been gathered, processor problems have been identified and SIGMET has implemented improvements to their hardware. ATD has continued to take data with RVP8 in 2004 and has performed data analysis.

In June of 2004 ATD delivered to the ROC a phase coding algorithm/software (with cooperation of NSSL) called the SZ-2 algorithm. The SZ-2 algorithm will be used at the lowest tilt angles of the NEXRAD radars and is scheduled to be deployed on the NEXRAD radars in 2005.

Range-Velocity Ambiguity Mitigation

The following data were gathered by S-Pol at 0.5 degree elevation on 28 March 2004 using RVP8 at the Marshall field site near Boulder, CO. A long PRT scan (PRT=3.125ms) was followed by a short PRT scan (PRT=0.8ms) separated by about 30 seconds. The unambiguous range for the long PRT is 468km (i.e., no folded echoes) while the unambiguous range for the short PRT is about 120km.

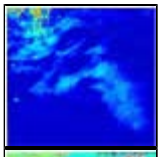


Figure 1 (left, click for full-sized image) shows the ``power'' from the long PRT scan. The dark lines show the borders of the first, second and third trip regions for the short PRT scan.

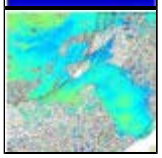
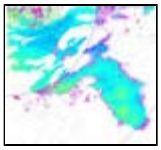
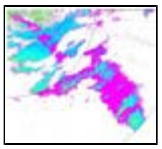


Figure 2 (left, click for full-sized image) shows the SZ-2 recovered velocity without censoring while Fig.3 (below left, click for full-sized image) shows the SZ-2 recovered velocity with censoring applied.



At 120km in the beginning of the second trip in Figure 2 (above left), leakage from the strong first trip ground clutter echoes causes the seen ring. The white areas of the censored image (Fig 3, left) are due to the SNR threshold of 3dB. The purple areas indicate poor quality data identified by the SZ-2 algorithm.



In sharp contrast, Figure 4 (left, click for full-sized image) shows the same velocity field of Fig. 1 but with the current NEXRAD WSR-88D censoring algorithm applied and as can be seen, much more velocity data is censored. Thus, the SZ-2 phase coding algorithm can greatly increase the amount and quality of the velocity data viewed by NWS weather forecasters. For more in depth description of the NEXRAD activities see the EOL/NCAR NEXRAD webpage.

Anomalous Propagation Clutter Mitigation

The ATD Anomalous Propagation (AP) clutter mitigation scheme consists of a fuzzy logic-based radar echo classifier as well as a reflectivity and radial velocity compensation algorithm. The radar echo classifier (REC) detects AP ground clutter echoes and precipitation echoes. The compensation algorithms correct the bias in the reflectivity and radial velocity fields that exist from the application of the ground clutter filter. Output from the REC ensures that the compensation algorithms are only applied to precipitation echoes. The AP clutter mitigation scheme has been deployed on each S-POL field experiment since STEPS in 2000, including the North American Monsoon Experiment (NAME) in July and August of 2004.

The REC AP clutter Detection Algorithm (APDA) was deployed on the National Weather Service WSR-88D radar

network in the Open Radar Product Generation (ORPG) in September 2002. During 2004, the ORPG Enhanced Precipitation Preprocessing (EPRE) algorithm was modified to use the APDA algorithm to remove ground clutter contamination before radar-derived rainfall estimates are calculated. Further, the ORPG Common Operations and Development Environment (CODE) software has been installed at ATD. This package facilitates the transition of radar algorithms from research to operational status on the WSR-88D. At ATD, the CODE is being used not only to enhance the current operational implementation of the REC AP Detection Algorithm, but also to implement the REC Precipitation Detection Algorithm (PDA) and the reflectivity compensation algorithm. Both are planned for deployment in the WSR-88D radar network beginning in 2005. The PDA and the reflectivity compensation algorithm will be added to EPRE to further enhance rainfall estimates, at a future date.

(top)

Sounding Systems -
Integrated Sounding System | TAOS | GPS Dropsonde | Driftsonde | GAUS

ISS/MISS/MAPR (Integrated Sounding System)

Integrated Sounding System components received some timely modernization and added capabilities which were valuable during two FY04 field deployments. Three ISS participated in the North American Monsoon Experiment (NAME) (Sonora and Baja, Mexico), and two ISS (MISS and MAPR) were deployed to the Sierra Rotors project in California. FY04 development activities for the ISS have been highlighted here.

TAOS (Tethered Atmospheric Observing System)

In FY '04 TAOS participated in two projects, the Hudson Valley Ambient Meteorology Study (HVAMS) and the North American Monsoon Experiment (NAME). For HVAMS, night flights were made in the Hudson River Valley south of Albany, NY during the month of October. Data was collected during calm cool wet evenings in support of an effort to understand CO2 processes. A user's sensor was included on the flight train and for the first time CO2 was measured using TAOS.

GPS Dropsonde

The 8-year old GPS Dropsonde system is currently used on over 20 aircraft throughout the world supporting both scientific research and operational needs. FY04 development activities for the Dropsonde have been highlighted here.

Driftsonde

In FY04, development efforts began for integrating the Vaisala RS-92 radiosonde into Driftsonde (left) replacing the current NCAR GPS Dropsonde that has been used for past Driftsonde flight tests. The RS-92 sonde will reduce costs and the weight of the system or allow for a large sonde payload. This work has been comprised of testing the RS-92 algorithms and developing receiving hardware specifically for the RS-92. and testing RS-92 software libraries on the Driftsonde main computer processor. Other work has been in the evaluation and testing of GPS receiver to be used in a Wind only sonde. System analysis of a Super pressure balloon was performed to look at the future replacement of the zero-pressure balloon.

GPS Advanced Upper-air Sounding System (GAUS)

The new ATD GPS Advanced Upper-air Sounding System (GAUS) is under development to replace the venerable GPS LORAN Atmospheric Sounding System (GLASS). The last project for the tried and true GLASS system was the North American Monsoon Experiment (NAME). GAUS incorporates Vaisala RS92 next generation radiosonde, has portability, built-in test capability and flexibility for multiple channel operations, and delivers users final processed data with high precision and additional GPS position data. Vaisala RS92 radiosonde promises to deliver high quality wind measurements from the ground with code-correlating GPS technology, as well as pressure, temperature and humidity measurements all transmitted digitally to the receiving station. Digital technology will reduce missed data due to noise and increase overall reliability in the system. Vaisala RS92 provides much better humidity measurement with the heated twin-sensor design and the new reconditioning procedure before launch. A prototype GAUS has been deployed in TELEX and proven to be successful.

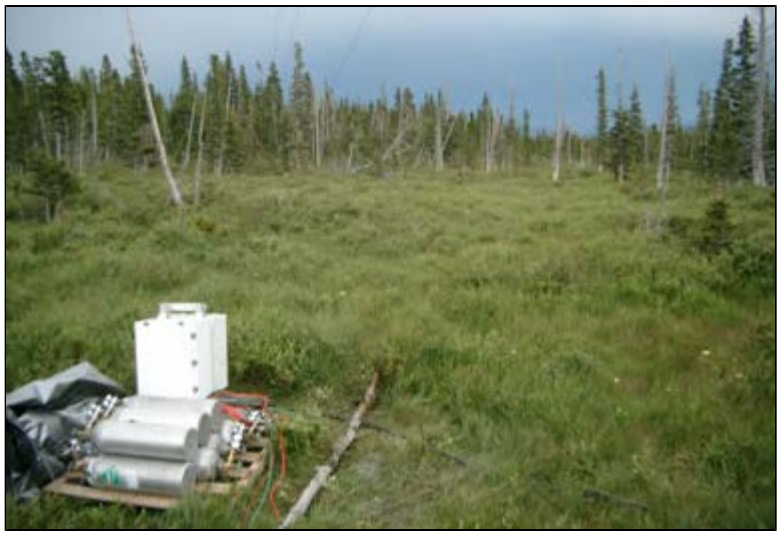
(top)

Surface Flux Systems - Integrated Surface Flux Facility | AIRCOA | Adaptive Sensor Array

ISFF (Integrated Surface Flux Facility)

The ISFF is designed to study exchange processes between the atmosphere and Earth's surface. This includes the direct measurement of fluxes of momentum, sensible and latent heat, trace gases, and radiation as well as standard atmospheric and surface variables. FY04 development activities for the ISFF have been highlighted here.

Autonomous Inexpensive Robust CO2 Analyzer (AIRCOA)



In support of the CME deployment and future experiments to measure local and regional CO2 variations, ATD developed an autonomous, inexpensive, and robust CO2 analyzer, (AIRCOA). ATD's B. Stephens constructed 4 AIRCOA units after initial design testing and deployed three of these in the field during the CME campaign. The figure at the left shows two AIRCOA units at the Willow Site of the project. These units measure CO2 concentrations at 6 levels on a tower, producing individual measurements every 2.5 minutes precise to 0.1 ppm CO2 and closely tied to the WMO CO2 scale. A key component in the robustness of these analyzers is near real-time data processing with extensive automated diagnostic tests to verify normal operation, with new results available from a web interface every day

ASA (Adaptive Sensor Array)

Progress on ASA (formerly ISA) continued this year with the deployment of a prototype system. FY04 development activities for the ASA have been highlighted here.

(top)

Airborne Observing Systems - Select From:

HAIPER

In FY04, modifications to the GV were completed by Gulfstream and Lockheed. These modifications included the installation of three under wing hard points on each wing, three 20.5-inch diameter view ports (two up-looking and one down-looking), several fuselage hard points and aperture plates, cabin attachment points (seat rails), and research power and signal wiring. High pressure testing of the modified fuselage was successfully conducted in September and preparations were made for ferrying of the aircraft from Greenville, SC to Savannah, GA for interior and exterior completion at the Savannah Air Center. The figure to the left shows the newly-modified GV receiving final placement of the NSF and NCAR logo templates on the fuselage.

Over the past year, the various HIAPER infrastructure subgroups made significant progress toward the development of critical research systems for the aircraft. The data acquisition system development group – headed by Mike Spowart and Dick Friesen of the HPO – has led the effort to develop a next generation data system that is faster, smaller, lighter, and consumes less power than the current NSF/NCAR C-130 system. The new GV data system is built around a PC-104 (ISA bus) architecture and will continue to provide all of the standard digital interfaces supported by the C-130 system. Older, non-standard digital interfaces (e.g., the PMS probe 2D interface) will be discontinued and replaced by a new USB interface. Construction of the data sampling modules (DSMs) to be used to acquire data from instrumentation mounted on the aircraft was completed in FY04, as was environmental testing of the DSM prototype. Chris Webster and Mike Daniels continued to oversee the effort to develop new data visualization and access software for the GV. Software engineers from throughout ATD contributed time and expertise to this software development effort, resulting in the creation of several prototype display packages by the conclusion of FY04.

Other HIAPER infrastructure preparation efforts undertaken during FY04 included the award of subcontracts for installation of the intercommunication system (ICS) and SATCOM systems and an Airborne Flight Information System (AFIS) on the GV. The ICS installation will be performed by Garrett Aviation and Savannah Air Center personnel during the aircraft interior and exterior completion time period, and Atlas Telecom will undertake installation of the SATCOM systems and the AFIS following the delivery of the GV to UCAR/NCAR.

In July, two of the ATD pilots – Henry Boynton and Lowell Genzlinger – completed an intensive flight simulator training course in Savannah, GA to receive their credentials to pilot the GV. Additionally, a number of ATD personnel traveled to July during this same month to participate in an “all hands” training program for the aircraft. This latter series of classes provided the participants with the opportunity to learn about emergency and safety procedures for the aircraft and to take part in a drill involving the evacuation of the smoke-filled cabin of a life-size GV cabin model into water. ATD maintenance team members Bob Beasley, Brent Kidd, and Jim Nolan began the GV maintenance training program in September and will complete the course in early October.

Jeffco Hangar

Work commenced on expanded hangar facilities at Jeffco shortly after the start of FY 04. Excavation of the site was completed by January 2004. Underground utility and foundation work was accomplished during February and March. The steel building was delivered in mid-April. Erection of the building started shortly thereafter and continued through the summer. By the end of FY 04, the hangar building was complete. 2 items, sealing and coating the hangar floor and some landscape work remained to be finalized before the project could be called finished. It is expected that both items will be done before the arrival of HIAPER.

C-130

In the past few years, the NCAR C-130 aircraft has been put to the test on a couple of demanding air-sea interaction experiments that involve extensive low-level flight legs in quiescent conditions (e.g. DYCOMS-II and EPIC) to measure turbulent momentum flux. Careful examination of these data sets by Marie Lothon (visitor to MMM and ATD) and Donald Lenschow, as well as EPIC scientists (Chris Bretherton and Charlie Cornish, University of Washington, Seattle) and Steve Esbensen (Oregon State University, Corvallis) revealed modulation of the momentum flux by the aircraft heading and inertial subrange spectra of the velocity components that departed somewhat from theoretical predictions. In an effort to improve the quality of the velocity measurements, ATD undertook an inflight "trailing cone" calibration of the static pressure measurement under the direction of Allen Schanot. Lothon and Lenschow applied the new calibration to

the DYCOMS-II data and found a considerable improvement in the momentum flux measurement. Lenschow has also been collaborating with Bjorn Stevens and Verica Savic-Jovcic (University of California, Los Angeles) on the use of wind measurements from 60 km diameter circles in DYCOMS-II for estimating divergence and vorticity in the marine stratocumulus-capped boundary layer. They found that the standard procedures used for calibrating the air motion system are not adequate for this demanding application. They are working on a protocol that should extend the capabilities of the system to these measurements.

(top)

Remote Sensing Systems

SABL (Scanning Aerosol Backscatter Lidar)

SABL was deployed on the C-130 in two field campaigns and received significant improvements in FY04. Specifically, the field campaigns were AIRS II and Ocean Waves. FY04 development activities for SABL have been highlighted here.

NCAR CO2 and O2 Calibration Facility

ATD has completed assembly of primary components of the NCAR CO2 and O2 Calibration Facility. These include a box to hold 25 large high-pressure gas cylinders oriented horizontally and insulated as necessary to prevent fractionation, a control module to selectively deliver pressure-regulated gases from these cylinders to a cryogenic drier and the concentration instrumentation, a high-precision commercial CO2 analyzer, a repackaged version of the RAF Oxygen Analyzer (ROXAN), and a suite of long-term (~20 years) calibration standards tied to Scripps Institution of Oceanography and NOAA CMDL WMO calibration scales. ATD used this facility to calibrate over 30 CO2 reference cylinders used in the CME and ACME campaigns.

Data and Network Services

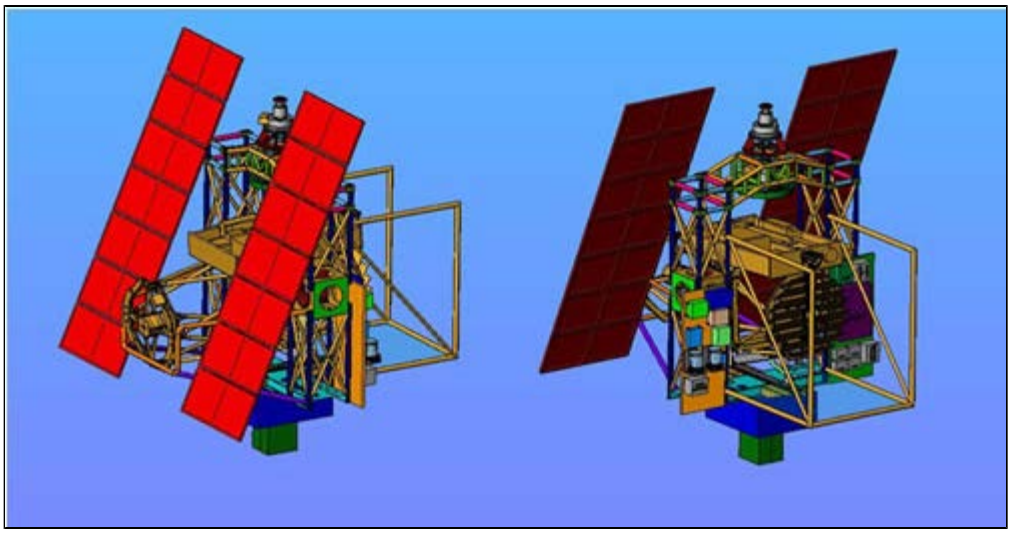
In FY 2004, ATD completed migration to the Active Directory client/server architecture for the Windows desktops, which will enhance computer reliability, facilitate remote management and create a more secure environment. RDP improved ATD data accessibility by connecting ATD to the UCAR Data Portal pilot program. RDP also began building a metadata database, using HIAPER as its first platform, to electronically manage descriptive data for our holdings. When completed, this metadata database will facilitate automation, electronic documentation and consistency for all aspects of ATD metadata. Our data can connect to digital libraries, online analysis tools and data catalogs and our community will see improved data quality since we can better track dataset history, calibration and documentation through the use of this infrastructure.

In preparation for future deployments, ATD collaborated with Unidata and JOSS to bring new capabilities to the RDCC. Chief among these are the use of Unidata's Integrated Data Viewer (IDV) to display S-Pol Radar data, GOES 1km satellite data, aircraft tracks and sounding data into one integrated three dimensional display for future projects. In addition to the operational goals of providing an extraordinary level of real-time data and communication services, ATD's FY04 preparations served an educational purpose - that of creating tutorials regarding the analysis of atmospheric data that will be used by students in the atmospheric sciences.

(top)

Design and Fabrication

Purchase of a new 4-axis machining center occurred in the second quarter of FY 2004. This new machine tool increases the physical size capability,



accuracy and productivity of machined parts produced by the group. DFS supported a number of major projects as well as numerous small projects.

Some of the major projects were:

- Sunrise balloon borne solar telescope;
- Driftsonde;
- HIAPER infrastructure and instrumentation development;
- S-Pol deployments and improvements;
- APOL developments;
- Eye safe Lidar (REAL) developments;
- Water vapor DIAL developments;
- and a Laser induced fluorescence inlet.

(top)

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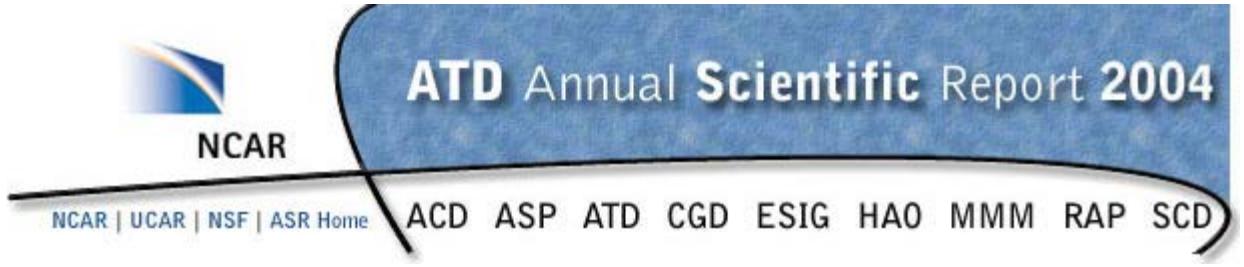

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Jump to ATD Achievements in: Research

ATD Achievements - Field Programs Select From:

ATD exemplifies NCAR's community service function. ATD's activities advance the community's observational capabilities through the deployment of existing facilities and the development, sometimes over many years, of new instrumentation and platforms. Two thirds of all ATD support activities serve university users and most involve users from several universities. Many university and NCAR scientists regard ATD's capabilities and services as the primary justification for a national center. In FY04, ATD participated in 12 Field Projects throughout North America utilizing 12 of our facilities as well as the C-130.

FY 04 Field Programs

Name	Facilities	Dates	PI's
HVAMS	ISFF, TAOS	Sept. 15 – Oct. 31, 2003	Dr D Fitzjarrald, University of Albany
AIRS II , ATReC	C130, SABL, Dropsonde	Nov. 10 – Dec. 12, 2003	Dr J. Hallett, DRI, U. of North Dakota
TELEX	Dropsonde	10 May – 20 June 2004	D. MacGorman, Oklahoma University/CIMMS and NSSL
WISP-04	S-Pol, S-Polka	Feb. 15 – Mar. 30, 2004	J. Vivekanandan (ATD) M. Politovich (RAP)
Ocean Waves	C130, SABL	Jan. 5 – Feb. 6, 2004	K. Melville, Scripps Inst. Of Oceanography
Sierra Rotors	MAPR, MISS, and Mobile GLASS	Mar. 1 – Apr. 30, 2004	V. Grubisic, DRI
NAME	S-Polka, ISS, and GLASS	Jul. 1 – Aug. 15, 2004	S. Rutledge (CSU)
ACME	C130, ISFF	Apr. 1 – Jul 31, 2004	D. Schimel (CGD/NCAR) R. Monson, S. Buhr, D. Ojima, B. Stephens, L. Sternberg
OHATS	ISFF	Aug. 5 – Sep. 5, 2004	P. Sullivan (MMM/NCAR), J. Edson (WHOI), J. Wyngaard (Penn State University), T. Horst (ATD/NCAR), D. Lenschow (MMM/NCAR), C.

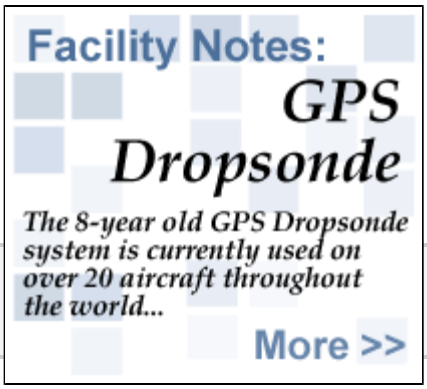
			Moeng (MMM/NCAR), and J. Weil (CIRES, University of Colorado).

Hudson Valley Ambient Meteorology Experiment (HVAMS) (top)

Nine **ISFF** stations and **TAOS** were deployed in New York's Hudson Valley from 15 September through 31October 2004 between Albany and Kingston, NY. David Fitzjarrald from SUNY, Albany, designed this study to examine how local topography and land use patterns affect boundary layer dynamics under predominantly fair weather conditions. During the intensive observation period of HVAMS, a fine-scale network of turbulence observations, enhanced remote sensing capability and aircraft measurements was used to study the physical mechanisms responsible for surface-atmosphere exchanges in this 500 km valley that stretches from New York City to the Canadian border. The nine ISFF were located at sites featuring different land use types and local exposure conditions to capture heterogeneities in radiative and surface fluxes, and to describe the evolution and structure of the nocturnal boundary layer and effects of land-surface heterogeneity on transport and dispersion. TAOS was used to assess environmental stability, moisture, temperature and winds in the lowest 300 m of the atmosphere and to analyze the development, decay and horizontal extent of the NLLJ. The Wyoming King Air provided flux measurements.

Alliance Icing Research Study II (AIRS II) and the Atlantic-THORPEX Regional Campaign (ATReC) (top)

Dr John Hallett of the Desert Research Institute and several co-investigators requested the use of the **NSF C-130 with SABL** in support of the Alliance Icing Research Study II (AIRS-II) field program. This was the second phase of a multi-agency, multi-platform project designed to investigate the current capabilities for remote sensing of aircraft icing. C-130 flight operations were conducted out of Cleveland Ohio and closely coordinated with other research assets. Its primary function was to characterize the cloud-active aerosol content of the upwind source region of a target area located near Montreal, Canada. AIRS-II was endorsed by the Aircraft Icing Research Alliance (AIRA), which consists of government organizations within North America interested in aircraft icing. It was also supported by the WMO World Weather Research Program project on Aircraft In-Flight Icing. ATD flew 81 research flight hours during the project.



ATReC was a joint effort of Atlantic THORPEX regional study and the Aircraft Icing Research Study II (AIRS II). The University of North Dakota Citation supported the project with coordinated flight tracks in conjunction with the NASA ER-2. The Citation's primary mission was to provide **Dropsonde** data in real time to support project goals. These dropsonde data were placed on the Global Telecommunications System for inclusion into model runs, from the aircraft immediately after completion of a drop.

Thunderstorm Electrification and Lightning Experiment (TELEX) (top)

For a second year in a row, instrumented balloons were launched into storms during the Thunderstorm Electrification and Lightning Experiment (TELEX), which took place from May to June 2004 in Oklahoma. The broad objective of this two-year program is to understand how lightning and other electrical storm properties are dependent on storm structure, updrafts, and precipitation. The 2004 study aimed at testing and revising hypotheses concerning the inter-relationship among the wind field, microphysical characteristics, electrical structure, and lightning of isolated severe storms and of large storm systems. Balloon soundings launched from a NSSL mobile van were used to measure the electric field profile of storms. **Dropsondes used as upsondes** were flown along with an electric field meter on the same balloon to acquire vertical soundings of electric fields, winds and thermodynamic parameters.

WISP-04 (top)

The objective of this project, which took place at the Marshall Radar Site, was to develop techniques for detecting super cooled liquid droplets in single and mixed phase clouds. The project was funded by FAA and a number of NSF, NOAA and NASA observational facilities were used in the project. S-Pol radar with a new Ka-band radar system, GPS on mobile GLASS, NOAA Ka-band radar systems, a number of ground-based radiometers, video disdrometer, and Citation research aircraft from University of North Dakota were all used for observing clouds and precipitation along the front range.

Facility Notes: S-Pol
S-Pol has seen some major modifications during FY04 and has been deployed on two major field projects...
More >>

Ocean Waves (top)

Dr Ken Melville of Scripps and Dr Carl Friehe of U.C. Irvine received funding from NSF for use of **NSF C-130** in support of the Ocean Waves I program. Data were collected to study the coupling between the marine atmospheric boundary layer and the marine oceanic boundary layer through the surface wave field. Special attention was paid to the effects of wave breaking on air-sea fluxes and boundary layer development. Flight operations were conducted from Huatulco, Mexico with flight legs targeting air-sea interactions over the eastern Pacific Ocean where the wintertime flow regime immediately off the coast was characterized by strong gap flow winds that originate in the Gulf of Mexico and transit through the mountain passes.

A variety of optical sensors including **SABL** was be used to measure the surface wave field. In situ measurements of various surface fluxes, meteorological and chemical, and profiles of the thermal structure in the upper mixed layer of the ocean were used to study the coupled development of the surface wave field and the air-sea boundary layer in off-shore wind conditions. The **GPS Dropsonde system** documented the environment of the marine atmospheric BL to within a few meters of the surface.

Facility Notes: SABL
SABL was deployed on the C-130 in two field campaigns and received significant improvements in FY04...
More >>

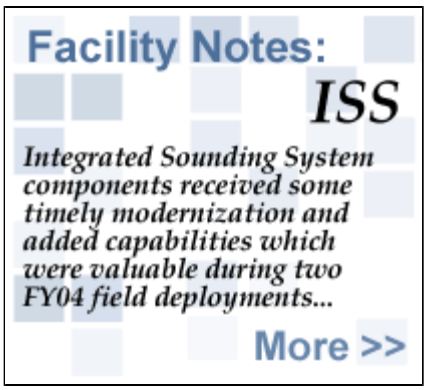
Sierra Rotors (top)

The Sierra Rotors Project was an NSF-funded project to study mountain-wave induced rotors in the lee of the Sierra Nevada in Owens Valley. Rotors are intense horizontal vortices with strong turbulence that can pose severe aeronautical hazards. The eastern slopes of the southern Sierra Nevada make up the tallest, steepest, quasi-linear topographic barrier in the contiguous United States, and are well-known for generating large-amplitude mountain waves and strong rotors over the Owens Valley. The main objective of this project was to establish quantitative characteristics of the rotor behavior as well as to evaluate the extent to which current operational mesoscale models can reliably forecast the occurrence of rotors. NCAR/ATD deployed a mobile Integrated Sounding Systems (**MISS**) and a fixed **ISS with MAPR** near Independence as well as a mobile GLASS system near Fresno, CA. Sierra Rotors served as the pilot study for the Terrain-induced Rotor Experiment (T-REX), scheduled for spring 2006.

For more information, see the section on Community Research: Remote Sensing of Terrain-Induced Waves and Rotors on our Research Achievements page.

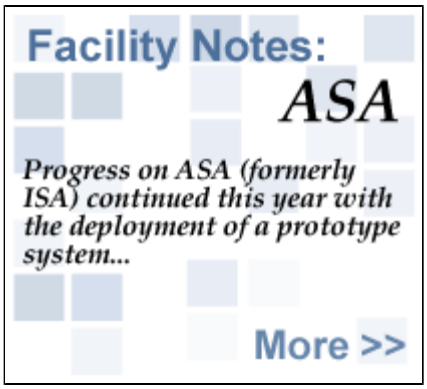
NAME (top)

The North American Monsoon Experiment (NAME) was an internationally coordinated, multi-agency project that investigated the sources of warm season precipitation over North America. The project focused on observing and understanding the key components of the North American monsoon system and variability within the context of the evolving land surface-atmosphere-ocean annual cycle. Richard Johnson from CSU was funded to deploy three Integrated Sounding Systems (**ISS**) and one GPS/Loran Atmospheric Sounding System (**GLASS**) on the east and west side of the Gulf of California. Steve Rutledge was the main PI for NCAR's **S-Pol radar**, which was temporarily located about one hour north of Mazatlan to observe and describe the daily cycle of convective rainfall, the structure and location of precipitation systems, and to characterize the microphysics. To support the high frequency soundings component of NAME, ATD temporarily hired 15 US and 2 Mexican students for the duration of the project, providing a substantial educational component to the project.



Airborne Carbon in the Mountains Experiment (ACME) (top)

The **C-130 and three ISFF** were deployed by NCAR/ATD in support of the Airborne Carbon in the Mountains Experiment (ACME) in summer 2004. Dr David Schimel (NCAR - MMM) was funded by NSF (Biocomplexity) and collaborated with CU, CSU, U. Miami, and NCAR ATD, and CGD to combine airborne data with ground-based measurements to obtain a more accurate picture of carbon exchange over complex terrain on regional scales. Results from the field program will also be used in testing computer models of forest ecosystem function. These models could potentially help in accurately assessing to what extent carbon dioxide storage in Western mountain forests--a potentially important "sink" for the greenhouse gas--may be slowing down as the ongoing drought and wild fires affects tree growth.



The C-130 operated from its home base at Jefferson County Airport in Colorado and airborne measurements focused on carbon dioxide, moisture fluxes, carbon monoxide and fast ozone. ATD flew a total of 54 hours on the NCAR C-130 aircraft over large regions of the Colorado Rocky Mountains, making continuous measurements of CO2, CO, O3, and water vapor concentrations, and collecting discrete flask samples for 13C and 18O isotope ratios in CO2 (University of Utah). In addition to these primary measurements, ATD also flew the MCR scanning radiometer with thermal and vegetation channels (Tschudi), collected flask samples for radiocarbon measurements and for verification of our in situ CO2 and CO measurements (Scripps Institution of Oceanography), and collected high rate CO2, CO, O3, and water vapor data for direct eddy-correlation flux estimates (Campos).

The flights were conducted according to a combination of experimental designs, including morning to afternoon Lagrangian flux measurements, regional survey measurements for assimilation into a high-resolution ecosystem-atmosphere model, morning sampling of nocturnally respired CO2 and its concentration by topography and dispersion by turbulence, flask sampling to resolve elevation gradients in isotope signatures, and direct flux measurements. Our analyses of these data are just beginning, but preliminary results are encouraging. During the Lagrangian experiments and regional surveys, ATD observed CO2 drawdowns of several ppm in boundary-layer CO2, representing significant CO2 uptake by the forests and strong signals for use in our analyses. Also, in large mountain valleys ATD observed on the order of 30 ppm of respired CO2 pooling as deep as 1000 ft. and persisting until 10 AM, which may suggest techniques for making respiration estimates on relatively large scales. Our results are already helping the community adapt plans for the North American Carbon Program

to improve constraints on mountain carbon fluxes. Our airborne measurements will be compared to and integrated with the extensive ongoing carbon and ecosystem measurements at Niwot Ridge and an enhanced network of ground-based measurements deployed as part of the broader Carbon in the Mountains Experiment (CME).

To enhance the existing carbon-cycle measurements at this site, ATD deployed three ISFF towers which continuously monitored temperature, humidity, 3-dimensional winds, CO2 fluxes, and high-accuracy CO2 concentrations at multiple levels up to 30 m in the Como Creek watershed on Niwot Ridge near Nederland, CO. Twelve prototype low-level Adaptive Sensor Array (**ASA**) sites were deployed to characterize soil respiration. The figure above left shows the installation of the ground sensors. In response to results from a pilot experiment in 2002, ATD's Hydra instrument was deployed to sample CO2 concentrations at 12 locations along a 260m transect that crossed the local drainage between the University of Colorado's Ameriflux tower and one of the ISFF towers.The CO2 concentration instruments included the HYDRA system with 18 inlets and three new AIRCOA units with six inlets each. These observations will be used to fully resolve the atmospheric transport of CO2 in order to accurately measure the net ecosystem carbon exchange, and as input to a regional-scale data-assimilation model to improve our understanding of the processes controlling carbon cycling by mountain forests.

Ocean Horizontal Array Turbulence Study (OHATS) (top)

Dr Peter Sullivan (NCAR/MMM) and colleagues from Woods Hole Oceanographic Institute (WHOI) and Penn State University requested the use of **ISFF** sonic anemometers in summer 2004 for the Ocean Horizontal Array Turbulence Study (OHATS). OHATS is part of an ongoing effort to investigate wind-wave interactions and their impacts on weather forecasts and climate variability.

An array of 18 sonic anemometers was deployed on the Air-Sea Interaction Tower (ASIT), a 12-meter platform that is located off the coast of Martha's Vineyard. The sonic anemometers were suspended below the tower in two arrays of 9 sonics each at about 5 and 5.5 meters above mean sea level. Other measurements, provided by WHOI and ingested by the ISFF data system, include an independent CSAT3 sonic at a height of 9 m, collocated with a Licor 7500 fast water vapor and CO_2 sensor and a Vaisala hygrothermometer; three laser wave height sensors; and an inertial motion package attached to the crosswind array. The PIs studied the physical processes that generate and/or modulate the turbulent transfer of momentum, heat, and mass through the atmospheric surface layer to the underlying surface, especially how wind-generated waves and swell influence the marine surface layer and air-sea fluxes. The ultimate goal of the research is to improve how these wave-induced processes are simulated in numerical models. Data collection from these arrays began in early August 2004 and ended in early October 2004, which allowed collection of data that captured a wide range of conditions.

INTEX-NA Field Study (NASA Deployment) (top)

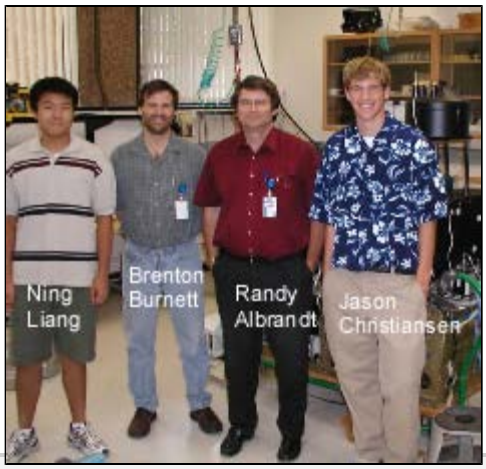
The modified TDLAS system was deployed this past summer during the NASA-funded 2004 INTEX-NA field campaign to study North American pollution outflow and chemical transformations. The system improvements worked extremely well in all respects, and this allowed us to successfully acquire ambient CH2O measurements on 19 out of the 20 mission flights. Preliminary field data have been submitted and ATD is in the process of preparing finalized data to NASA.

Education and Outreach

Select From:

ATD values its role in reaching out to and guiding the next generation of scientists. In FY04, ATD scientists acted as thesis committe members to Ph.D. candidates, adjunct faculty for atmospheric research programs, and opened their doors and gave of thier time to undergrads and high school students to enlighten and inspire.

APOL



APOL's Biocomplexity Project was created by two highschool teachers (Brenton Burnett and Randy Albrandt) and two high school students (Ning Liang and Jason Christiansen) and was designed to serve the secondary education community in developing public understanding of climate change science and associated technologies. Visit APOL's site to see their work in describing the context of carbon's role in climate change, how APOL's laser spectrometer addresses important questions, and how this new laser system functions.

Expanding Your Horizons Conference

The Expanding Your Horizons Conference is an annual event organized by the Boulder Branch of the American Association of University Women (AAUW) and the University of Colorado at Boulder. Its aim is to encourage pre-teen and teenaged girls to study math and science, to increase awareness of the options available in non-traditional careers, and to meet women whose careers depend on math, science, engineering and technology.

The conference was held on April 3rd in the CU engineering center, and was attended by close to 200 girls from schools along the Front Range. Thirty presenters were each asked to lead three fifty-minute workshops to groups of 12 girls each. ATD's Kate Young presented a workshop focused on atmospheric profiling with radiosondes and

dropsondes (specifically temperature, dewpoint, and relative humidity measurements) and skew-t diagrams. Young created a hands-on portion in which the girls examined and plotted data from a shortened sounding file. They created a simplified skewt diagram by plotting temperature and dewpoint versus pressure. She then explained to them how these diagrams can be used to detect moist (cloud) and dry layers. As always, this enjoyable workshop was a great experience for these young women to learn more about the opportunities available to them.

Postdoc Fellowships

Weibring, Petter - Lund University, Sweden

Graduate Research Assistants

Roller, Chad, Rice Univeristy - Biocomplexity

Novella, Nick, Creighton University - Field Project Deployment

Pettigrew, Brian University of Missouri - Field Project Deployment

Kleefish, Stacy University of Illinois - Field Project Deployment

Husted, Linsay University of North Carolina - Field Project Deployment

Franks, Cristopher Creighton University - Field Project Deployment

Castro, Christopher Colorado State Univeristy - Field Project Deployment

Rogers, Peter Colorado State Univeristy - Field Project Deployment

Undergraduate Students, non-Science

Agee, Brad - Ball State University - Field Project Deployment

Cavanaugh, Liam - University of Colorado, Boulder - Field Project Deployment

Derner, Katie - Augustana - Field Project Deployment

Gallup, Mark - University of Arizona - Field Project Deployment

Lutz, Isaac none - Field Project Deployment

McIntyre, Heather - Metro State - Field Project Deployment

Peterson, Max - University of British Columbia - Field Project Deployment

Roesch, Conrad - University of Colorado - Field Project Deployment

Schellinger, Jennifer - California State University - Field Project Deployment

Spowart, Kirk - University of Colorado - Field Project Deployment

Torres, Rebeca - San Jose State University - Field Project Deployment

Formal Teaching Arrangements

Brown, William, Thesis Committee Member, Amanda Cox, University of Colorado.
Brown, William, Thesis Committee Member, Simon Alexander, University of Adelaide, Australia.

Campos, Teresa, Thesis Committee Member, Gannet Hallar, University of Colorado.

Hubbert, John, Adjunct Faculty, blank, Colorado State University.
Hubbert, John, Thesis Committee Member, Nitin Bharadwaj, Colorado State University.

Lee, Wen-Chau, Thesis Committee Member, Yang Yang, University of Hawaii.
Lee, Wen-Chau, Thesis Committee Member, Ren-Feng Liu, National Taiwan University.
Lee, Wen-Chau, Thesis Committee Member, blank, National Central University, Taiwan.
Lee, Wen-Chau, Adjunct Faculty, University of Hawaii.
Lee, Wen-Chau, Thesis Committee Member, Shirley Murillo, University of Hawaii.

Poulos, Gregory, Adjunct Faculty, Colorado University, Boulder.
Poulos, Gregory, Thesis Committee Member, Justin Cox, PhD, University of Utah.
Poulos, Gregory, Adjunct Faculty, University of Utah.

Stith, Jeff, Thesis Committee Member, Nick Anderson, University of North Dakota.

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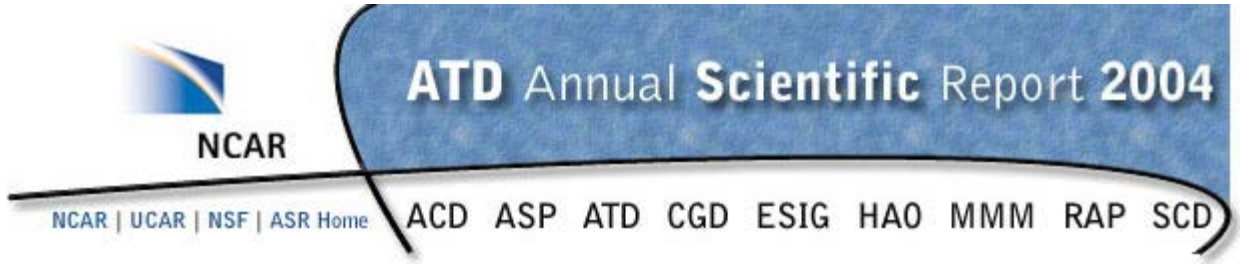


Community Service

Select From:

Field Projects

ATD exemplifies NCAR's community service function. ATD's activities advance the community's observational capabilities through the deployment of existing facilities and the development, sometimes over many years, of new instrumentation and platforms. For more information on this critical service ATD provides to the Atmospheric Research community, please visit the Field Projects page of this report.

Community Research

In addition to our state-of-the-art observing facilities, field support and data services, ATD plays another important role in the atmospheric research community - that of collaborative scientific research and analysis of data gathered from field projects. In FY 04, ATD collaborated with scientists from all over the globe to further understand such atmospheric phenomena as terrain-induced waves and rotors, airflow across rugged terrain, turbulance and fluxes in the boundary layer, ambient formaldehyde, and ice propagation. For more detail, visit our ATD Achievements - Research page.

External Scientific, Policy, or Educational Committees and Advisory Panels

Campos, Teresa, Member, Gannet Hallar Ph.D. Thesis Committee, also the Reader, University of Colorado Department of Astrophysical, Planetary and Atmospheric Sciences, November, 2003.
Campos, Teresa, Member, Biogeosciences Initiative Steering Committee, NCAR Strategic Initiatives, 2004.
Campos, Teresa, Member, Upper Troposphere / Lower Stratosphere Initiative Steering Committee, NCAR Strategic Initiatives, 2003-present.

Cohn, Stephen, Chair, Organizing Committee, 7th International Symposium on Tropospheric Profiling, 2003-present.
Cohn, Stephen A., Member, Organizing Committee, 11th Conference on Aviation, Range, and Aerospace Meteorology, 2004.

Fried, Alan, Co-Chair, International Topcial Meetings, Laser Applications to Chemical Analysis, 2004-2006.
Fried, Alan, Member, International Advisory Committee, Fifth Conference on Tunable Diode Laser Spectroscopy, 2004-2005.
Fried, Alan, Member, Special Session Convener on Tropospheric Photochemistry, American Geophysical Union Meeting, 2004.

Haggerty, Julie, Member, Organizing Committee for IGARSS06 conference, IEEE Geoscience and Remote Sensing Society, 2004-2007.
Haggerty, Julie, Member, NCAR Biogeoscience Initiative Advisory Panel, blank, 2004, ongoing.

Kessinger, Cathy, Member, Artificial Intelligence Applications in the Atmospheric Sciences, AMS, 2003-2005.

Lee, W.-C., Member, Master and Ph.D Thesis Committee, University of Hawaii, 2002 - Present.

Mayor, Shane, Member, Committee on Laser Atmospheric Studies, American Meteorological Society, 2003-2006.

Poulos, Gregory S., Co-Chair, Mountain Meteorology Conference, 11th Conference on Mountain Meteorology, 2002-present.
Poulos, Gregory, Chair, Mountain Meteorology Committee, American Meteorological Society, 2003 - present.
Poulos, Gregory, Member, Facilities Advisory Panel, National Science Foundation, 2003 - present.
Poulos, Gregory, Member, TREX Steering Committee, Terrain-induced Rotors Experiment, 2004 - present.

Richter, Dirk, Secretary, blank, Rocky Mountain Optical Society, 2004-present.

Rogers, Dave, Member, steering committee, NCAR UTLS Strategic Initiative, 2003 - present.
Rogers, Dave, Member, steering committee, NCAR - Ice Initiation in Clouds, 2003 - present.

Spuler, Scott, Vice President, blank, Rocky Mountain Optical Society of America, September 2004 - present.

Stephens, Britt, Member, Implementation Group 3 - Exchange of Greenhouse Gases, The Surface Ocean - Lower Atmosphere Study (SOLAS), 2003 - present.

Stith, Jeff, Member, International Commission on Clouds and Precipitation, blank, 1996-2004.
Stith, Jeff, Member, International Commission on Clouds and Precipitation, blank, 1996-2004.

Wang, Junhong, Member, AMS committee on measurements, blank, 2004-2007.
Wang, Junhong, Member, NCAR/UCAR ECSA, blank, 2002-present.
Wang, Junhong, Member, Steering committee of 'communicating science initiative', NCAR/UCAR, 2003-present.

Weckwerth, Tammy, Member, Annual Awards Jury, UCAR, 2002-present.
Weckwerth, Tammy, Member, EOL AD search committee, NCAR, 2004.
Weckwerth, Tammy, Member, UCAR Awards' Jury, blank, 2002 - present.

Wilson, James, Member, NEXRAD Technical Advisory Committee, blank, 1992 - present.
Wilson, James, Member, Working Droup on Nowcasting, World Weather Research Program, 2003 - present.

Editorships

Poulos, Gregory, Guest Editor, Journal of the Atmospheric Sciences, 2002-Oct 2003.
Weckwerth, Tammy, Associate Editor, Mon. Wea. Rev., 1998 - present.
Weckwerth, Tammy, Associate Editor, J. Atmos. Sci., 2003 - present.

Workshops and Colloquia

AVAPS Users Group Meeting, April 20, 21 2004, Terry Hock, ATD.

Expanding Your Horizons, 3 April 2004, Kate Young (presenter), AAUW (Boulder Branch).

Flux Measurement Techniques Informal Workshop, 6 April 2004, Chris Fairall and Judith Perlinger, NOAA ETL Clouds, Radiation and Surface Processes Division.

Ice Initiation, 7-8 June, 2004, Dave Rogers, Jeff Stith, Andy Heymsfield, Sharon Lewis, NCAR Director's Opportunity Fund.

Awards

NCAR Outstanding Accomplishment Awards (link)

Outstanding Publication

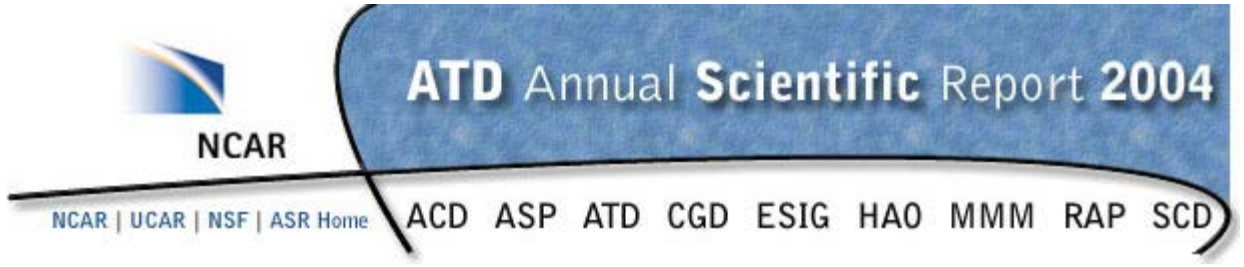
"For original research published as papers or books, or for works that connect atmospheric science with other disciplines or public policy."

Thomas Horst, for his participation in two recent articles describing work on the Horizontal Array Turbulence Study, which revealed the need for new models of a type of turbulence known as subfilter scale. ("HATS: Field observations to obtain spatially filtered turbulence fields from crosswind arrays of sonic anemometers in the atmospheric surface layer," Journal of Atmospheric Science, 41, 1566–1581, 2004; and "Structure of subfilter-scale fluxes in the atmospheric surface layer with application to large-eddy simulation modeling," Journal of Fluid Mechanics, 482, 101–139, 2003).

Mentoring

"For exemplary and sustained mentoring efforts that directly enhance one or more persons' career development."

Jim Wilson, for providing meaningful mentorship to a broad range of people, from junior and senior scientists, administrators, and engineers to various levels of students.



Publications

Select From:

Referreed - Journal Articles

Banta, R.M.,, L.S. Darby*, J.D. Fast*, J.O. **Pinto**, W.J. Shaw*, C.D. Whiteman*, 2004, Nocturnal low-level jet in a mountain basin complex. I. Evolution and effects on local flows, J. Appl. Meteor., 132.

Bluestein, Howie, **W.-C. Lee**, **M. Bell**, C. Weiss*, A. Pazmany*, 2004, Mobile-Doppler-radar observations of a tornado in a supercell near Bassett, Nebraska on 5 June 1999., Monthly Weather Review, 131, 2968-2984.

Cohn, Stephen A., 2004, Flow in complex terrain: Observations by radar wind profilers and anemometers near Juneau, Alaska, J. Appl. Meteor., 43, 437-448.

Cox, A. W., W. J. Steenburgh*, D. E. Kingslill*, J.C. Shafer*, B. A. Colle*, O. Bousquet*, B. F. Smull*,, 2004, Kinematic Structure of a Wasatch Mountain Winter Storm during IPEX IOP3, Mon. Wea. Rev., in press.

Davis, C., N. Atkins*, D. Bartels*, L. Bosart*, M. Coniglio*, G. Bryan*, W. Cotton*, D. Dowell*, B. Jewett*, 2004, The Bow Echo and MCV Experiment (BAMEX): Observations and opportunities., Bull. Amer. Meteor. Soc,, 85, 1075-1094.

Davis, D.D., F. Eisele, G. Chen*, J. Crawford*, G. Huey*, D. Tanner*, D. Slusher*, L. Mauldin*, **S. Oncley**, 2004, An overview of ISCAT 2000, Atmos. Env., 38, 5363-5373.

DeMott, Paul, Sassen, Poellot, Baumgardner, Brooks, Prenni, Kreidenweis, **David C. Rogers**, 2003, African dust aerosols as atmospheric ice nuclei, Geophys. Res. Lett, 30.

DeMott, Paul, Cziczo, Prenni, Murphy, Kreidenweis, Thomson, Borys, **David C. Rogers**, 2003, Measurements of the concentration and composition of nuclei for cirrus formation, Proc. Nat'l Acad. Sci., 100, 14655-14660.

Dilling, Lisa, S.C. Doney*, J. Edmonds*, K.R. Gurney*, R. Harriss, **B. Stephens**, and others, 2004, The role of carbon cycle observations and knowledge in carbon management., Annual Review of Environment and Resources, 28, 521-558.

Doney, Scott, R. Anderson*, J. Bishop*, K. Caldeira*, C. Carlson*, M.-E. Carr*, **B. Stephens**, others, 2004, Ocean Carbon and Climate Change (OCCC): An Implementation Strategy for U. S. Ocean Carbon Cycle Scie, 108 pp..

Doviak, R.J., G. Zhang, **S.A. Cohn**, **W.O.J. Brown**, 2004, Comparison of spaced-antenna baseline wind estimators: Theoretical and simulated results, Radio Science, 39, doi:10.1029/2003RS002931.

Faloona, I., **D. Lenschow**, **T. Campos**, B. Stevens*, M. van Zanten*, B. Blomquist*, D. Thornton*, , 2004, Observations of entrainment in Eastern Pacific marine stratocumulus using three conserved scalars, Journal of Atmospheric Sciences, in press.

Gerbig, Christoph, J.C. Lin*, S.C. Wofsy*, B.C. Daube*, A.E. Andrews*, **Britton Stephens**, P.S. Bakwin*, 2004, Toward constraining regional-scale fluxes of CO2 with atmospheric observations over a continent: 1. , J. Geophys. Res., 108,

4756.

Gerbig, Christoph, J.C. Lin*, S.C. Wofsy*, B.C. Daube*, A.E. Andrews*, **Britton Stephens**, P.S. Bakwin*, 2004, Toward constraining regional-scale fluxes of CO2 with atmospheric observations over a continent: 2. , J. Geophys. Res., 108, 4757.

Harasti, P. R., C. J. McAdie*, P. Dodge*, **W.-C. Lee**, J. Tuttle, S. T. Murillo*, F. D. Marks*, 2004, Real-time implementation of single-Doppler analysis methods for tropical cyclones: Algorithm improve, Weather and Forecasting, 19, 219-239.

Horst, Tom, J. Kleissl*, **D.H. Lenschow**, C. Meneveau*, C.-H. Moeng, M.B. Parlange*, P.P. Sullivan, J.C. Weil, 2004, HATS: Field Observations to Obtain Spatially Filtered Turbulence Fields from Crosswind Arrays of Son, J. of the Atmospheric Sciences, 61, 1566 - 1581.

Hubbert, **John, S. Ellis**, G. Meymaris, M. Dixon, 2003, NEXRAD Range-Velocity Mitigation: SZ(8/64) Phase Coding for the RVP8 Processor, FY2003 Annual Report, 54pp.

Kingsmill, D. E., S. Yuter*, A. Heymsfield, P. V. Hobbs*, A. V. Korolev*, **J. L. Stith**, A. Bansemer, <, 2004, TRMM Common Microphysics Productes: A tool for evaluating spaceborne precipitation retrieval algorit, J. Appl. Meteor. , In Press.

Lang, Timothy, S. A. Rutledge*, **J. L. Stith**, 2004, Observations of Quasi-Symmetric Echo Patterns in Clear Air with the CSU-CHILL Polarimetric Radar, J. Atmos. Oceanic Technol. , 21, 1182-1189.

Lin, John, C. Gerbig*, S.C. Wofsy*, B.C. Daube*, A.E. Andrews*, **Britton Stephens**, P.S. Bakwin*, 2004, Measuring fluxes of trace gases at regional scales by Lagrangian observations: Application to the CO, J. Geophys. Res., 109, D15304.

Maria, S.F., L.M. Russell*, B.J. Turpin*, R.J. Porcja*, **T.L. Campos**, R.J. Weber*, B.J. Huebert*, 2003, Source signatures of carbon monoxide and organic functional groups in ACE-Asia submicron aerosol typ, J. Geophys. Res. -- Atmospheres, 108(D23), Art. No. 8637.

Mayor, Shane D., **Scott M. Spuler**, 2004, Raman-shifted Eye-safe Aerosol Lidar, Applied Optics, 43, 3915-3924.

Moeng, Chin-Hoh, **G. S. Poulos**, M. M. Lemone, 2003, Preface - William Blumen Memorial CASES-99 Special Issue, Journal of Atmospheric Sciences, 60, 1.

Oncley, S.P., M. Buhr*, **D.H. Lenschow**, D. Davis*, S.R. Semmer, 2004, Observations of Summertime NO Fluxes and Boundary-Layer Height at the South Pole, during ISCAT 2000 U, Atmos. Env., 38, 5389-5398.

Poulos, Gregory, Sean Burns, 2003, An evaluation of bulk Ri-based surface layer flux formulae for stable and very stable conditions wit, Journal of Atmospheric Sciences, 60, 2523-2537.

Riggan, P.J., R.G. Tissell*, R.N. Lockwood*, J.A. Brass*, J.A.R. Pereira*, H.S. Miranda*, A.C. Miranda*, 2004, Remote measurement of energy and carbon flux from wildfires in Brazil, Ecological Applications, 14(3), 855-872.

Riggan, P., R. Tissell*, R. Lockwood*, J. Brass*, J. Pereira*, H. Miranda*, A. Miranda*, **T. Campos**, 2004, Remote measurement of energy and carbon fluxes from wildfires in Brazil, Ecological Applications, 14(3), 855-872.

Roy, B., J. B. Halverson*, **J. Wang**, 2004, The influence of radiosonde 'age' on TRMM field campaign soundings humidity correction, J. Atmos. Oceanic Technol., 21, 470-480.

Stevens, Bjorn, **D.H. Lenschow**, I. Faloona*, C.-H. Moeng, D.K. Lilly*, B. Blomquist*, G. Vali*, A. Band, 2003, On Entrainment Rates in Nocturnal Marine Stratocumulus, Quarterly Journal of the Royal Meteorological Society, 129(595), 3469-3493.

Stith, Jeff, **J. A. Haggert**y, A. Heymsfield, C. A. Grainger*, 2004, Microphysical Characteristics of Tropical Updrafts in Clean Conditions, J. Appl. Meteor. , 43, 779-794.

Tjernstrom, M, C. Leck*, P.O.G. Persson*, M.L. Jensen*, **S.P. Oncley**, A. Targino*, 2004, The summertime arctic atmosphere: Meteorological, measurements during the Arctic Ocean Experiment 200, Bull. Amer. Meteor. Soc., 85, 1305-1321.

Wakimoto, R. M, H. V. Murphey*, R. G. Fovell*, **W.-C. Lee**, 2004, Mantle echoes associated with deep convection: Observations and numerical simulations., Monthly Weather Review, 132, 1701-1720.

Wakimoto, Roger, **H Cai**, H. V. Murphey*, 2004, The Superior, Nebraska Supercell during BAMEX., Bull. Amer. Meteor. Soc., 85, 1095-1106.

Wakimoto, Roger, H. V. Murphey*, **H Cai**, 2004, The San Angelo Supercell of 31 May 1995: Visual Observations and Tornadogenesis, Mon. Wea. Rev., 132, 1269-1293.

Wang , Junhong, 2004, Evaluation of performance of the dropsonde humidity sensor using data from DYCOMS-II and IHOP_2002, J. Atmos. Oceanic Technol., in press.

Weckwerth, Tammy, **D.B. Parsons**, S.E. Koch*, J.A. Moore*, M.A. LeMone, B.B. Demoz*, C. Flamant*, B. Geert, 2004, An Overview of the International H2O Project (IHOP_2002) and Some Preliminary Highlights, Bull. Amer. Meteor. Soc., 85, 253-277.

Wetzel, Melanie, M. Meyers*, R. Borys*, R. McAnelly*, W. Cotton*, A. Rossi*, P. Frisbie*, D. Nadler*, D. Low, 2004, Mesoscale Snowfall Prediction and Verification in Mountainous Terrain, Weather and Forecasting, 19, 806 - 828.

Yu, Tian-you, **W.O.J. Brown**, 2004, High-resolution atmospheric profiling using combined spaced antenna and range imaging techniques, Radio Science, 39, doi:10.1029/2003RS002907.

Zhang, Guifu, R.J. Doviak*, **J. Vivekanandan**, **W.O.J. Brown**, **S.A. Cohn**, 2004, Performance of correlation estimators for spaced-antenna wind measurement in the presence of noise, Radio Science, 39, doi:10.1029/2003RS003022.

Conference Reprints

Brown, William, **D.B. Parsons**, J.O. **Pinto**, **B. Morley**, 2004, VTMX: Profiling the stable nocturnal boundary layer, Preprints, Fifth conference on Urban Environment, Vancouver, BC, AMS.

Cohn, Stephen A., H.B. Bluestein*, **W.O.J. Brown**, **M.E. Susedik**, 2004, The Mobile Integrated Sounding System (MISS): Development and First Results, Preprints, 20th International Conference on Interactive Information and Processing Systems (IIPS) for Meteorolo, Seattle, WA, American Meteorological Society.

Cohn, Stephen A., 2004, Mountain valley flow observations with a boundary layer wind profiler, Preprints, 11th Conference on Mountain Meteorology and the Annual Mesoscale Alpine Program (MAP), Bartlett, NH, American Meteorological Society.

Cohn, Stephen A., John Lewis*, John Hallett*, 2004, The February 28, 2002 Reno Dust Storm: A case study, Preprints, 13th Joint Conf on the Applications of Air Pollution Meteorology with the Air and Waste Management, Vancouver, BC (Canada), American Meteorological Society, CD.

Cohn, Stephen A., Jamie Braid, Carl Dierking*, Marcia Polotovich, Charles Wade, 2004, Weather patterns of Juneau Alaska and their relationship to aircraft hazards, Preprints, 11th Conference on Aviation, Range, and Aerospace Meteorology, Hyannis, MA, AMS, CD.

Cohn, Stephen A., Robert Barron, Al Yates, Al Rodi*, Peter Neilley*, Alex Praskovsky, Larry Cornman, 2004, Field programs to investigate hazards to aviation in Juneau, Alaska, Preprints, 11th Conference on Aviation, Range, and Aerospace Meteorology, Hyannis, MA, AMS, CD.

Cox, J. A., W. J. Steenburgh*, **G. S. Poulos**, 2004, The sensitivity of thermally-driven mountain flows to land cover change., Preprints, 11th Conference on Mountain Meteorology, Bartlett, NH, AMS, 213-216.

Dilling, "Lisa, S.C. Doney*, J. Edmonds*, K.R. Gurney*, R. Harriss, **B. Stephens**, and others, 2004, The role of carbon cycle observations and knowledge in carbon management, Annual Review of Environment and Resources, 28, Matson, Gadgil, Kammen, Annual Reviews "521-558.

Grubisic, Vanda, **Stephen A. Cohn**, 2004, Sierra Rotors Project: Preliminary Findings, Preprints, 11th Conference on Mountain Meteorology and the Annual Mesoscale Alpine Program (MAP), Bartlett, NH, American Meteorological Society, CD.

Haggerty, Julie, **A.E Cox**, 2004, Airborne passive microwave measurements of surface properties for wildland fire applications, Proceedings, 8th Specialist Meeting on Microwave Radiometry and Remote Sensing Applications, Rome, Italy.

Haggerty, J.A., **J. Vivekanandan**, and D. Serke, 2004: Evaluation of satellite and radar cloud retrieval methods during

IMPROVE-2 icing events, 11th Conference on Aviation, Range, and Aerospace Meteorology, Hyannis, MA, Oct 4-8.

Hubbert, John, **S. Ellis**, M. Dixon, G. Meymaris, 2004, Experimental Evaluation of SZ(8/64) Phase Coding with Censoring for Range-Velocity Ambiguity Mitigat, Preprints, RADAR 2004, Toulouse, SEE.

Hubbert, John, **S. Ellis**, M. Dixon, G. Meymaris, 2004, Range-Velocity Ambigity Mitigation via Phase Coding: Experimental Results, Proceedings, European Conference on Radar Meteorology and Hydrology, Visby, Gotland, Sweden, Copernicus GMBH, 45-50.

Hynek, S. A., W. J. Steenburgh*, **G. S. Poulos**, 2004, Oxygen isotope ratios of recently fallen snow over the Wasatch Mountains of northern Utah. , Preprints, 11th Conference on Mountain Meteorology, Bartlett, NH, AMS, 87-91.

Kessinger, Cathy, **S. Ellis**, **J. Van Ande**l, J. Yee, **J. Hubbert**, 2004, Current and Future Plans for the AP Clutter Mitigation Scheme, Preprints, 20th IIPS on Meteorology, Oceanography and Hydrology, Seattle, WA, AMS, CD.

Lee, J. L., A. E. MacDonald*, Y.-H. Kuo, **W.-C. Lee**, W. Wang, 2004, Use of radar data for TC initialization and predictions, Preprints, , 26th Conf. On Hurricane and Tropical Meteorology, Miami, FL, AMS, 554-557.

Lee, W.-C., **M. Bell**, 2004, Kinematic structure of Hurricane Isabel (2003) near landfall from the Morehead City WSR-88D, Preprints, 26th Conf. On Hurricane and Tropical Meteorology, Miami, FL, AMS, 566-567.

Lund, Tom, P. P. Sullivan, **G. S. Poulos**, 2004, Large eddy simulation of a weakly stable boundary layer using dynamic subgrid-scale models., Preprints, 16th Symposium on Boundary Layers and Turbulence, Portland, ME, AMS, 165-167.

Mayor, Shane D., **Scott M. Spuler**, **Bruce M. Morley**, 2004, NCAR's New Raman-shifted Eye-safe Aerosol Lidar, Proceedings, 22nd International Laser Radar Conference, Matera, Italy, European Space Agency , 53-56.

Mueller, Steven, **Stephen A. Cohn**, Alex Praskovsky, 2004, Aircraft-correlated turbulence measurements with the Doppler On Wheels, Extended Abstract, 11th Conference on Aviation, Range, and Aerospace Meteorology, Hyannis, MA, AMS, CD.

Murillo, S. T., P. Dodge*, **W.-C. Lee**, G. M. Barns*, 2004, Implementing a single Doppler radar technique for tropical cyclones and integrating radar-derived wi, Preprints, 26th Conf. On Hurricane and Tropical Meteorology, Miami, FL, AMS, 606-607.

Poulos, G. S., et al.*, 2003, Exceptional mesoscale features of the Great Western Storm of March 16-20, 2003, Preprints, 10th Conference on Mesoscale Processes, Portland, OR, AMS, 167-172.

Poulos, Gregory, J. S. Snook*, D. A. Wesley, M. P. Meyers*, E. J. Szoke*, 2004, An investigation of record heavy lee side orographic snowfall during the great western storm of Marc, Preprints, 11th Conference on Mountain Meteorology, Bartlett, NH, AMS, 234-237.

Spuler, Scott, Shane Mayor, 2004, Raman-shifted Eye-safe Aerosol Lidar Development, Proceedings, Laser Applications to Chemical and Environmental Analysis, Annapolis, Maryland, Optical Society of America.

Stith, Jeff, **J. Haggerty**, C. A. Grainger*, A. Detwiler*, 2004, A comparison of the microphysical and kinematic characteristics of mid-latitude and tropical convect, Preprints, 14th International Conference on Clouds and Precipitation, Bologna, Italy, International Commission on Clouds and Precipitation, 674-677.

Stith, Jeff, **D. C. Rogers**, 2004, Instrument Development and Education in Airborne Science, Preprints, 13th AMS Conference on Education, Seattle, WA (US), AMS.

Wang , Junhong, 2004, Evaluation of performance of the dropsonde humidity sensor, Proceedings, Eighth Symposium on Integrated Observing and Assimilation Systems for Atmosphere, Oceans, and Land S, Seattle, Washington.

Wesley, D. A., J. S. Snook*, **G. S. Poulos**, 2004, Mesoscale Model Simulations in Forecast Mode of the Great Western Storm of 16-20 March 2003, Preprints, Weather Analysis and Forecasting, Seattle, WA, AMS, 116-121.

Wesley, Douglas, **G. S. Poulos**, J. S. Snook*, M. P. Meyers*, 2004, Anomalously large snowfall variations across small spatial scales in the Rocky Mountain Front Range:, Preprints, 11th Conference on Mountain Meteorology, Bartlett, NH, AMS, 222-227.

Seminars and Presentations

Cai, Huaqing, Scientific or Technical, Comparison between Tornadic and Nontornadic Mesocyclone Using Fractal Geometry , 28 June--- 1 July, 2004, Chinese Academy of Science, COAA, etc., 150.
Cai, Huaqing, Scientific or Technical, Observations of 11 June Dryline During IHOP--- A Null Case for Convection Initiation, 14-18 June,2004, France, MeteoFrance, 50.
Cai, Huaqing, Scientific or Technical, Preliminary ELDORA Observations of IOP 3 and IOP 12 During BAMEX, 1-3 March, 2004. St. Louis, MO, BAMEX Science Meeting, 50.
Cai, Huaqing, Scientific or Technical, Tornadogenesis and Fractal Geometry, 30 March, 2004, ATD Seminar, 20.

Campos, Teresa, Scientific or Technical, Potential NCAR Facility In Situ Trace Gas Measurements for HIAPER, 28 October 2003, NCAR UT/LS Strategic Initiative, 120.
Campos, Teresa, Scientific or Technical, NCAR Community Airborne Tunable Diode Laser Hygrometer: Preliminary Evaluation of AIRS-II Performanc, 30 March 2004, NCAR ACD Research Report (internal group), 30.
Campos, Teresa and Julie Haggerty, Scientific or Technical, Airborne Characterization of Wildfire Fuels and Burn Scars: An Introduction to NCAR's Airborne Plat, 8 October 2003, Raytheon Space Systems, NPOESS Algorithm, Modeling and Simulation section, 15.

Cohn, Stephen A., Scientific or Technical, Mountain-valley flow observation with a boundary layer wind profiler, 21 June 2004, 11th Conference on Mountain Meteorology, 150.
Cohn, Stephen A., Scientific or Technical, Weather patterns of Juneau Alaska and their relationship to Aviation Hazards, 12 October 2004, 11th Conference on Aviation, Range, and Aerospace Meteorology, 200.

Haggerty, Julie, Non-Technical (school, community groups), Atmospheric Measurements from Aircraft, 18 Feb 2004, Foothill Elementary School, 25.]

Hall, Samuel, Scientific or Technical, Tunable Diode Laser Hygrometer, 26 November, 2003, AIRS-II Field Science Meeting, 15.

Lee, Wen-Chau, Scientific or Technical, Evolution and Structure of Hurricane Charley (2004) near Landfall, 7 October 2004, National Taiwan University, Taiwan, 50.
Lee, Wen-Chau, Scientific or Technical, Evolution and Structure of Hurricane Charley (2004) near Landfall, 11 October 2004, National Central University, Taiwan, 40.

Mayor, Shane, Scientific or Technical, NCAR's Raman-shifted Eye-safe Aerosol Lidar, 15 December 2003, University of Washington, Seattle, WA, 25.
Mayor, Shane, Scientific or Technical, NCAR's New Raman-shifted Eye-safe Aerosol Lidar, 8 March 2004, Los Alamos National Laboratory, 30.
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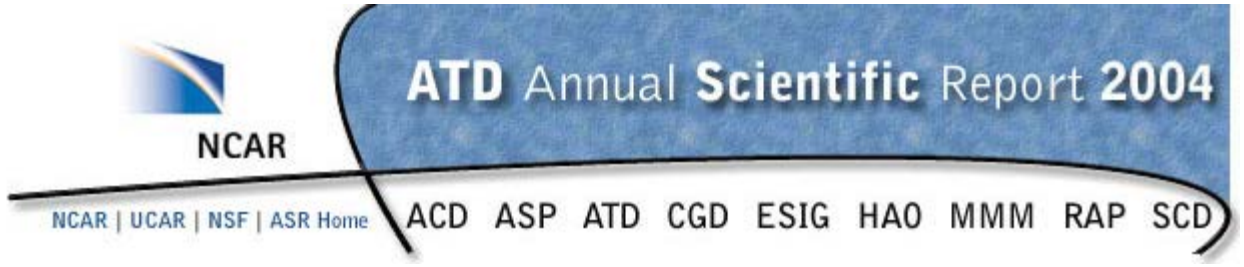

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Josh Wurman	Kathryn Young	Liz Zhang	

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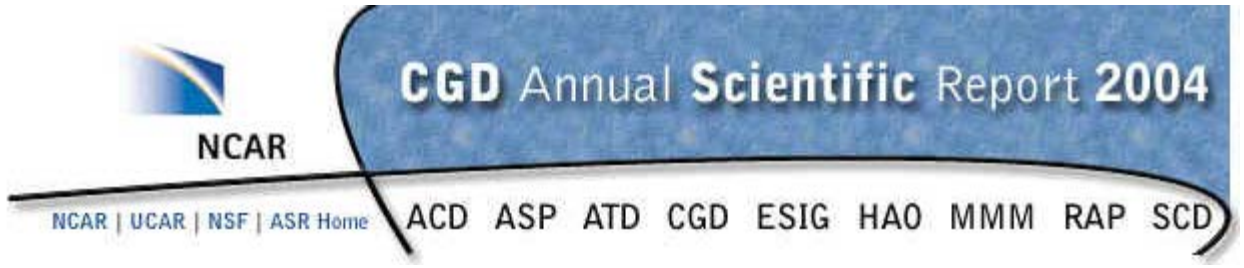

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CGD Director's Message from James Hurrell

The Annual Scientific Report (ASR) highlights the major research accomplishments of the past year, and there are many to report from the Climate and Global Dynamics Division (CGD) of NCAR. The accomplishments are strongly aligned with and supportive of the vision and mission of the institution, and they reflect the hard work and dedication of the entire CGD staff as well as the indispensable contributions of many colleagues from the university, government and international research communities. I am proud and honored to be working with such a great group of people.

Our mission in CGD is to: (1) obtain a comprehensive understanding of the Earth's climate system components and the interactions among them; (2) to represent this understanding in models of the components and of the coupled system; and (3) to further our understanding by applying the models to scientific and societal questions and thereby provide a basis for prediction of weather and climate. Over the past year, we continued to fulfill this mission through a strong record of achievement in scientific research, community modeling and data set development. We are also very proud of our community service, leadership of national and international research programs, and educational and outreach activities. Accomplishments in these areas are detailed throughout the ASR.

A major focus of divisional activities over the past year was improving the Community Climate System Model (CCSM). Enhancements to versatility and sophistication were made in all individual model components: atmosphere, land, ocean and sea ice. The latest version of the model, CCSM3, is being used for a wide variety of studies concerning climate variability and climate change. Most prominent among these are key simulations for the next major assessment of the Intergovernmental Panel on Climate Change (IPCC). These simulations were not only done at NCAR in 2004, but at several Department of Energy (DOE) labs as well as the Earth Simulator in Japan. Such collaborations allowed for larger ensembles of simulations at higher resolution for longer periods of time than would have otherwise been possible. The IPCC integrations also included important provisions for model data needed by groups interested in impacts, mitigation, and regional modeling at high resolution.

Coordinated by a Scientific Steering Committee (SSC) consisting of both NCAR and external scientists, the CCSM project runs under NSF and DOE sponsorship at NCAR. In addition, NOAA and NASA play important roles through the U.S. Global Change Research Program and U.S. Climate Change Science Program. In June 2004, CCSM3 was released to the worldwide community. The release included a comprehensive suite of control integrations, including simulations of present-day and pre-industrial conditions at three different model resolutions. The new release was also designed to be very portable across a variety of computer architectures.

The 9th Annual CCSM user workshop was held in Santa Fe, New Mexico in July 2004.&; Attendance, which has increased every year, exceeded 330 participants, more than three times the number of attendees at the first workshop in 1996. University scientists represented the largest group (135), followed by NCAR (120) and DOE (49) scientists. The SSC began planning of the next major scientific directions for the project. One important theme is process-oriented high-resolution modeling targeted at remaining systematic biases in CCSM3 integrations. The second major thrust is the development of a first generation fully coupled climate-chemistry model. This system will include the physical components in CCSM, along with new modules for prognostic aerosols, isotopes of water and carbon dioxide, reactive gas chemistry, oceanic and terrestrial biogeochemistry, and chemical transport. All of these modules were under active development in 2004.

In addition to efforts supporting the development and continuous improvement of a comprehensive climate modeling system, CGD scientists made significant advances toward increased understanding of atmospheric and climate variability and climate change through the parallel development and analysis of observational, assimilated, model-generated and model-forcing datasets, and the application of these datasets in empirical studies and diagnostic analyses to document comprehensively climate variability, its causes and the processes involved.

Major new advances were made by CGD scientists and collaborators in 2004 in our understanding of the diurnal cycle of precipitation, the mechanisms responsible for interannual and longer variations of major climate phenomena such as the El Niño-Southern Oscillation (ENSO), monsoons and annular modes, extreme events, and multi-decadal variations throughout the Pacific. Accomplishments over the past year also include comprehensive diagnostic studies of the global and regional atmospheric moisture, heat, and energy budgets; observational analyses of upper ocean and sea ice variations; new analyses of the total mass of the atmosphere and its variations globally; a new look at the flow of energy through the climate system; new knowledge and insights into several aspects of the global water cycle, droughts and their historical variability; increased scientific understanding of land-atmosphere interactions, and in particular surface forcing of climate; advances in documenting and understanding climate variability over the past millennium, as well as much farther back in time; understanding the sources of predictability in the tropical Atlantic region; and in applying concepts and methodologies developed by the climate dynamics community to diagnose and interpret climate change scenarios.

CGD scientists also played leadership roles in 2004 in designing and advocating the global climate observing system and articulating the need for and benefits of a climate information system; in evaluating, improving, restructuring, and computing high-level derived products from climate datasets including atmospheric reanalyses; developing advanced data assimilation techniques, including work as part of the NCAR Data Assimilation Initiative; and advancing assimilation techniques for biogeochemistry and carbon cycle studies. Also, through both the CCSM3 climate change simulations and other analysis efforts, CGD scientists became heavily involved in the next IPCC assessment as convening lead authors, lead authors and contributing authors, consistent with the mission statement of NCAR.

Finally, I would like to note that many of these accomplishments came under the leadership of Maurice Blackmon, who took on a special assignment for the NCAR Directorate in June of 2004. Maurice faithfully served CGD as Division Director for the better part of a decade, and under his watch the program flourished. Thank you, Maurice, for your hard work and dedication.

Sincerely,

Jim Hurrell
CGD Director

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Executive Summary

The mission of the Climate and Global Dynamics (CGD) Division is to: (1) obtain a comprehensive understanding of the Earth's climate system components and the interactions among them; (2) to represent this understanding in models of the components and of the coupled system; and (3) to further our understanding by applying the models to scientific and societal questions and thereby provide a basis for prediction of weather and climate. The Division fulfills this mission through a strong record of achievement in scientific research, community modeling and data set development in collaboration with colleagues from the university, government and international research communities. The staff of CGD also fulfill the mission of NCAR through their community service, leadership of national and international research programs, and educational and outreach activities.

Development and Evaluation of Community Climate Models

The development and continuous improvement of a comprehensive climate modeling system that is at the forefront of international efforts to understand and predict the behavior of the Earth's climate continues to be a high priority of CGD research. This requires strong support of ongoing fundamental research on climate processes operating in the atmosphere, ocean, land and cryosphere. It also requires the continual development of software engineering methods to improve performance and portability, and extensive infrastructure and support for external collaborators and users.

1. Process-oriented research

Atmosphere

A major effort during FY04 was the development and release of the new Community Atmosphere Model (CAM3). CAM3 includes a large number of significant improvements and enhancements to the treatment of physical processes. These include: cloud and ice-phase processes; interactions among water vapor, solar radiation, and terrestrial thermal radiation; effects of aerosols, including prognostic sulfate, on the reflection and absorption of solar radiation; and dynamical frameworks suitable for modeling atmospheric chemistry. CAM3 also includes new standard capabilities such as a Slab Ocean Model (SOM) configuration, a single column modeling (SCM) feature, and improvements to the software engineering implementation of the model. The CAM3 consists of configurations at multiple resolutions, where the T85 spectral Eulerian configuration is the highest resolution atmospheric model configuration ever released by NCAR, and leads the way for other global modeling activities. CAM3 is incorporated as the atmospheric component of the Community Climate System Model (CCSM3). In strong collaboration with colleagues at the Geophysical Fluid Dynamics Laboratory (GFDL)of NOAA, CGD scientists continued to make progress toward understanding sensitivities and the sources of agreement or differences in climate sensitivity between CCSM and the GFDL coupled climate model.

Ocean and Cryosphere

Research in FY04 to improve our understanding of the large-scale ocean circulation and the dynamics of climate through studies of the important processes in the ocean and sea-ice, in air-sea-ice interactions, and in coupled systems continued. New treatments of physical processes in the ocean and sea-ice components of CCSM3 include improvements to the representation of the ocean mixed layer; inclusion of solar heating by chlorophyll; infrastructure for

studying vertical mixing in the ocean; advanced sea ice rheology; explicit ice-thickness distribution physics; explicit treatment of brine pockets; and an improved scheme for horizontal advection of sea ice . In addition, CGD scientists are actively involved in two funded Climate Process Team (CPT) proposals. These are highly collaborative projects, bringing observationalists, process modelers, and modeling centers together to expedite the incorporation of new discoveries into climate models. The funded proposals concern the deep gravity currents and entrainment with particular emphasis on their role in water mass formation, and hence, the thermohaline circulation, and the interaction between mesoscale eddies and mixed layers. Among the objectives are to develop new or modified parameterizations that can be reliably used in ocean models and to assess their impacts on the climate model simulations. In addition, collaborative efforts in high resolution (0.1º) global ocean modeling continued to establish the role of mesoscale ocean processes in the mean climate and the response to climate forcing.

Land

Scientists in CGD continued their work in FY04 to implement biogeochemistry and its feedback on climate in the Community Land Model (CLM) and CCSM. This work resulted in a new version of the land model that includes detailed treatments of terrestrial carbon and nitrogen cycles, and interactions of the water and energy budgets with biogeochemical processes. The new model also includes a greatly improved scheme for representing the biophysical and biochemical characteristics of sunlit and shaded fractions of the canopy, as well as a simple algorithm for prognostic wildfire. Offline simulations demonstrate that the land biogeochemistry behaves reasonably under prescribed atmospheric forcing. Simulations coupling the new land model to the atmosphere in CCSM3 (with prescribed ocean and ice boundary conditions) suggest that both the improved canopy integration scheme and the prognostic carbon and nitrogen cycles have a significant impact on the coupled climate simulation. A major contributor to climate feedback in the new model is the prognostic canopy leaf area, which causes the seasonal, interannual, and long-term dynamics of the canopy to respond directly to the model climate, in contrast to the default land model which prescribes the seasonal cycle and spatial distribution of canopy leaf area from satellite observations. This effort involves strong collaborative work between CGD and the Atmospheric Chemistry Division (ACD).

2. CCSM

The CCSM3 was released on June 23, 2004 to climate scientists worldwide. CCSM3 includes major improvements in its physics and software that expand the range of scientific investigations that can be undertaken. The release was one of the highlights of the Ninth Annual CCSM Workshop held in Santa Fe, New Mexico during July 2004. Using CCSM3, the CCSM Climate Change Working Group and the Kyosei Consortium are completing an extensive suite of climate simulationsfor the upcoming Fourth Assessment Report (AR4) by Working Group One of the Intergovernmental Panel on Climate Change (IPCC). This production effort has also strongly involved scientists and software engineers at the Oak Ridge National Laboratory (ORNL), National Energy Research Supercomputing Center (NERSC) and the Lawrence Berkeley National Laboratory (LBNL).

The CCSM3 release includes the model code, comprehensive documentation, and the largest set of model results ever provided to the community. It includes four NCAR technical notes on the new atmosphere, land, dynamic vegetation, and sea ice models. The range of computer hardware suitable for CCSM applications has been expanded and should enable investigators to run CCSM on Linux systems popular in university departments. As of October 2004 nearly 170 groups had downloaded CCSM code. For the first time, the model produces realistic simulations over a wide range of spatial resolutions, enabling inexpensive simulations lasting several millennia or detailed studies of continental-scale climate change.

The project is distributing simulations for the present climate and recent past using the new Earth System Grid (ESG) developed with support from the Department of Energy. The ESG will also serve as the main pathway for distribution of the multi-model ensemble of climate-change simulations for the IPCC AR4.

Because of major enhancements to the component models, the climate produced by CCSM3 has greater fidelity to the observed climate than simulations from previous generations of CCSM. The improvements include better simulations of surface temperatures, snow and sea-ice distributions, ocean currents, and teleconnections between ENSO and the northern Pacific. These and other scientific features of the new model will be discussed in a special two-volume issue of the *Journal of Climate*. The software engineering underlying CCSM3 will be presented in a special issue of the *International Journal of High Performance Computing Applications*.

3. WACCM

CGD scientists have worked closely with ACD and High Altitude Observatory(HAO) colleagues toward the implementation of interactive chemistry and a solar module in the Whole Atmosphere Community Climate Model (WACCM). Implementation of interactive chemistry is completed, and a large number of scientific studies using WACCM are underway. Once the solar cycle module has been incorporated the effects of the

solar cycle on the middle atmosphere and improvements to tropical wave variability will be explored. Plans are to release to the community WACCM version 3 in early 2005. Using CCSM as a common numerical framework, interdivisional development of WACCM continues the evolution toward complete Earth system models at NCAR.

Climate Analysis: Diagnostic, Theoretical and Modeling Studies

A goal of this high priority CGD research is to increase our understanding of atmospheric and climate variability and climate change through parallel development and analysis of observational, assimilated, model-generated and model-forcing datasets; and, by using these datasets for empirical studies, diagnostic analyses, and model experimentation to document comprehensively climate variability, its causes and the processes involved. Further, systematic numerical experimentation using models provides insights and assesses predictability that may allow attribution of observed variability to processes and causes. A crucial question is how well do we simulate the full spectrum of natural variability in models such as CCSM, and thereby provide a sound basis for future projections? The answer depends on a strong and balanced program in data analysis, theoretical and model application studies.

1. Empirical and diagnostic analyses of models and observations

Atmosphere

During FY04 CGD scientists published studies contributing to significant advances in the understanding of a wide variety of phenomena. A small sampling includes studies of: the diurnal cycle of precipitation, the total mass of the atmosphere and its variations globally, the flow of energy through the climate system, the global water cycle, droughts and their historical variability, the prospects for increasing extremeswith climate change, the role of tropical oceans in observed regional climate change, multi-decadal variations in surface pressure and rainfall throughout the Pacific, analyses of upper ocean and sea ice variations and the sensitivity of the atmosphere to those variations, and studies of tropical Atlantic variabilityand the role of air-sea interaction. Going beyond the physical system, several aspects of how climate variability affects terrestrial and marine ecosystems were also published.

Ocean

An emphasis of ocean research during FY04 was the analysis of the CCSM integrations in support of the IPCC AR4. Among other studies, CGD scientists have investigated: the attribution and impact of upper ocean biases, including the mean and seasonal cycle of equatorial temperature, salinity, and velocity; the ventilation rate of the thermocline and deep ocean in simulations of the 20 th Century; the response of the thermohaline circulation (THC) to transient climate forcing, primarily focusing on the dominant physical processes affecting the THC; the heat uptake in the ocean component of CCSM; the variability in the North Pacific using chlorofluorocarbon (CFC) ages and ideal age in a CCSM Parallel Ocean Program (POP) experiment with realistic forcing data; the dominant modes of sea ice variability in the Southern Hemisphere; and the consequences of a seasonally ice-free Arctic Ocean.

Land

Considerable efforts continued in FY04 to increase scientific understanding of land-atmosphere interactions, and in particular surface forcing of climate. One example was climate model simulations performed to examine the sensitivity of simulated climate to different specifications of present-day land cover and natural potential vegetation. Uncertainty in the classification of present-day vegetation can produce large differences in the simulated climate. Present-day vegetation has generally cooled surface climate, especially in the middle latitudes due to the higher albedo of croplands compared to natural vegetation. Simulations using land cover for the year 2100 showed that the land cover forcing of climate can be large, especially in tropical South America and in the U.S., where agricultural land is projected to become more extensive. Other work within the division demonstrated that the degree of land-atmosphere interaction varies widely between current state-of-the-art atmospheric general circulation models.

2. Climate observations

CGD scientists played leadership roles in FY04 in designing and advocating the global climate observing system, institutionalizing reanalysis, and articulating the need for and benefits of a climate information system. In addition, CGD maintained a leadership position in the development of data assimilation techniques, including work as part of the NCAR Data Assimilation Initiative (DAI). CGD scientists are also involved in assimilation techniques for biogeochemistry and carbon cycle studies. As part of these efforts, CGD researchers played a lead role in the Airborne Carbon in the Mountains Experiment (ACME) that focused on quantifying carbon fluxes in mountain and mountain-valley complex landscapes using airborne and ground-based flux measurement techniques.

3. Community Data Set and Software Development

An ongoing CGD activity in FY04 continued to be the acquisition, evaluation, improvement, and restructuring of datasets, the production of high-level derived products, and improved community access to data and documentation through data catalogues. Software tools to increase access to and display of data continue to be developed, and a substantial service activity within CGD has been devoted to outreach and teaching of data processing software, in particular the NCAR Command Language (NCL) developed in collaboration with Scientific Computing Division (SCD).

4. Climate predictability

A goal of the CGD program is to define and extend the spatio-temporal domain over which scientifically and societally useful forecasts can be made. Efforts in FY04 included research to: model the initial uncertainty in atmospheric ensemble prediction through the development of a statistical model of analysis error; understand the sources of predictability in the tropical Atlantic region; and apply concepts and methodologies developed by the climate dynamics community to diagnose and interpret climate change scenarios. An example of the latter involved the analysis of a 62-member ensemble of CCSM simulations for the years 1940-2080 to study the interplay between the natural modes of variability of the atmosphere and long-term trends in the mean atmospheric circulation resulting from the secular forcing trends. The large sample size made it possible to detect and diagnose the two-way interaction between modes and trends.

5. Paleoclimate

Paleoclimate research within CGD during FY04 was conducted on studies of deep time, the past 150,000 years, and the past millennium. The boundary between the Late Permian and Triassic periods at 251 Ma marks the largest extinction recorded in Earth's history, and CGD researchers are carrying out the first fully coupled climate simulation for this period using CCSM. Considerable effort was also placed on simulating and constructing high-resolution paleoclimate records of climate variability and abrupt climate change over the last deglacial and the Holocene. Abrupt changes at these times occurred over decades to centuries and were associated with the transition from the Holocene climatic optimum to the Neoglacial, during which temperature decreased in the middle to high latitudes and precipitation decreased in the tropics. CCSM simulations of the last millennium are key to understanding the roles of natural and anthropogenic forcings in the observed climate record. A clear solar influence has been found on the century time scale that is stronger than previously assumed. However, the same simulations also show that the late 20 th century warming cannot be attributed to solar irradiance changes.

6. Climate Change

Through both climate change simulations and analysis efforts, CGD scientists continued in FY04 to play a national leadership role in climate change research. CGD scientists remain heavily involved in IPCC AR4 as convening lead authors, lead authors and contributing authors, consistent with the mission statement of NCAR. The centuries long simulations and ensembles have allowed CGD scientists to conduct studies addressing all five of the key global change issues identified by the Climate Change Science Program (CCSP) and the U.S. Global Change Research Program (USGCRP): (1) seasonal to interannual climate variability; (2) climate change over decades to centuries; (3) changes in ozone, ultraviolet radiation, and atmospheric chemistry; (4) changes in land cover and in terrestrial and aquatic ecosystems; and (5) the role of aerosols.

Education and Outreach

CGD scientists in FY04 continued a strong tradition of participation in education and outreach activities. This included mentoring of Advanced Study Program (ASP) and Significant Opportunities in Atmospheric Research and Science (SOARS) students, leading tours of NCAR and giving public talks, visiting K-12 classrooms, participating in educational workshops and colloquia, providing scientific content for educational videos and websites, and handling many requests from the media. In addition, several CGD scientists contributed directly to the new Climate Discovery Exhibit at the NCAR Mesa Laboratory.

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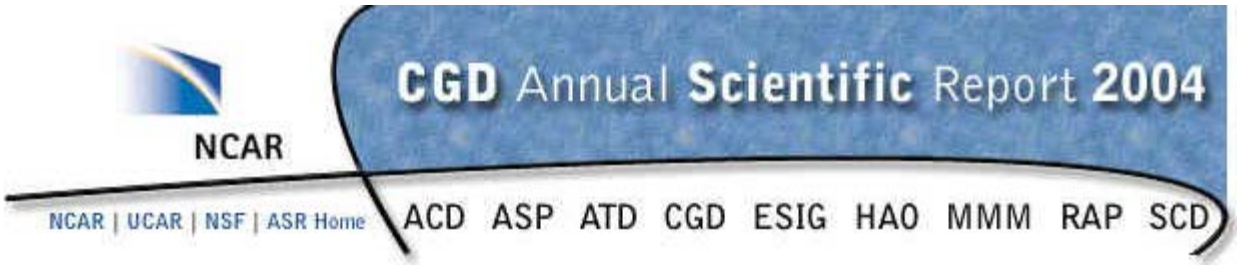

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Climate Analysis Section Narrative

Climate Analysis Section (CAS) research has the goal of increasing our understanding of atmospheric and climate variability and climate change through parallel development and analysis of observational, assimilated, model-generated, and model-forcing datasets; and, by using these datasets for empirical studies, diagnostic analyses, model experimentation, and model evaluation, to document comprehensively the variability, its causes, and the processes involved. CAS staff are also heavily involved in designing and advocating the global climate observing system and national and international programs.

In CAS a central ongoing thrust of considerable importance to the research and university communities is the acquisition, evaluation, improvement, and restructuring of datasets, development of climatologies and high-level derived products, while facilitating access to data and documentation in catalogs available through the Internet. The datasets are used extensively in diagnostic, theoretical, and modeling studies, including validation of the Community Climate System Model (CCSM). CAS collaborates closely with the Data Support Section (DSS) of NCAR's Scientific Computing Division (SCD) in all observational data-related activities. Tools to increase access to and display of data are being developed in conjunction with SCD's Data Portal activity https://dataportal.ucar.edu:8443/cdp/index.jsp.

CAS research is focused on the atmosphere and its interactions with the surface of the Earth and oceans on a wide range of temporal and spatial scales. Included are studies of the diurnal cycle, intraseasonal variability, interannual variations such as the El Niño-Southern Oscillation (ENSO), the North Atlantic Oscillation (NAO), annular modes, the Tropospheric Biennial Oscillation (TBO), extreme events, and interdecadal variations and longer period trends including paleoclimate. Also included are comprehensive diagnostic studies of the global and regional atmospheric moisture, heat, energy, and momentum budgets; observational analysis of upper ocean and sea ice variations; heat and fresh water budgets in the ocean, and the water cycle on land. CAS scientists interact with other CGD sections especially through the analysis, validation, and diagnosis of divisional climate models.

CAS research spans many topics, but includes several studies that are considered to be

part of national and international programs including the Climate Change Science Program, International Satellite Cloud Climatology Project (ISCCP), Global Energy and Water Cycle Experiment, Climate variability and predictability (CLIVAR), Past Global Changes (PAGES), Intergovernmental Panel on Climate Change (IPCC), International Geosphere-Biosphere Programme, and the World Climate Research Programme as a whole. CAS is also involved in developing the Global Climate Observing System, the Global Earth Observing System of Systems, and the United States component through the Interagency Working Group on GEO (IWGEO). Of special note is that CAS is contributing results of data analyses to the Fourth Scientific Assessment of IPCC (AR4); all CAS scientists are contributing authors, while Kevin Trenberth (CAS) and Gerald Meehl (joint with CAS and Climate Change Research Section, CCR) are convening lead authors.

Dataset Development

CAS staff members, and Dennis Shea, Lesley Smith, and Adam Phillips, in particular, continue to collaborate with SCD's DSS to acquire, evaluate, and reformat data. David Stepaniak has moved from CAS to DSS, which strengthens these collaborations. Ongoing efforts in these areas include analyses of conventional, satellite, and model data. In addition to the normal updates to existing datasets, some recent additions to the CAS data catalogs (http://www.cgd.ucar.edu/cas/dcats.html) include 1) Global Precipitation Climatology Project version 2 combined precipitation dataset updated through the end of 2003; 2) Palmer Drought Severity Index (PDSI) updated through 2003; 3) ERA-40 Adjusted Surface Pressure Anomalies; and 4) SSM/I Monthly Mean Water Vapor version 5 (Remote Sensing Systems) for July 1987–January 2004. A top-level catalog was created by SCD and CAS for the NCAR Community Data Portal outlining all CAS catalog datasets. See: https://dataportal.ucar.edu:8443/cdp/index.jsp. Stepaniak developed a new Web page devoted to "Vertically Integrated Mass, Moisture, Heat, and Energy Budget Products Derived from the NCEP (National Centers for Environmental Prediction)/NCAR Reanalysis," providing the community with complete background and access to a total of 36 monthly mean fields spanning 1979 to 2001 – see http://www.cgd.ucar.edu/cas/catalog/newbudgets/. Shea continues to update the NCAR Instructional Aid entitled "An Introduction to Atmospheric and Oceanographic Datasets," which is available at http://www.cgd.ucar.edu/cas/tn404/. It serves as a 'data-primer' for students and those in other fields of research. It describes the general characteristics of atmospheric and oceanographic datasets and how to determine what data are available and where they are located.

Smith has responsibility for the online dataset catalog on the Web, which has been upgraded and added to in the past year. It documents all the observationally-based global datasets developed in CAS in the network Common Data Format (netCDF). Many datasets have been revamped and reconstructed into new formats. Continuing development of expert user guidance and commentary on quality and utility of datasets related to climate variability is led by Phillips, Clara Deser, and James Hurrell (all CAS). The primary purpose of this activity is to catalog and provide easy access to a basic set of historical datasets for interdisciplinary studies of climate variability. The need for this activity has been articulated at several U.S. CLIVAR planning workshops.

Sylvia Murphy (CCSM) and Shea continue to participate in development of a general purpose data processing tool based on SCD's NCAR Command Language. Processing and graphical capabilities continue to be added to facilitate climate research, in particular, model-to-model and model-to-observed comparisons. A Web site

(http://www.cgd.ucar.edu/csm/support/) contains many up-to-date examples. Several activities have been pursued including coordination of a diagnostics working group to facilitate the creation and dissemination of model component (atmosphere, ocean, ice, and land) diagnostics packages; the ability to access and process data in the Hierarchical Data Format-Earth Observing System format (HDF-5); and tutorial workshops on data processing and visualization. Five three-day workshops were held during 2004, four at NCAR and one at the National Ocean Service in Silver Spring, Maryland.

Trenberth, Smith, and Stepaniak continue to evaluate global reanalyses from NCEP/NCAR and from the European Centre for Medium-range Weather Forecasts (ECMWF). The focus has shifted to the new ERA-40 re-analyses from ECMWF. The vertically-integrated mass, moisture, heat, and energy budgets for the atmosphere documentation of products is at http://www.cgd.ucar.edu/cas/catalog/tn430/. The data can be downloaded from the Web browser, and all of the fields are available through anonymous ftp, via ftp://ftp.ucar.edu/cgd/cas/tn430/. The products are all global vertically-integrated grids as individual monthly mean time series from 1979 through 1993 (ERA-15), or 2001 for NCEP and monthly, seasonal, and yearly averages (climatologies). Fields from ERA-40 will be developed in the near future. Trenberth, Smith, and John Fasullo (CAS, who replaced Stepaniak) have begun preliminary evaluations of ERA-40 fields. Initial work is on vertically-integrated mass fields, including water vapor.

Hurrell, with James Hack (Climate Modeling Section, CMS), James Rosinski (CMS), Julie Caron (CMS), and Shea, finished the construction of a new lower boundary forcing dataset for studies with the Community Atmosphere Model (CAM). A method was developed for “blending” sea surface temperature (SST) products from NCEP and the Hadley Centre, and for reducing the number of spurious sea ice concentrations associated with the original SST products. In addition, CAM simulations to assess the atmospheric impact of the new relative to old SST datasets were completed. The need for this documentation lies not only in the fact that CAM is a widely-used community tool, but that other major modeling centers (e.g., the Geophysical Fluid Dynamics Laboratory (GFDL) and NASA) are also employing the new SST product in their modeling activities.

Climate Observations and Analysis

Trenberth was a lead author in the Second Report on the Adequacy of the Global Observing Systems for Climate in support of the United Nations Framework Convention on Climate Change, and is a lead author also on the follow-on Implementation Plan that was made available for review and is in final stages of revision. He has also been extensively involved with the IWGEO, as well as service on several relevant NOAA committees.

Climate Diagnostics

Hurrell, Trenberth, and Shea continue work to carefully evaluate variations in storm tracks associated with global patterns of circulation variability. They are making use of nearly 50 years of NCEP/NCAR reanalysis data band-passed filtered to retain synoptic time scales. The quality of the reanalyses for such a task is also being assessed.

Postdoctoral fellow Jeffrey Yin (CAS) published work from his Ph.D. thesis with David Battisti (University of Washington) on the structure of baroclinic waves in the NCEP/NCAR reanalysis. Using regression analysis of 6-hourly data, they demonstrated that baroclinic

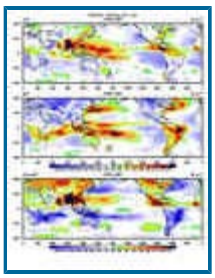
waves tilt poleward with height, although the observed tilt is smaller than that predicted by previous theoretical and modeling studies. They also produced an improved estimate of the meridional ageostrophic wind, which enhances the poleward tilt of baroclinic waves. Yin is currently using the lag regression and eddy energy budget analysis techniques developed in his thesis to evaluate the structure of baroclinic waves and storm tracks in the NCAR CAM version 3 (CAM3) and the GFDL Atmosphere Model version 2 (AM2) compared to the ERA-40 and NCEP/NCAR reanalyses.

Trenberth and Smith analyzed the total mass of the atmosphere, which varies mainly from changes in water vapor loading, using global mean surface pressure, specific humidity, and precipitable water from the ERA-40 reanalyses from ECMWF. The mass of the dry atmosphere is estimated to be constant for the equivalent surface pressure to within 0.01 hPa based on changes in atmospheric composition. Global reanalyses satisfy this constraint for monthly means for 1979–2001 with a standard deviation of 0.065 hPa. New estimates of the total mass of the atmosphere and its dry component, and their corresponding surface pressures are larger than previous estimates owing to new topography of the Earth's surface that is 5.5 m lower for the global mean. Global mean total surface pressure is 985.50 hPa, and the total mean mass of the atmosphere is 5.1480×10^{18} kg, with an annual range due to water vapor of 1.5×10^{15} kg. The mean mass of water vapor is estimated as 1.27×10^{16} kg, and the dry air mass as $5.1352 \pm 0.0003 \times 10^{18}$ kg. The water vapor contribution varies with an annual cycle of 0.29 hPa range, a maximum in July of 2.62 hPa, and a minimum in December of 2.33 hPa. During the 1982–1983 and 1997–1998 El Niño events, water vapor amounts, and thus total mass, increased by about 0.1 hPa in surface pressure or 0.5×10^{15} kg for several months. Some evidence exists for slight decreases following the Mount Pinatubo eruption in 1991, and also for upward trends associated with increasing global mean temperatures, but uncertainties due to the changing observing system compromise the evidence.

Using the ERA-40 reanalyses for 1958 to 2001, an analysis by Trenberth, Smith, and Stepaniak was made of global patterns of monthly mean anomalies of atmospheric mass to examine whether global patterns of behavior exist requires analysis of all seasons together. Empirical orthogonal function (EOF) analysis, R-mode varimax rotated EOF analysis, and cyclostationary EOF (CSEOF) analysis tools were used to explore patterns and variability on interannual and longer time scales. Clarification is given of varimax terminology, and procedures that have been previously misinterpreted. The dominant global monthly variability overall is associated with the Southern Annular Mode (SAM), which is active in all months of the year and exhibits a great deal of natural unforced variability. The third most important pattern is the Northern Annular Mode (NAM) and associated NAO. Neither of these are really global modes, although they co-vary on long timescales in association with tropical or external forcing. For monthly data, the second mode corresponds to ENSO, which is truly global in extent. It exhibits more coherent evolution with time and projects strongest onto the interannual variability, where it stands out by far as the dominant mode in the CSEOF analysis. Unlike CSEOF analysis, standard EOF and varimax analyses are not able to evolve with time of year unless the analysis is stratified by season. Varimax analysis is able to extract the SAM, NAM, and ENSO modes very well, however.

Further analysis of the mean annual cycle and variability of vertically-integrated atmospheric energy and heat budgets by Trenberth and Stepaniak has been featured in the Symons lecture of the Royal Society. The focus is the flows of energy through the

climate system, whereby the incoming radiant energy is transformed into various forms (internal heat, potential energy, latent energy, and kinetic energy) moved around in various ways primarily by the atmosphere and oceans, stored and sequestered in the ocean, land, and ice components of the climate system, and ultimately radiated back to space as infrared radiation. Results are presented for the energy transformations, transports, uptake, storage and release, and the processes involved for the region 60°N to 60°S for the solstitial seasons and their differences to highlight the annual cycle. Values are provided for the seasonal uptake and release of heat by the ocean that substantially moderate the climate in maritime regions. Challenges in better determining the surface heat balance and its changes with time are discussed.



This figure shows vertically integrated atmospheric diabatic heating for 1979–2001 averages computed from NCEP/NCAR reanalyses as a residual. The bottom panel highlights the drivers of the monsoon systems and its seasonal reversal, while the top panels show the main heating for the mean climate in each season. The latent heating dominates the diabatic heating patterns. Trenberth et al. (2004)

Advanced Study Program (ASP) postdoctoral fellow Sungsu Park, together with Deser and Michael Alexander (Climate Diagnostics Center, CDC/NOAA), have completed a comprehensive study on estimation of the surface heat flux response to SST anomalies over the global oceans. The surface heat flux feedback is a key quantity needed for understanding and modeling the nature of large-scale air-sea interaction in climate variability studies. This work uses ship-derived estimates of turbulent energy fluxes and satellite-derived estimates of radiative fluxes to derive the surface heat flux response to local SST anomalies. The remote influence of ENSO is accounted for through simple linear regression analysis. Over most of the global oceans, the feedback is negative, implying a damping of SST anomalies via surface heat fluxes. However, in particular regions and seasons the feedback may be positive, implying an amplification of SST anomalies. Positive feedbacks are mainly associated with the following atmospheric responses to positive SST anomalies: (1) reduced surface wind speed (positive turbulent heat flux feedback) over the tropical western North Atlantic and Indian Oceans, (2) reduced marine boundary layer stratocumulus cloud fraction (positive shortwave radiative flux feedback) over the Namibian stratocumulus deck, and (3) enhanced atmospheric water vapor (positive longwave radiative flux feedback) in the vicinity of tropical deep convection region over the Indian Ocean that exceeds the negative shortwave radiative flux feedback associated with enhanced cloudiness.

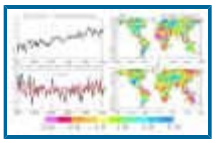
By combining a stochastically-forced entraining ocean mixed layer model with the ISCCP satellite-derived radiation data, Park is trying to understand how marine stratocumulus (MSC) feed back on the climate system through air-sea interaction over the midlatitude North Pacific Ocean in summer. A preliminary analysis indicates that MSC significantly increase year-to-year persistence of the SST anomalies during summer in the midlatitude North Pacific. The relative contributions of the other components, including turbulent heat

flux feedback, remote ENSO forcing, and oceanic entrainment (or reemergence) on the SST persistence are also being examined to assess the importance of the MSC-SST feedback.

Meehl, in collaboration with Harry van Loon (Colorado Research Associates), and Julie Arblaster, diagnosed decadal timescale variability in the latter part of the 20th century from NCEP/NCAR reanalyses and gridded precipitation from Climate Modeling and Analysis Program, and found consistency with an earlier modeling study in that the signal of increased solar forcing on the timescale of the 11 year solar cycle involves an intensification of the climatological precipitation maxima in the tropics, as well as an alteration of the vertical temperature structure also consistent with the earlier modeling study.

The Water Cycle

Aiguo Dai (CAS), along with Trenberth and Taotao Qian (CAS), have derived a monthly dataset of PDSI from 1870 to 2003 using historical precipitation and temperature data for global land areas on a 2.5° grid. Over Illinois, Mongolia, parts of China, and the former Soviet Union where soil moisture data are available, the PDSI is significantly correlated (r = 0.5 to 0.7) with observed soil moisture content within the top 1 m depth during warm season months. The strongest correlation is in late summer and autumn, and the weakest correlation is in spring when snowmelt plays an important role. Basin-averaged annual PDSI co-vary closely with streamflow. The results suggest that the PDSI is a good proxy of both surface moisture conditions and streamflow. An EOF analysis of the PDSI reveals a fairly linear trend resulting from trends in precipitation and surface temperature and an ENSO-induced mode of mostly interannual variations as the two leading patterns. The global very dry areas, defined as PDSI < –3.0, have more than doubled since the 1970s, with a large jump in the early 1980s due to an ENSO-induced precipitation decrease and subsequent expansion primarily due to surface warming while global very wet areas (PDSI > +3.0) declined slightly during the 1980s. Together, the global land areas in either very dry or very wet conditions have increased from 20% to 38% since 1972, with surface warming as the primary cause after the mid-1980s. These results provide observational evidence for increasing risk of droughts as anthropogenic global warming progresses and produces both increased temperatures and increased drying.



This figure shows leading modes of PDSI variations correspond to a trend and ENSO. Dai et al (2004).

Dai led a team of prominent researchers, including Peter Lamb (University of Oklahoma), Trenberth, Mike Hulme (University of East Anglia, United Kingdom), Phil Jones (University of East Anglia, England), and Pingping Xie (Climate Prediction Center, NCEP/NOAA), to rebut erroneous published conclusions concerning the reality of the drought in the Sahel. Using rainfall data from a fixed station network, they show that decreasing rainfall trends are widespread in the Sahel during the later part of the 20th century, and that the decreasing trend in Sahel regional rainfall is not an artifact of changing station networks. They show that the rainfall model used in Chappell and Agnew is incorrect, their modeled

rainfall time series is totally unrepresentative of a Sahel rainfall average, their conclusion about the Sahel rainfall trends being an artifact of changing station locations is emphatically wrong, and their speculative statements about the implications of their results for other studies and other regions of the world are completely unfounded.

Trenberth continues work on manifestations of global climate change on accelerating the hydrological cycle and the prospects for increasing extremes. The issue of how the hydrological cycle will change as the climate changes is complicated considerably by somewhat independent changes in pollution (aerosol), whereby increases typically act to short-circuit the hydrological cycle. However, with warming, the main prospect is for increased water holding capacity and associated increased water vapor in the atmosphere. The rate of increase of 7% K-1 is much greater than projected rates of increase in overall evaporation and precipitation, which are more like 1–2% K-1 and are governed by the surface heat budget. Hence, the prospects are for increases in precipitation intensity but decreases in duration or frequency of precipitation. In addition, increased rain at expense of snowfall is likely, with major impacts on snow pack (storage) and soil moisture. The changes directly impact partitioning into soil moisture and runoff, and make prospects of both droughts and floods more likely.

Dai and Trenberth have used the estimated river discharge data and the E-P fields derived from the ECMWF and NCEP/NCAR reanalyses to derive new estimates of meridional transport of fresh water by the oceans. Preliminary results show improved agreement with in situ data based on direct estimates. Compared with earlier indirect estimates, the new estimates show increased southward transport in the Atlantic Ocean and increased northward transport in the South Pacific. However, the E-P fields are being evaluated.

Dai, together with Qian and Trenberth, has started to estimate the global continental fresh water discharge since 1950 by combining historical records of streamflow and model-simulated surface runoff (forced by reanalysis and station data). The Community Land Model (CLM) has been run offline forced by observation-based 3-hourly surface data (precipitation, surface solar radiation, surface air temperature, wind speed, and specific humidity). Surface observations of cloud cover were used to correct the erroneous trends in the reanalysis surface solar radiation. The satellite-based 3-hourly estimates of surface solar radiation for 1983–2001 from ISCCP were used to adjust the biases in the reanalysis solar data. The 6-hourly mean precipitation rates from the reanalysis were adjusted to represent realistic combination of frequency and intensity using observed precipitation frequency maps. The CLM was first run hundreds of years using recycled forced data to get a stable state for deep soil water. The historical CLM simulations (from 1948–2002), together with available observational datasets, will be used to study the changes and variations in terrestrial water fluxes (evaporation, precipitation, runoff, streamflow, and continental discharge) and surface moisture conditions (soil moisture contents, surface humidity, drought indices) during the last 50 years, especially since the mid-1970s when rapid global warming has occurred.

Dai collaborated with X.-Z. Liang and others at the Illinois State Water Survey and University of Illinois at Urbana-Champaign in using the MM5-based regional climate model (CMM5) to study the diurnal cycle of United States summer precipitation. They found that the model performance is very sensitive to the choice of cumulus parameterization schemes whose skills are highly regime selective. The Grell scheme realistically simulates the nocturnal precipitation maxima and the associated eastward propagation of convective

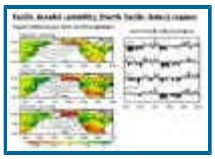
systems over the Great Plains, where the diurnal timing of convection is controlled by the large-scale tropospheric forcing; whereas the Kain-Fritsch scheme is more accurate for the late afternoon peaks in the southeast U.S. where moist convection is governed by the near-surface forcing. In radar rainfall data and the simulation with the Grell scheme, another weaker eastward-propagating diurnal signal is evident from the Appalachians to the east coast. The result demonstrated the importance of cumulus schemes and provided a realistic simulation of the central United States nocturnal precipitation maxima.

El Niño-Southern Oscillation and Other Tropical Studies

Fasullo examined biennial characteristics of Indian monsoon rainfall to explore the coincidence of ENSO with the near 3-year peak the all-India rainfall spectrum. He found the oft-cited, weak-to-strong transitions in monsoon rainfall to be uniquely associated with El Niño-La Niña transitions, and showed the 3-year peak in rainfall's power to coincide with the ENSO spectrum. The temporal and spatial structure of biennial power within India was shown to mirror the strength of the ENSO-monsoon teleconnection. Statistically robust and previously undocumented occurrences of biennial persistence were also identified. The role of an independent Indian Ocean mode in instigating biennial fluctuations in the monsoon is therefore called into question.

Dai's work in collaboration with Adam Monahan (University of Victoria, Canada), has been completed and published. They examined the spatial and temporal structures of ENSO nonlinearity in several observed and model datasets, and found that the anomaly spatial pattern that changes sign between El Niño and La Niña events (the "linear" signal) strongly resembled that of the first EOF, while that which does not change sign (the "nonlinear" signal) resembled the pattern of the second EOF. Of several coupled models considered, the spatial structure of the El Niño/La Niña asymmetry was partly captured only by the GFDL R30 model.

Deser, together with Phillips and Hurrell, published a comprehensive study on the observed linkages between multi-decadal variability of the Aleutian Low in wintertime and conditions in the tropical Indo-Pacific during the last ~100 years. Their results provide strong evidence that the tropical Indo-Pacific Ocean is a key driver of North Pacific climate change on multi-decadal time scales. Modeling experiments are underway to address the mechanisms for this linkage.



This figure shows (left) epoch difference maps of winter SLP (contours) and land precipitation (color shading) for high-low North Pacific Index (NPI) regimes. The right shows the North Pacific 1899–2002: -NPI; winter precipitation difference coastal Alaska-Japan; winter surface air temperature NW Canada and Alaska; and EOF1 of winter-spring monthly SST anomalies. Deser et al. (2004).

In related work, Deser, together with Rosanne D'Arrigo (Lamont-Doherty Earth Observatory, Tree-Ring Laboratory) and other co-authors, completed an analysis that extends the observational work to paleoclimate records covering nearly four centuries. Specifically, they analyzed a suite of tree-ring chronologies from land areas surrounding

the North Pacific Rim and a suite of coral records from the tropical Indo-Pacific Ocean to assess their degree of association on decadal time scales. The results show that the strength of association between the low and high latitude proxy records varies over time, with the 20th century showing the most coherent linkages.

Park, Deser, and Alexander, are completing a study of the influence of ENSO and local cloud-SST feedbacks upon SST anomaly persistence in the North Pacific. This work uses new estimates of surface heat flux feedbacks (see *Climate Diagnostics*), and a simple entraining stochastic climate model to investigate why summer SST anomalies in the North Pacific are so persistent despite their weak thermal inertia due to a shallow mixed layer.

The North Atlantic

Deser, with Ramalingam Saravanan (CDP) and Gudrun Magnusdottir (University of California at Irvine), published a study based on a suite of experiments using the CCM3 to investigate the relative sensitivity of the model's atmospheric circulation to observed trends over the past 50 years in winter sea ice extent and SST over the North Atlantic/arctic sector. They found a stronger sensitivity to the sea ice anomalies than SST anomalies. The response is a weak negative feedback on the NAO. The total response resembled closely the leading pattern of internal circulation variability in the model, although an additional “direct” near-local response was also apparent.

In a follow-up study Deser, together with Shiling Peng (CDC/NOAA), is using a simple modeling framework to gain insight into the dynamical processes responsible for the hemispheric atmospheric circulation response to sea ice and SST anomalies seen in the CCM3 experiments described above.

In related work Deser, together with Robert Tomas (CCR and CAS), is conducting a 100-member ensemble of short (4-month) integrations with the same SST/sea ice forcing and saving the output daily. Each ensemble member begins from a different initial condition on December 1, selected from a long control run, and is paired with a control integration that begins from the same initial condition but has no sea ice/SST forcing. These integrations should shed light on the evolution of the response to its equilibrium structure and on the dynamical processes at work.

Christophe Cassou (CAS), together with Deser and Hurrell, published two studies on the NAO. The first documented the spatial asymmetry of the two phases of the NAO and their associations with tropical and North Atlantic SSTs. The second examined the role of summer SST anomalies in the North Atlantic and their impact upon the following early-winter NAO. They found a statistical association in the observational data for an impact via a tropical atmospheric bridge. The physical basis for this empirical association was examined by means of modeling experiments using CCM3.

Hurrell, along with Martin Hoerling (CDC/NOAA), Phillips, and Taiyi Xu (CDC/NOAA), completed two papers examining the role of tropical forcing in boreal winter North Atlantic climate change over the last half of the 20th century. In the first paper diagnoses of ensembles of atmospheric general circulation model (AGCM) experiments demonstrate that the observed upward trend in the winter NAO index since 1950 is a virtually deterministic response to the temporal history of SSTs and that tropical SST forcing is of

primary importance. In the second paper it is further established through idealized SST experiments that progressive warming of the Indian Ocean since 1950 is the principal contributor to the NAO changes. Moreover, it is demonstrated from coupled model experiments that the Indian Ocean warming likely has a strong anthropogenic component.

This figure shows trends in the NAO stem from trends in tropical sea surface temperatures and their effects on the atmosphere via precipitation and latent heat release. Hurrell et al. (2004)

Hurrell, Hoerling, and Phillips are nearing completion of a new study that examines the nature and causes for the regional downward trajectories of both northern and southern African monsoon rainfall over the latter half of the 20th century. Used are ensembles of five different AGCMs forced by the observed evolution of the global oceans since 1950, as well as control simulations with fully coupled ocean-atmosphere CCSM. One main finding is that the observed drying trends during both monsoon seasons fall within the distribution function of the simulated trends drawn from the AGCM experiments. They are not, however, consistent with the probability distribution function (PDF) of 50-year trends occurring from the unforced CCSM. In fact the PDFs of 50-year trends from these two different simulation datasets are almost mutually exclusive. This suggests that the observed downward trajectories of African monsoon rainfall since 1950 have been intimately controlled by the observed trajectory of global SSTs, though the responsible air-sea interactions may not be those occurring from natural variations alone. The possibility cannot be dismissed, however, that the simulated natural variability of the CCSM is too weak. Analysis of long integrations using other coupled models is in progress to assess robustness.

Hurrell, Phillips, Cassou, Chris Folland (Hadley Centre, United Kindom Meteorological Office), and Simon Brown (Hadley Centre, United Kingdom Meteorological Office) have completed their analysis of an ensemble of numerical experiments designed to assess the limitations of forcing AGCM with observed SSTs. The work primarily examines how coupling affects the variance and persistence of extratropical atmospheric properties, but it was extended to examine in more detail the effects of interactive SSTs on the tropical climate as well.

Hurrell and Folland continue their examination of the annual cycle of climate and climate change over the Atlantic investigating the mechanisms responsible for the variability through analyses of both observed and climate model data. They find a significant change in the summer European climate, whereby a summer season of higher-than-average surface pressure over northern Europe is accompanied by reduced rainfall over the tropical North Atlantic and North Africa. Based on analysis of variance techniques that separate climate variability into forced (i.e., due to SST variations) and unforced (i.e., due to internal atmospheric dynamics) components, their results suggest the observed low-frequency extratropical changes in summer climate arise indirectly from processes that affect tropical Atlantic precipitation on long time scales, such as the inter-hemispheric gradient in tropical Atlantic SST.

Hurrell and Mark Rodwell (ECMWF), a scientific visitor to CAS over the summer of 2003, published their work examining the response in five different atmospheric general

circulation models (GCM) (including CAM) to realistic, optimally chosen North Atlantic SST anomalies. Together with Marie Drevillon (CERFACS), Claude Frankignoul (Universite Pierre et Marie Curie), Holger Pohlmann (Max Planck Institute), Martin Stendel (Danish Meteorological Institute), and Rowan Sutton (Reading University), they illustrate a consistent response among the models that is similar to observational estimates.

Hurrell has published several articles dealing with climate variability and ecology. He also served as a co-editor of a 2004 Oxford University Press book entitled Marine Ecosystems and Climate Variation with Nils Chr. Stenseth (University of Oslo), Geir Ottersen (Institute for Marine Research, Bergen Norway), and Andrea Belgrano (University of New Mexico). With Ottersen and Stenseth, Hurrell wrote the book's introductory chapter that overviews the main currents and hydrography of the Atlantic Ocean and how the Atlantic is affected by large-scale variations in leading patterns of atmospheric variability. The chapter also provides an overview of oceanographic processes believed to be of particular importance to marine ecology, and it concludes with an account of how diverse the responses of ecology are to coupled atmosphere-ocean climate variability. In the same book Hurrell and Robert Dickson (Centre for Environment, Fisheries and Aquaculture Science) published a chapter that focused on the NAO and its forcing of the North Atlantic Ocean.

With Stenseth, Ottersen, Atle Mysterud (University of Olso), Mauricio Lima (Center for Advanced Studies in Ecology and Biodiversity, Chile), Kung-Sik Chan (University of Iowa), Nigel Yoccoz (Division of Arctic Ecology, Norwegian Institude for Nature Research), and Bjørn A°dlandsvik (Institute of Marine Research, Bergen Norway), Hurrell published an overview of climate patterns within the context of the ecological effects of climate variability by making use of climate indices. Whereas the considerable influence of both the ENSO and the NAO on ecological processes has been demonstrated, several other large-scale climate patterns are also of ecological interest. Both the advantages and disadvantages of using climate indices, which by definition reduce complex space and time variability into simple measures, in ecological studies are discussed.

Hurrell, in collaboration with Stenseth, Chan, Amir Shabbar (Meteorological Service of Canada), Stan Boutin (University of Alberta), Eli Rueness, Dorothee Ehrich, Kjetill Jakobsen, and Ole Chr. Lingjærde (all with the University of Oslo), studied how the dynamics of Canadian lynx (Lynx canadensis) abundance are geographically structured according to the influence of large-scale climatic regimes. This structuring matches zones of differential snow conditions, in particular surface hardness, as determined by the frequency of winter warm spells. Through a modified functional response curve it is shown that various features of the snow may influence lynx interaction with its main prey species, the snowshoe hare (Lepus americanus): softer snow reduces the killing capacity of lynx. This study highlights the importance of snow, and exemplifies how large-scale climatic fluctuations can – mechanistically – influence population biological patterns.

Decadal Variability

Deser, together with Shoshiro Minobe (Hokkaido University, Japan), Niklas Schneider (University of Hawaii), and four others, completed a review paper on Pacific decadal variability. This study, solicited by the International CLIVAR Program, summarizes the observed features, proposed mechanisms and current state of predictability of Pacific climate variability on decadal time scales.

Deser, together with Antonietta Capotondi (CDC/NOAA), Alexander, and Arthur Miller (Scripps Institution of Oceanography), completed a study on low-frequency pycnocline variability in the Gulf of Alaska using output from the NCAR CSM Ocean Model (NCOM) forced with time-varying atmospheric conditions during 1958–1997. They found that a large fraction of the pycnocline variability can be explained by local Ekman pumping due to local wind stress curl anomalies, while wave processes also contribute in coastal regions.

Deser, along with Capotondi, Alexander, and Michael McPhaden (Pacific Marine Environmental Laboratory/NOAA), completed a study on the anatomy and decadal evolution of the Pacific subtropical ocean circulation cells using output from the NCOM forced with time-varying atmospheric conditions during 1958–1997. They found that the interior equatorward mass transports of these circulation cells decreases after the mid-1970s, consistent with observations, and that the poleward western boundary current transports increase. The meridional mass transport convergence into the equatorial zone is strongly correlated with SSTs in the central and eastern Pacific.

Dai, in collaboration with Aixue Hu (CCR), Meehl, and Warren Washington (CCR), analyzed the variations of the Atlantic thermohaline circulation (THC) in a 1200-year control run and future climate change simulations using the Parallel Climate Model (PCM). The Atlantic THC intensified during the first century of the control run due to rapid cooling in the upper North Atlantic Ocean, and then became increasingly shallower and weaker due to freshening in surface oceans. Through potential vorticity conservation, the subpolar ocean gyre centered at the Labrador Sea contracted from (expanded to) the east, and the North Atlantic Current shifted southward (northward) as the THC gained (lost) strength and depth. A strong and deep THC leads to increased oceanic heat convergence and thus warming in the northern North Atlantic Ocean, thereby reducing the North Atlantic Deep Water production and eventually weakening the THC, a mechanism that might have contributed to large multi-decadal (~24 year) oscillations in the THC's strength. In the greenhouse gas forced simulations, the THC weakens during the 21st century. In the 22nd century the THC continues to weaken if CO_2 keeps rising, but stabilizes if the greenhouse gases level off. This THC weakening results from larger warming in the upper and North Atlantic Ocean than the deeper and southern Atlantic basin, while salinity changes are small.

Meehl collaborated with Hu to examine aspects of multi-decadal variability in the PCM as seen in observations. In particular, sustained droughts and "megadroughts" in the Indian monsoon and southwestern United States regions were connected to the dominant pattern of multi-decadal SST variability in the Pacific in model and observations. The mechanism producing such multi-decadal climate variations in Pacific SSTs in the model involves coupled air-sea and tropical-midlatitude processes involving slowly propagating wind-forced ocean Rossby waves near 20°N and 20°S.

Model Evaluations

The study by Dai and Trenberth on the diurnal cycle in the CCSM version 2 (CCSM2), with a focus on precipitation and moist convection, was completed and published. The CCSM2 captures the diurnal amplitude and phase of surface air temperature over land, but over the ocean the amplitude is too small. The CCSM2 overestimates the mean total cloud amount from ~15°S–15°N and over northern mid- and high-latitude land areas in

winter, whereas it underestimates the cloud amount by 10–30% in the subtropics and parts of the mid-latitudes. Problems also exist in the marine stratocumulus regions west of the continents. In the CCSM2, warm-season daytime moist convection over land starts about four hours too early compared with observations, and plateaus from 1100 to 1800 LST, in contrast to a sharp peak around 1600–1700 LST in observations.

Dai collaborated with Ying Sun, Susan Solomon, and Robert Portmann of NOAA Aeronomy Laboratory in a study to evaluate current climate models' ability to simulate precipitation frequency, intensity, and the number of heavy-rain days. They analyzed daily precipitation data from worldwide rain gauges and seven fully coupled climate models. Although the current models are able to simulate the total precipitation amount well, most of them are unable to fully capture the spatial patterns of precipitation frequency and intensity. For light precipitation (1–10 mm day-1), most models overestimate the frequency, but produce patterns of the intensity that are in broad agreement with observations. For heavy precipitation (> 10 mm day-1), most models significantly underestimate the intensity but simulate the frequency well. The average number of the heavy rain days, which accumulate about two thirds of annual rainfall on average, is a simple index capturing the combined effects of frequency and intensity on water supply. Most of the models show large deficiencies in simulating the spatial distribution of the heavy rain days. The results indicate that precipitation variability remains a substantial challenge for most current climate models.

Deser, together with Capotondi, Saravanan, and Phillips, are contributing a paper to the *Journal of Climate* special issue devoted to the documentation of the CCSM3 and its component models. This study will document aspects of the ENSO phenomenon in CCSM3, including the spatial and temporal patterns of SST, precipitation, sea level pressure, surface wind, and ocean thermocline depth anomalies associated with ENSO over the global tropics. Additionally, the atmospheric teleconnections to the extra-tropics will be documented. The relationship between the temporal scale (e.g., frequency) and meridional scale of ENSO in the coupled model will also be explored within the dynamical framework of the delayed oscillator paradigm. Tropical Atlantic variability independent of ENSO will also be documented.

Young-Oh Kwon (ASP postdoctoral fellow) and Deser are analyzing Pacific decadal variability in the atmosphere and ocean from an 800-year segment of the CCSM2 control integration. Prominent spectral peaks at ~16 years and ~40 years are evident in oceanic variables such as SST and subsurface temperature throughout the North Pacific Ocean. The temporal and spatial structure of these decadal oscillations and the nature of the upper ocean heat budget during a composite decadal cycle are being evaluated to gain insight into the mechanisms responsible for the variability.

Meehl collaborated with Claudia Tebaldi (Research Applications Program) and Doug Nychka (GSP) to diagnose patterns of frost days and heat waves in the 20th century related to processes that produce these phenomena. They then related these processes to possible future changes. They found that the observed trend in frost days in the latter part of the 20th century (greater decreases of frost days in the western United States compared to the eastern United States) was most directly associated with changes in atmospheric circulation over that time period. Similarly, the observed pattern of heat waves over the United States and Europe in the latter part of the 20th century, derived from NCEP/NCAR reanalysis data, was related to the climatological atmospheric circulation, with greater heat wave occurrence over the southwestern United States,

southern and upper midwest, and eastern seaboard of the United States.

Meehl also collaborated with Ping Liu (University of Hawaii), Bin Wang (University of Hawaii) and Ken Sperber (Lawrence Livermore National Laboratory, LLNL) in a study of the Madden-Julian Oscillation (MJO) in the CAM. In the standard CAM version, MJO variability is very weak. By substituting another convection scheme in the model that is known to better simulate MJO variability, the MJO simulation in this modified version of CAM becomes much more realistic. This shows that the convection scheme is most directly responsible for simulating the MJO in an atmospheric model and suggests future improvements in the CAM.

Hurrell, Phillips, Hack, Caron, and Yin are contributing a new paper to the *Journal of Climate* special issue devoted to documentation of the CCSM3 and its component models. In particular, these authors are examining the dynamical aspects of CAM in uncoupled mode, including the seasonal variation of its mean state and its intraseasonal and interannual variability. Comparisons are made to not only observations, but also to an earlier version of the CCM3.

Tom Wigley (CAS), in collaboration with Caspar Ammann (CCR), Ben Santer (LLNL), and Sarah Raper (Alfred Wegener Institute for Polar and Marine Research), has considered the effects of volcanic eruptions on climate using both PCM and Model for the Assessment of Greenhouse-gas Induced Climate Change (MAGICC). The results from 16 PCM simulations are used to reduce internally-generated noise and obtain an improved estimate of the underlying response of 20th century global-mean temperature to volcanic forcing. MAGICC is then used with the same forcing and the same climate sensitivity as the AOGCM to emulate the AOGCM results. The upwelling-diffusion energy balance model (UD EBM) and AOGCM results are in excellent agreement, justifying the use of the UD EBM to determine the volcanic response for different climate sensitivities. The maximum cooling for any given eruption is shown to depend approximately on the climate sensitivity raised to power 0.37. After the maximum cooling for low-latitude eruptions, the temperature relaxes back towards the initial state with an e-folding time of 29–43 months for sensitivities of 1–4°C. Comparisons of observed and modeled coolings after the eruptions of Agung, El Chichon, and Pinatubo give implied climate sensitivities that are consistent with the IPCC range of 1.5–4.5°C equilibrium warming for 2 x CO_2. The cooling associated with Pinatubo appears to require a sensitivity above the IPCC lower bound of 1.5°C, and none of the observed eruption responses rules out a sensitivity above 4.5°C.

Anthropogenic Climate Change and Detection

Dai, Meehl, Washington, and others analyzed the climate change simulations under the Department of Energy-sponsored Accelerated Climate Prediction Initiative Program using the PCM. An initialization to 1995 ocean conditions removes a large part of the unforced oceanic temperature and salinity drifts that occurred in the standard 20th century integration. The results suggest that the affect of small errors in the oceans (such as those associated with climate drifts) on coupled GCM-simulated climate changes may be negligible.

Article 2 of the United Nations Framework Convention on Climate Change has as its objective the stabilization of greenhouse gas concentrations in the atmosphere. The choice of a CO concentration stabilization target, considered by Wigley, depends on the

following: what is considered to be ‘dangerous anthropogenic interference with the climate system’; the forcings that might arise from non-CO_2 gases; and the climate sensitivity. These three factors are specified probabilistically, as probability density functions, and combined to produce a PDF for the CO_2 concentration target. There is a probability of 17% that the stabilization target should be less than the present level, and the median target is 536 ppm. The effects of reducing the emissions of non-CO_2 gases and/or implementing adaptation strategies are considered probabilistically and shown to alter these figures significantly.

This work has been extended by Wigley in collaboration with Richard Richels (Electric Power Research Institute) and Alan Manne (Stanford University) to consider the issue of climate stabilization rather than concentration stabilization. Thermal inertia of the oceans requires concentrations to decrease after a global-mean temperature stabilization point has been reached in order to maintain a stable climate. Focusing on temperature change is judged to be more meaningful than focusing on changes in atmospheric composition. The analysis explicitly incorporates several uncertainties critical to future temperature change: economic growth, climate sensitivity, and the rate of ocean heat uptake. Concentration ceilings necessary to limit temperature change to 2°C and 3°C are considered. The influence on investments in technology is addressed in the analysis. Differences in the assumed technological future that correspond to billions of dollars in investment costs can translate into trillions of dollars worldwide in terms of mitigation costs over the 21st century.

As an application of MAGICC, Wigley has considered the issue of the climate change commitment. Due to oceanic thermal inertia, even if the composition of the atmosphere were fixed at present levels, global-mean warming and sea level rise would continue. These constant-composition (CC) commitments and their uncertainties are quantified. The constant emissions (CE) commitment is also considered. The eventual CC warming commitment lies between 0.2°C and more than 1°C. The CE warming commitment is much larger (2–6°C by 2400). The CC sea level rise commitment ranges from negligible to more than 30 cm/century (central estimate, 10 cm/century). The corresponding CE commitment ranges from 6 cm/century to more than 50 cm/century (central estimate, 25 cm/century). Avoiding these changes requires, eventually, a reduction in emissions to substantially below present levels. For sea level rise a substantial long-term commitment may be impossible to avoid.

To investigate sea level rise over many centuries under CO_2 concentration stabilization scenarios, Wigley and Raper have developed a new Glacier and Small Ice Cap (GSIC) model. To justify the need for such a model, they show that the corresponding model used in the IPCC Third Assessment Report (TAR), if applied to times beyond 2100, imposes an unrealistic upper bound on GSIC melt. A modification to the TAR model is introduced that allows it to be extended beyond 2100 with asymptotic melt equal to the initially available ice volume (V0). The modification has a negligible effect on the original TAR formulation out to 2100 and provides support for the IPCC method over this time period. The sensitivity of GSIC melt to uncertainties in V0 and mass balance sensitivity is examined, and melt results are given for a range of CO_2 concentration stabilization cases. Approximately 73–94% of GSIC ice is lost by 2400.

The issue of natural climate variability is addressed by Peter Foukal (Heliophysics, Inc.),

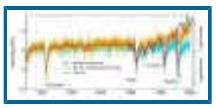
Gerald North (Texas A&M University), and Wigley. They assess the likelihood of significant low-frequency solar irradiance changes using recent astronomical evidence. Recent reconstructions of solar irradiance extending back to the 17th century have relied mainly on reconstructions of relatively large, multi-decadal irradiance variations based on photometry of other Sun-like stars. In fact, very few true Sun-like stars have been identified, so the basis for these reconstructions is suspect. If these speculative low-frequency irradiance variations are ignored, the fraction of past climate changes attributable to solar variations is much reduced, with important implications for our understanding of features like the Little Ice Age and the early 20th century warming.

In collaboration with Santer, Wigley has produced a review of 'fingerprint' (i.e., pattern correlation) method for detection and attribution. The work uses tropopause height as a detection variable to illustrate the 'constant pattern' approach pioneered by Klaus Hasselmann (Max-Planck-Institut fur Meteorologie). Observed changes from the NCEP/NCAR and ERA-15 reanalyses are compared with fingerprints for the sum of anthropogenic and natural (solar plus volcanic) forcing derived from the NCAR/DOE PCM. Both 'raw' and 'optimized' fingerprints are considered, and full spatial patterns, and patterns with global-mean changes removed are considered. Observed-model agreements are always strong and highly statistically significant. The primary causes for decadal time scale tropopause height changes are increases in well-mixed greenhouse gases (that warm the troposphere) and stratospheric ozone depletion (that cools the stratosphere). Both factors are required to explain the observed height changes.

Unravelling the causes of recent climate change is also the focus of a paper by Santer, Wigley and 16 other authors from a number of institutions (including Ammann, Meehl and Washington). This work examines changes in the height of the tropopause using the ERA-40 reanalysis, and uses optimized pattern correlation methods to identify the fingerprint of human-induced changes in the observational record. Over 1979–2001, the height of the tropopause increased in the ERA-40 data by nearly 200 m. The spatial pattern of height increases is consistent with predictions from PCM for the response to anthropogenic forcing factors and cannot be explained by natural variability alone. ERA-40 temperature data for the troposphere and the stratosphere are shown to agree well with satellite-based microwave sounding unit data from two independent sources. The results support the reality of significant human-induced temperature changes in both the troposphere and the stratosphere, and confirm earlier results that changes in regions have contributed to the observed tropopause height increase.

Wigley, in collaboration with Steve Smith (Joint Global Change Research Institute, JGCRI) and Hugh Pitcher (JGCRI), has developed new projections for future SO_2 emissions using the MiniCAM integrated assessment model. An income-based parameterization for future SO_2 emissions controls is developed using purchasing power parity (PPP) income estimates and their relation to historical controls. As a result of increases in both concerns about pollution and the economic ability to institute emissions controls for SO_2 that accompany increasing per capita wealth, SO_2 emissions for almost all of the IPCC Special Report on Emissions Scenarios (SRES) scenarios eventually decline over the next century to levels substantially below those of today – except in scenarios where future incomes in developing nations increase slowly. Under a climate policy that limits CO2 emissions, SO_2 emissions lie in a relatively narrow range, in part because of their common fossil-fuel sources.

Also in collaboration with Smith, Wigley has examined the role of climate forcing agents other than carbon dioxide using the MiniCAM integrated assessment model for no-climate-policy and policy emissions scenarios. Non-CO_2greenhouse-gas forcing is dominated by methane and tropospheric ozone. Assumptions about the prevalence of methane recovery and local air pollution controls in the no-policy cases are a critical determinant of methane and ozone-precursor emissions. When these factors are considered, emissions of these gases are reduced substantially relative to earlier estimates, such as those in the SRES. Climate change predictions based on at least some of the SRES scenarios are therefore likely to be overestimates. The indirect influence of mitigation policies on SO_2 emissions is also considered. While aerosols have only relatively small effects on climate by the end of the century, there is a significant interaction in the early 21st century between policies to reduce CO_2 emissions and SO_2 emissions, even in the presence of SO_2-related pollution control policies. The attendant reduced aerosol cooling more than offsets the reduction in warming that accrues from reduced CO_2.



This figure shows tropopause height changes: Model (PCM) vs observed from ERA-40 after 1958. Means are forced to be the same 1958–1999. Bold lines are low pass filtered. The orange and blue envelopes are measures of the variability. The model, with all forcings, follows the analyses well, although volcanic events are overdone. (Santer, Wigley et al. 2004)

General Overviews

Trenberth, along with Berrien Moore (University of New Hampshire), Tom Karl (National Climatic Data Center/NOAA), and Carlos Nobre (Centro de Pronostico del Teimpo y Estudios Climatico, del Instituto Nacional de Investigaciones Espaciales), has put forward a future perspective on monitoring and prediction of the Earth's climate as a keynote talk at the International CLIVAR conference. They point out that, not only is the climate changing and will continue to do so regardless of any mitigation actions, but observations and information available are also changing as technological advances take place. Accordingly, they highlight the need for a climate information system that embraces a comprehensive observing system to observe and track changes and the forcings of the system as they occur, and which develops the ability to relate one to the other and understand changes and their origins. Observations need to be taken in ways that satisfy the climate monitoring principles and ensure long-term continuity, and which have the ability to discern small but persistent signals. They propose some benchmark observations to anchor space-based observations and trends, including a much-needed step forward in the quality of water vapor observations. The health of the monitoring system must be tracked and resources identified to fix problems. Fields must be analyzed into global products and delivered to users while stakeholder needs are fully considered. Data should be appropriately archived with full and open access, along with metadata that fully describe the observing system status and environment in which it operates. Reanalysis of the records must be institutionalized along with continual assessment of impacts of new observing and analysis systems. Some products will be used to validate and improve models, as well as initialize models and predict future evolution on multiple time scales using ensembles. Attribution of changes to causes is essential, and it is vital to

fully assess past changes and model performance and results in making predictions to help appraise reliability and assess impacts regionally on the environment, human activities, and sectors of the economy. They claim that such a system will be invaluable and further provides a framework for priority setting new observations and related activities.

Trenberth, with Phil Arkin and Eugenia Kalnay (University of Maryland), James Laver (Climate Prediction Center/NOAA), and Siegfried Schubert (Goddard Space Flight Center/NASA), wrote up results of a workshop on “Ongoing analysis of the climate system.” They point out that one essential aspect of a comprehensive climate observing system is the capability to synthesize observations into a coherent, internally consistent depiction or analysis of the evolution and present state of global climate. To further the planning that will ensure such a national capacity, the workshop was held involving about 65 scientists and agency managers. The workshop provided guidance on the steps needed to ensure that ongoing developmental ocean, atmosphere, and land surface data assimilation/reanalysis efforts remain complementary, and identified near-term, high priority actions required for future atmospheric reanalyses that will: 1) deal more effectively with the changing climate observing system and with uncertainties in analyzed fields; 2) improve the description of atmospheric interactions with the land, ocean and cryosphere; and 3) improve the description of the hydrological cycle.

Trenberth reviewed the role of the ocean in climate as the opening keynote introduction to NOAA’s new Annual Report of the State of the Ocean and Ocean Observing System for Climate. He discussed the importance of the ocean being wet, having large heat capacity, its geographic distribution, its role in the hydrological cycle, the role of currents in transporting heat, fresh water, and chemicals, the thermohaline circulation, the annual cycle, sea ice, coupled ocean-atmosphere interactions, and sea level changes. Ultimately, he provided a comprehensive justification for better observations of the ocean.

Trenberth, John Overpeck (University of Arizona) and Susan Solomon (Aeronomy Lab, NOAA) wrote a full report and a summary for *Eos* on a workshop on “Exploring drought and its implications for the future.” The meeting was titled more fully “A Multi-millennia Perspective on Drought and Implications for the Future” and was organized on behalf of the international CLIVAR-PAGES joint working group. The meeting was attended by approximately 70 people and brought a focus of new ideas, observations, analyses, and theories about drought to improve understanding, analysis approaches, and predictive capabilities. The main focus regionally was on North America and Northern Africa, the two regions with the largest amount of available, drought-related paleo-data and research, as well as serious ongoing droughts. For a full report see http://ipcc-wg1.ucar.edu/meeting/wg1/Drght

Trenberth points out that, while urbanization and other changes in land use have an impact on surface air temperatures, the Kalnay and Cai *Nature* report claim that urbanization and land-use change have a major effect on the climate in the United States is flawed. They used surface temperatures obtained from NCEP/NCAR 50-year reanalyses (NNR), and their difference compared with observed station surface temperatures as the basis for their conclusions on the grounds that the NNR did not include these anthropogenic effects. However, the NNR also overlooked other factors, such as known changes in clouds and in surface moisture, which are more likely to explain Kalnay and Cai’s findings. Although urban heat-island effects are real in cities, direct estimates of the effects of rural land use change indicate a cooling rather than a

warming influence that is due to a greater reflection of sunlight.

Karl and Trenberth reviewed “Modern global climate change” as part of Science’ State of the Planet series in December 2003. They point out that modern climate change is dominated by human influences, which are now large enough to exceed the bounds of natural variability. The main source of global climate change is from human-induced perturbations of the composition of the atmosphere primarily resulting from emissions associated with energy use, but on local and regional scales urbanization and land use changes are also important. Although there has been recent progress in monitoring and understanding climate change, there remain many scientific, technical, and institutional impediments for precise planning for, adapting to, and mitigating the effects of climate change. There still exists considerable uncertainty about the rates of change that can be expected, but it is clear that these changes will be increasingly manifested in important and tangible ways, such as changes in extremes of temperature and precipitation, decreases in seasonal and perennial snow and ice extent, and sea level rise. Anthropogenic climate change is now likely to continue for many centuries into the future. They suggest that we are venturing into the unknown with climate and its associated impacts could be quite disruptive.

Wigley has produced a review of simple climate models, from one-box energy balance models (EBMs) to multi-box upwelling-diffusion (UD) EBMs. The latter is illustrated using the MAGICC mode (downloadable from www.cgd.ucar.edu), which couples a UD EBM to a range of gas-cycle models to investigate future climate change due to anthropogenic emissions of greenhouse gases and aerosol precursors. Because of their computational efficiency, simple climate models are valuable when a large number of climate simulations are required, as is the case for probabilistic projections of future warming. Some examples of probabilistic projections are given in this review.

Wigley has compared future climate change under no-policy and policy emissions pathways. Future emissions under the full range of SRES scenarios are used as examples of no-climate-policy scenarios, while the WRE CO_2 concentration profiles are given as examples of stabilization pathways. An alternative ‘overshoot’ pathway is introduced where concentrations initially rise above the eventual stabilization level. Probabilistic projections (as PDFs) for global-mean temperature under the SRES scenarios are given. The relative importance of different sources of uncertainty is determined by removing individual sources of uncertainty and examining the change in the output temperature PDF. Emissions and climate sensitivity uncertainties dominate, while carbon cycle, aerosol forcing, and ocean mixing uncertainties are shown to have only small effects. Uncertainties in regional climate change are also considered by comparing normalized changes (i.e., changes per 1°C global-mean warming) across multiple models and using the inter-model standard deviation as an uncertainty metric.

Wigley has also produced an extensive review of input needs for downscaling of climate data for the California Energy Commission. Downscaling refers to the production of high spatial resolution information from coarser-resolution AOGCM output. Statistical and dynamical (i.e., the use of regional climate models) methods, and their relative strengths and weaknesses are reviewed. The analysis concentrates on the western USA.

Climate Change Research Section Narrative

The Climate Change Research Section (CCR) is part of the Climate and Global Dynamics (CGD) Division at the National Center for Atmospheric Research (NCAR) in Boulder, Colorado.

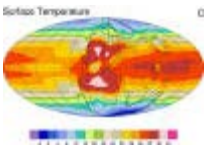
The CCR section makes extensive use of state-of-the-art coupled climate system models to study the sensitivity and stability of the Earth system to a variety of forcings, including changes of greenhouse gases, aerosols, solar irradiance, volcanic forcing, land characteristics, and land use change. This section is a focal point for NCAR and university paleoclimate research and serves as a resource to the paleoclimatic and climate change research community in the use of the Community Climate System Model (CCSM). CCR scientists collaborate closely with major U.S. Department of Energy (DOE) laboratories in developing and using high-performance coupled climate models to address national climate research and policy questions.

Paleoclimate:

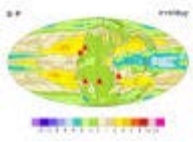
Simulating the Climate of the Late Permian

Jeffrey Kiehl (CCR) and Christine Shields (CCR) have been researching one of the more intriguing time periods in Earth's history, the boundary between the Late Permian and Triassic periods at 251 Ma (1). This boundary marks the largest extinction recorded in Earth's history, where across this boundary approximately 90% of marine and terrestrial species were lost. Associated with this event was an extended period of magma activity and extended ocean anoxia. What caused such a catastrophic change in life? A number of hypotheses have been proposed to explain various aspects of the extinction and climate of this time period. No one hypothesis can explain all of the paleo information for this period. Although a number of climate model simulations have been carried out for this period, no fully coupled climate model simulation has existed for this time period. Fully coupled climate models are required to accurately simulate the ocean circulation, since using specified ocean boundary conditions highly constrains the climate solution and does not allow for a coupling of atmospheric and land hydrological processes to the ocean, e.g., input of fresh water to the ocean.

Kiehl and Shields are carrying out the first fully coupled climate simulation for this time period. They are using paleogeography conditions and specified CO_2 levels for this time period in the recently released CCSM3. The coupled simulation is currently out ~1800 years, where the length of the integration is determined by the long time scales of the deep ocean circulation.

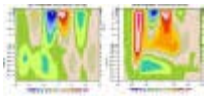


The above figure shows the annual mean surface temperature (°C) from years 1700-1709. The western tropical Panthalassic ocean has a warm pool of water with sea surface temperatures (SSTs) reaching 33 °C, compared to the present day western Pacific warm pool temperatures of 30 °C. The warmest regions over land occur in the subtropical desert regions.



One metric of the climate of this time period comes from the geographic location of evaporite deposits (2). These occur in shallow water regions where the evaporation minus precipitation (E-P) is positive. The above figure shows the annual mean E-P from the CCSM3 simulation, with the location of evaporite deposits marked by red triangles. All but one of these observed evaporite sites matches the model simulation of the region of positive E-P.

An important observation of this time period is the indication that the oceans were anoxic for an extended period (~20 My) (3) of time across the boundary. Low oxygen conditions could explain the limited marine life at this time. One hypothesis suggests that, in a warm greenhouse climate with an associated low pole to equator thermal gradient, ocean mixing to depth would be limited due to strong stratification. Shown below is the meridional overturning circulation for the Late Permian and Present day simulations from the CCSM3. Whereas in the present day world there is strong downward circulation at the poles, this does not exist in the late Permian. The late Permian deep ocean circulation is composed of two weak cells in each hemisphere. The implication of this is that the mixing of tracers such as oxygen to depth is limited for the warm world of the Late Permian. This simulation supports the idea of deep ocean anoxic conditions for this time period.

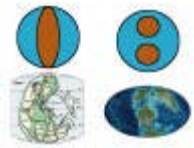


The present simulation indicates that the strength of the overturning circulation at depth (~3000 m) continues to slow down, indicating an even more sluggish deep ocean circulation than shown in the above figure. This result indicates the need for substantial computational resources to explore the realm of deep time, where deep ocean time scales play a critical role in biogeochemical processes relevant to life on Earth.

Future efforts in exploring the climate of the late Permian include: exploring the role of atmospheric chemical changes at this time including enhanced methane levels, fully coupled dynamic vegetation simulations, and coupling of biogeochemical processes. As shown fully coupled climate models can now be applied to questions of climates in deep time. These types of models can be used to integrate observations and test scientific hypotheses. They can also serve as a catalyst for more synergistic collaborations on key climate issues.

Other Deep-time Applications

Matt Huber and Ryan Sriver (Purdue University), collaborating with Bette Otto-Bliesner (CCR), Esther Brady (CCR), Shields, and Zav Kothavala (CCR), are demonstrating the feasibility of CCSM3 for “deep past” paleoclimates and theoretical climate dynamics. Benchmark idealized configurations, including a “sector world” and “two islands” are being tested. Techniques for accelerating the model spinup are needed due to uncertainties in the ocean state and the long equilibration time of the deep ocean and are being developed and validated as part of this collaboration.

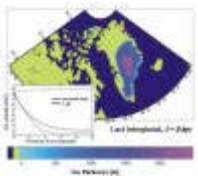


This figure shows idealized (top) and actual (bottom) "deep-time" continental distributions for a "sector world" (left) and "two islands" (right). It has been conjectured that the climate dynamics of these time intervals was largely a function of the continental geometries.

Huber, Rodrigo Caballero (University of Chicago), Otto-Bliesner, and Brady are analyzing CSM1.4 simulations for Present, Last Glacial Maximum, Eocene, and Cretaceous in terms of tropical and high-latitude modes of variability. These periods vary in terms of their paleogeography, topography, continental ice sheets, and atmospheric trace gas concentrations. In contrast to conventional wisdom, El Niño Southern Oscillation (ENSO) is a robust feature when a Pacific-like Ocean is present and gains preeminence in warm climates (Eocene and Cretaceous) when the equator-to-pole temperature gradient is reduced. There are records of ENSO going back to the Eocene.

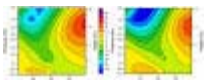
Climate of the last 150,000 Years

Otto-Bliesner (CCR), collaborating with Jonathan Overpeck (University Arizona), Shawn Marshall (University of Calgary), and Giff Miller (University of Colorado), studied the sensitivity of the Arctic climate and the Greenland Ice Sheet to summer warming at the beginning of the Last Interglacial (130,000 years before present) associated with late spring-early summer insolation anomalies associated with Milankovitch orbital forcing. This study used CCSM2 simulations in combination with a Greenland Ice Sheet model and terrestrial, marine, and ice core proxy records. CCSM2 seasonally warms the Arctic by up to 5°C, and forced with CCSM2 predicted surface temperature and precipitation changes, the Greenland Ice Sheet shrinks to half its present volume in 3500 years. Vegetation and ice sheet feedbacks still need to be incorporated and should indicate enhanced sensitivity.



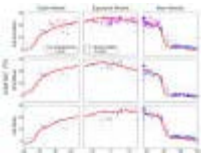
This figure shows the extent and thickness of the Greenland Ice Sheet after 5000 years when forced with CCSM predicted surface temperatures and precipitation for the Last Interglacial (LIG). Inset shows the time evolution of Greenland ice volume for present-day (blue line), the LIG (black line), and a future scenario of 4xCO_2 (red line) when forced with CCSM predictions.

Otto-Bliesner and Bob Tomas (CCR) are studying the mechanisms underlying decreased aridity in northern Africa in the Holocene. CCSM2 simulations for 8500 yr BP show that Milankovitch orbital variations in solar radiation for this past period enhance the North African monsoon with a more northern position of the Intertropical Convergence Zone (ITCZ), a stronger Tropical Easterly Jet, a displacement north of the African Easterly Jet, and stronger low-level westerlies at low latitudes. These dynamical changes over North Africa are analogous to conditions observed at present during wet years in the Sahel and sub-Saharan region.



This figure shows the time-average June-July-August zonal wind (m/s) over North Africa predicted by CCSM for present (left) and 8500 years before present (right). The CCSM simulates important features of present summer circulations, including equatorial westerlies near the surface and two easterly jets, the African Easterly Jet at 600-700 mb and the Tropical Easterly Jet at 150 mb.

As part of Paleoclimate Modeling Intercomparison Project Two (PMIP-2), CCSM3 at T42x1 resolution has been integrated for Preindustrial, Mid-Holocene, and Last Glacial Maximum forcings. Otto-Bliesner, Brady, Tomas, Sam Levis (TSS), Kothavala, and Gabriel Clauzet (Universidade de Sao Paulo, Brazil) are analyzing these simulations as part of the PMIP-2 project. Results will first appear in a special issue of *Journal of Climate* devoted to CCSM3. The results for the Last Glacial Maximum show a global surface cooling of 4.5°C compared to Preindustrial conditions and expanded sea ice in both hemispheres, a much colder and saltier deep ocean, and a shallower and weaker North Atlantic overturning cell.



This figures shows the Atlantic Ocean SST for the Last Glacial Maximum (LGM) as predicted by CCSM3 (red line) and estimated by the Climate Mapping, Analysis, and Prediction (CLIMAP) (dashed line), Mix et al. (pink circles), and Glacial Atlantic Ocean Mapping (GLAMAP) (blue circles) proxy reconstructions.

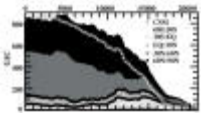
The “slab ocean” version of CCSM3 provides a useful tool to assess climate sensitivity for a variety of forcings. Otto-Bliesner, Brady, and Kothavala are comparing the response of this model to past and future forcings.

Otto-Bliesner participated with a group of researchers from 22 U.S. and international universities and laboratories to trace the spatio-temporal pattern of peak Holocene warmth (Holocene thermal maximum, HTM) across the Western Hemisphere of the Arctic. This collaboration is part of the Paleoenvironmental Arctic Sciences (PARCS) research initiative sponsored by the National Science Foundation (NSF). At the 16 terrestrial sites where quantitative estimates have been obtained, Holocene Thermal Maximum (HTM) temperatures (primarily summer estimates) were on average 1.6±0.8°C warmer than present (approximate average of the 20th century). The warming, though, was time-

transgressive over the western Arctic with warming in Alaska and northwest Canada coincident with precession-driven summer insolation anomaly, but delayed warming by about 4000 years in northeast Canada linked to the lingering Laurentide Ice Sheet.

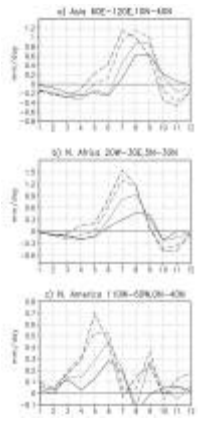
PMIP-1 compared the response of 18 Atmospheric General Circulation Models (AGCMs) to mid-Holocene (6000 years before present) solar forcing changes associated with Milankovitch orbital cycles. As a precursor to PMIP-2, seven modeling groups (NCAR, Hadley Centre, Laboratoire des Sciences du Climat et de l'Environment (LSCE),Meteorological Research Institute (MRI), Royal Netherlands Meteorological Institute (KNMI), Max-Planck, University of Wisconsin) performed AOGCM experiments for this same time period, albeit with varying specification of atmospheric trace gases. Otto-Bliesner collaborated with model intercomparisons of the AOGCMs. The expansion of the area influenced by the Afro-Asian summer monsoon during the mid-Holocene is one of the most striking features shown by paleoenvironmental data and was poorly simulated by the PMIP-1 AGCMs. Results from the Atmospheric Ocean General Circulation Models (AOGCMs) show that ocean feedbacks enhance the African monsoon and shift the belt of maximum precipitation further north. The models also show a northward shift of the northern limit of the boreal forest in response to simulated summer warming in the high-northern latitudes, and a northward expansion of temperate forests in North America in response to simulated winter warming. These northward shifts are supported by paleovegetation data.

Fortunat Joos and Stefan Gerber (University of Bern), Colin Prentice (University of Bristol), Otto-Bliesner, and Paul Valdes (University of Bristol) used time slice simulations of the last 21,000 years from CSM1.4 and the Hadley Centre Unified Model to drive the carbon component of the Bern Carbon Cycle Climate (Bern CC) model. The Holocene ice core record of a 20 ppm rise is matched by the model. Calcite compensation, in response to earlier terrestrial uptake, terrestrial carbon uptake and release, SST changes, and coral reef buildup, explain this increase. The greening of the Sahara, peat buildup, and land use probably influenced atmospheric CO_2 by only a few ppm.



This figure shows the cumulative changes in terrestrial carbon inventory predicted by the BERN CC model when forced by CSM (global changes indicated by dotted line) and Hadley Centre Unified Model (latitude bands indicated by shaded areas).

Zhengyu Liu (University of Wisconsin), Otto-Bliesner, John Kutzbach (University of Wisconsin), L. Li (Chinese Academy of Sciences), and Shields compared coupled climate simulations of the NCAR CSM1.4 and the University of Wisconsin Fast Ocean-Atmosphere Model (FOAM) on the evolution of global monsoons in the Holocene. The evolution of the six major summer monsoons, Asian, North African, North American, Australian, South American, and South African, are investigated for the insolation forcing of 3000, 6000, 9000, and 11,000 years before present. In the Northern Hemisphere, the models show an enhancement of the monsoons in the early Holocene and a gradual weakening toward the present, with ocean feedbacks modifying their forced response.



This figure shows monthly evolution of land precipitation anomalies from present predicted by CSM1.4 for 3500 (solid), 6000 (dot), 8500 (dash-dot), and 11,000 (dash) years before present for the Northern Hemisphere monsoons.

Clauzet, Ilana Wainer (Universidade de Sao Paulo, Brazil), Alban Lazar (Universidade de Sao Paulo, Brazil), Brady, and Otto-Bliesner examined the CSM1.4 simulation of the South Atlantic at the Last Glacial Maximum. Changes of mass transport within this basin are associated shifts in circulation features.

Carrie Morrill (CCR) is creating a database of high-resolution paleoclimate records for studying abrupt climate change during the last deglacial and the Holocene. These records have been selected from the large number of published paleoclimate records for their robust age models and well-supported climatic interpretations. Thus far, over 120 records have been compiled. Morrill is using these records to understand the timing, spatial patterns, and possible causes of several past abrupt climate changes. These include events in the mid-Holocene (~4000-6000 years ago) and early Holocene (~8200 years ago). Abrupt climate changes are identified in these records using a variety of non-parametric tests to identify discontinuities in the paleoclimate time-series. In collaboration with Claudia Tebaldi (Research Application Program), Morrill is further developing and refining these methods.

For the mid-Holocene, Morrill has found several periods of preferred change centered on ~4200 and ~5600 years ago. Abrupt changes at these times occurred over decades to centuries, and were associated with the transition from the Holocene climatic optimum to the Neoglacial during which temperature decreased in the middle to high latitudes and precipitation decreased in the tropics. The event at ~4200 years ago was also associated with archaeological evidence for the collapse of several ancient civilizations, including the Akkadian in Mesopotamia and the Indus in India and Pakistan.

Morrill, in collaboration with Bob Jacobsen (William and Mary), is constructing global maps of climate anomalies during the 8.2K event. These will be used for comparison with output from experiments planned for CCSM3 in collaboration with others in CCR and Oceanography. These experiments will examine the climatic impact of freshwater pulses to the North Atlantic that are similar to the glacial meltwater flood that caused the 8.2K abrupt climate change. The last synthesis of paleoclimate records spanning this event was completed in 1997 and, since then, there have been dozens of new records relevant to this subject published. Morrill and Jacobsen have identified several patterns that will be of use in model-data comparison. These include a temperature decrease of 1-2 ºC over Europe, regional drying in the tropics, and little evidence for change in the Southern Hemisphere.

Morrill, Otto-Bliesner, Caspar Ammann (CCR), and Brady are working with Dwight Owens and Dolores Kiessling of COMET to create a web-based learning module for undergraduates. The module explains how changes in the earth's orbit affect insolation seasonally and latitudinally and, in turn, how this drives glacial-interglacial cycles. The module contains a number of interactive exercises and animations. These can be used by instructors for classroom demonstrations and homework or lab exercises.

Morrill contributed a review of the mechanisms of abrupt climate change for the NOAA Paleoclimatology Program's "Paleo Perspective on Abrupt Climate Change" website www.ncdc.noaa.gov/paleo/abrupt/index.html. This website reviews the state of our current knowledge about the causes and effects of past abrupt changes.

This figure shows the location of paleoclimate proxy records that have been compiled from the published literature to study abrupt climate
changes during the Holocene.

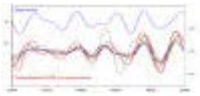
Natural Climate Variability During the Period of Annually Resolved Records

Ammann and Tomas, supported by the Weather and Climate Assessment Science Initiative of Linda Mearns (Environmental and Societal Impacts Program), use high-resolution paleoclimate proxy records in an attempt to extend the limited (~150 years) instrumental record. Prior centuries and millennia have exhibited significant natural climate variations that had a tremendous impact on the environment and societies around the world. Such records offers an ideal and highly relevant test bed for scientific evaluation of both empirical proxy-based research, as well as for testing the sensitivity and validity of global climate models normally applied for future climate simulations. Each of the approaches provides specific insights into the functioning of the climate system, but each also has its clear weaknesses. It is the goal of the research to work at the intersection of state-of-the-art climate models and the proxy-community in order to contribute to a better understanding of the range and causes of natural climate variability and to clarify nature's role in climate today and possibly in the future.

Climate Modeling Using NCAR-CSM 1.4 and NCAR-CCSM 3

After implementation of natural external forcing factors into the standard coupled model (explosive volcanism and solar irradiance changes), Ammann and collaborators (in particular Fortunat Joos) performed numerous historical transient simulations and short sensitivity studies of the recent past. A core element is the detection and attribution of climate changes to external forcing. Ammann studies ways to detect this impact in collaboration with statisticians and their

students (Philippe Naveau, University of Colorado; H-S. Oh, University of Alberta, Canada). The group developed multi-resolution techniques (based on discrete wavelet transforms and empirical mode decomposition methods) and state-space models (using modified Kalman filtering techniques taking skewed distributions into account) that are adapted to the typical signals of smooth solar irradiance changes and volcanic spikes, respectively. The detection work focused first on single time series, but has been expanded to large gridded datasets from model output. A clear solar influence has been found that is stronger than previously assumed. Because the same temporal fingerprint is also present in proxy reconstructions, the conclusions were drawn that the sun does affect climate on the century time scale (see Figure below). However, the same simulations also show that smaller rather than larger solar irradiance changes in the past are more consistent with the proxy based climate records, and independent of the possible magnitude of past solar changes, the late 20th century warming cannot be attributed to solar irradiance changes.



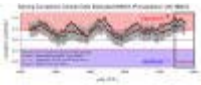
This figure shows wavelet decomposition of forcing (top: blue) and climate response as seen in CSM 1.4 Millennium simulation and a set of proxy reconstructions. The time scale is focusing on the dominant ~200-year deVries cycle.

The analysis is not restricted to large-scale Energy Balance questions, but the AO-GCMs are tested for specific response in the dynamics to the imposed radiative forcings. The proxy record is hinting at the possibility that the response of several climate modes might potentially be more systematic than previously thought. In such a case, and if the models should be able to reproduce a corresponding signature, this would tremendously enhance the predictive skills of climate models on regional scales. Collaborative work is looking into modes such as the North Atlantic Oscillation (NAO), ENSO and the Pacific Decadal Oscillation (PDO). Additional analysis is evaluating the monsoon response to the radiative forcing.

Ammann worked with Andrew Conley (CMS) on a 10-member ensemble simulation of the Mt. Pinatubo eruption (June 1991) with the coupled NCAR CCSM 3 model. Radiative fluxes and surface climate changes are studied. The volcanic aerosol is now a standard implementation in CCSM 3.

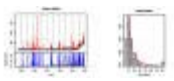
Proxy Climate Reconstructions: Methods, Uncertainty, and Optimization

Proxy-based climate reconstructions depend on a short calibration period using the assumption that the link to the climate parameter — and often also to teleconnected modes of variability — is stable over time. Models provide means to test these assumptions. Ammann and Eugene Wahl (Alfred University) evaluated the reliability of various climate reconstruction techniques using the fully forced coupled climate model output. Through this process, they help to optimize reconstruction efforts and determine crucial spatial gaps in the available proxy records.



This figure shows a test of single point stationarity: Artificial Central Chile Tree-Ring series of the past millennium based on subsampling of fully forced CSM 1.4 simulation. White noise was added to the precipitation series to match real world tree-ring to El Niño correlation.

On the forcing side, Ammann is working with a group at Rutgers University (under guidance of Alan Robock) on a new reconstruction of volcanic aerosol based on the largest collection of ice core data over the past millennia. The global ice coring community actively supports the work. In parallel, Ammann is collaborating on statistical modeling of temporal forcing distributions (primary solar frequencies, volcanic forcing as extreme value series). Such detailed characterizations of the forcing (see Figure below) provide a quantitative base for signal detection in noisy climate reconstructions. Solar forcing is approached through collaborations with proxy and modeling partners to establish a process understanding and detection framework to evaluate which dynamical pathways are most consistent in explaining climatic signals extracted from the proxy reconstructions.



This figure shows: Left: Result from automatic volcanic pulse detection (red) using the Greenland Ice Sheet Project Two (GISP2) ice core raw data with associated posterior probability (confidence: blue) in the signals. Right: Statistical distribution of extracted magnitudes of volcanic sulfate pulses with a fitted Pareto (extreme value) distribution with a clear heavy tail.

Regional Fidelity of Climate Simulations Compared with Proxy Data

A strong new emphasis of the research of Ammann is focused on the regional scale. This effort is pushing the frontiers of current paleoclimatic research aimed at evaluating and establishing spatial response patterns to radiative forcing. The research is not restricted to the past but has a clear application also in future climate assessment.

Tropical climate variability response to forcing: Previously regarded as most independent mode, ENSO variations over the recent past seem to contain significant externally forced response behavior: cooling in E equatorial Pacific during increase solar irradiance, but higher occurrence of warming during low-solar irradiance as well as after large volcanic eruptions.

Europe: Evaluation of dominating circulation regimes isolated in historical reconstructions and model. NAO and blocking cases with comparable behavior in control and low-solar case. No blocking was found in high-solar situation because of a too strong polar vortex and volcanic signal in circulation over Europe.

*E-Asia (China)***:** three selected time windows around significant volcanic or solar forcing periods as well as the drought episode that brought the Ming Dynasty to its knees. General circulation model (GCM) (NCAR-CSM and Goddard Institute for Space Studies (GISS)) analysis and Regional Modeling using GCM boundary conditions with MM5.

Centennial scale ocean anomalies: A strong ~125-year oscillation in the N-Atlantic ocean was found. Since no similar oscillations are known in the real world (except of about half the frequency), significant effort was put in to understand this variation. The impact is far reaching in atmosphere and ocean, including the thermohaline overturning.

Future Climate Change:

The Climate Change and Prediction (CCP) group consisting of Warren Washington (CCR), Gerald Meehl (CCR), Lawrence Buja (CCR), Aixue Hu (CCR), Vincent Wayland (CCR), Haiyan Teng (CCR), Gary Strand (CCR), David Lawrence (CCR), and Julie Arblaster (Bureau of Meteorology Research Centre) is one of the primary components of the joint NSF/DOE climate modeling research program. With a strong focus on climate change over decades to centuries, the CCP group continues to carry out centuries long climate simulations and ensembles addressing all five of the key global change issues identified by the Climate Change Science Program (CCSP) and the U.S. Global Change Research Program (USGCRP):

1. seasonal to interannual climate variability,
2. climate change over decades to centuries,
3. changes in ozone, ultraviolet radiation, and atmospheric chemistry,
4. changes in land cover and in terrestrial and aquatic ecosystems, and
5. the role of aerosols.

In June of 2004, the CCSM version 3 (CCSM3) became available for users. Since that time we have carried out over 5000 years of high-resolution climate change simulations with the new CCSM3 that have included the major forcings on the climate system such as ozone, land cover, solar variability, volcanoes, sulfate aerosols, and greenhouse gases for the Intergovernmental Panel on Climate Change (IPCC) simulations with climate forcings for the 20^{th}, 21^{st}, and 22^{nd} centuries. In addition, climate simulations with the Parallel Climate Model (PCM) continue, adding to the already existing large archive of simulations. It is expected that the CCSM3 and PCM will provide the largest set of IPCC simulations of 20^{th}, 21^{st} and 22^{nd} century climate for the IPCC Assessment Review 4 (AR4) of any group in the world. We have worked with the Program for Climate Model Diagnosis and Intercomparison (PCMDI) (see below) and used the DOE Earth System Grid (ESG) capability to make the data readily available to the broader climate research community.

Collaborations with Other Organizations

The CCP climate research program supports the DOE comprehensive climate modeling research program through climate model diagnosis and prediction of climate change from increasing greenhouse gas concentrations and other forcings of the climate system. This program relies on distributed research collaborations spanning NCAR, the Naval Postgraduate School (NPS), the Los Alamos National Laboratory (LANL), the Geophysical Fluid Dynamics Laboratory (GFDL), National Energy Research Scientific Computing Center (NERSC), Oak Ridge National Laboratory (ORNL), Argonne National Laboratory, PCMDI and several universities. This project will complement the National Oceanic and Atmospheric Administration's (NOAA) climate modeling program emphasizing decade-to-century climate prediction. The program is also tightly linked to DOE's component of the federal High Performance Computing and Communications Program through the High Performance Computing Research Centers at LANL and ORNL. The latter also has the Center for Computational Sciences and the National Leadership Computing Facility.

In 1998 at the National Workshop on Advanced Scientific Computation, the plans of DOE and the NSF were discussed. The DOE, NSF, and NASA have agreed to continue to collaborate on climate model development ,with emphasis on redesigning of the climate model components and the method of coupling components for newer generation supercomputers. This national effort has been transformed by each agency into computing initiatives that have led to increased computer capability. During the last few years, the NCAR DOE-supported research effort played a key role in the DOE Accelerated Climate Prediction Initiative (ACPI) Demonstration Project. This project has successfully concluded and the results were published this year. Our involvement in the DOE Climate Change Prediction Program (CCPP) Avant Garde project has resulted in the next generation flux coupler and improved aspects of the atmospheric model. The next generation flux coupler is now in the fully operational phase. The federal government has developed the CCSP which stresses reducing uncertainties. Special emphasis will be on improving climate models, as well as improved understandings of aerosols, regional climate change, and the impacts of climate change.

The coupled atmosphere, ocean, land/vegetation, and sea ice PCM has been in production at a number of centers for several years and is carrying out ensembles of climate change simulations including those for the IPCC AR4. The PCM continues to be used for climate change simulations with various climate forcings such as land cover and carbon aerosol forcings, and at the same time there has been a transition to the newly released CCSM version 3. The PCM is not undergoing any new development. However, because of the large number of existing PCM ensemble simulations, the PCM will continue to be used for climate sensitivity analysis. For example, two recent papers by Ben Santer of PCMDI along with DOE-funded collaborators Washington, Meehl ,and Arblaster have been published in *Science*. Both used PCM simulations to show that an increase in tropopause height and a warming of the troposphere have been mainly due to increases of greenhouse gases. These papers have generated a great deal of attention, and they indicate an additional measure of global warming other than surface air temperature. Another example is a recent paper in *Science* by Meehl and collaborator Tebaldi from RAP/ESIG. They analyzed PCM multi-member ensemble simulations of 20th and 21st century climate to show that heat waves will become more intense, more frequent and longer lasting in the 21st century due to an increase of greenhouse gases in the model. To support future PCM work such as this, the PCM is currently being ported to the Cray-X1 and Linux platforms.

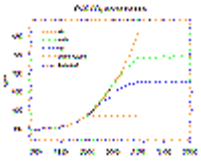
Both the NSF/CCSM Climate Change Working Group (CCWG) and the DOE CCPP are particularly interested in regional aspects of climate change. We have seen that by increasing the horizontal resolution with the uncoupled version of the Community Atmosphere Model (CAM) to T85 (developed by the Climate Modeling Section (CMS) and the CCSM Atmosphere Model Working Group), there has been substantial improvement in the regional aspects of precipitation especially in mountainous areas. This is particularly important for the western North American regions. Also, there is improvement in the surface winds in the Arctic Ocean region, which in turn improve the sea ice distribution. Even though there have been substantial improvements, there are some model biases that are not dependent on resolution. Working on such biases will be a high priority for CCSM in the next year and this Cooperative Agreement will contribute to the research involved in addressing them.

Since the CCSM3 release in the spring of 2004, we have worked with many CCSM scientists and software engineers preparing the climate forcing datasets for the twentieth century. We also worked with others to develop the future climate forcing scenario datasets for the twenty-first century. As noted above, it is expected CCSM will be one of the major contributors to the upcoming IPCC AR4. We also have performed the same scenario simulations with the PCM, which will allow for an intercomparison with same forcing between two different models. We are in the process of completing the simulations by November 2004.

The PCM continues to be used by researchers for additional simulations run on many different parallel supercomputers to further leverage existing climate simulations with greenhouse gases, sulfate aerosols, ozone, land cover, carbon aerosol, solar, and volcanic forcings. Most of the simulations for each forcing have an ensemble of four to five members. There are more than 100 simulations of a century or longer with a 1500 year control simulation for 1870 conditions. We believe this is the largest set of freely available climate forcing experiments ever completed by any modeling group, and is a significant achievement as this represents an unprecedented dataset to study climate variability and climate change. The data from the ensemble simulations are being archived at PCMDI and NCAR with total size of approximately 1.6 million files and 143 Tbytes. The data are freely available to researchers via the Internet by the use of the DOE/ SCIDAC sponsored Earth System Grid or by contacting PCMDI. We have already added over 100 Tbytes from the CCSM3 IPCC simulations to the archive.

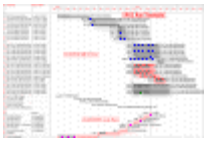
Description of IPCC Simulation Production Process

This production effort represents a multi-institutional distributed effort by scientists and software engineers at NCAR, ORNL, NERSC, and the Lawrence Berkeley National Laboratory (LBNL).



This figure shows IPCC CO_2 concentrations. In addition to CO_2, the simulations are run with solar, volcanoes, sulfate aerosols, ozone, and other greenhouse gases for the period 1870-2000. A spread of CO_2 concentrations for future forcing scenarios are used from years 2000-2200 that also include sulfate aerosols and ozone.

The IPCC scenarios that are being run can be categorized into two groups: a set of "commitment scenarios" and a number of "science scenarios" that explore alternative future emissions outcomes. The IPCC SRES science scenarios that were recommended to the global coupled climate modeling groups by the IPCC WG1 include SRES A2, SRES A1B, SRES B1. The A2, A1B, and B1 scenarios consist of five-member ensembles run from the year 2000 to the year 2100. Then, commitment scenarios are run with the concentrations of all atmospheric constituents in A1B and B1 held constant at year 2100 values, and the model continues to the year 2200 with five member ensembles. One of the ensemble members from each is continued for an additional 100 years to the year 2300 with constant year 2100 concentrations. There is also a 20th century commitment scenario that freezes concentrations at levels observed in the year 2000, and the model is run to the year 2100. For the first time, these runs are being carried out with the high-resolution T85 (roughly 140 km latitude-longitude resolution) version of the new CCSM3.

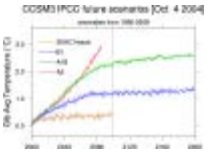


This figures shows the CCSM3 IPCC Run Plan: The IPCC scenario runs are being run at NSF/NCAR (blue), DOE/ORNL (green), and DOE/NERSC (red). Parallel runs on the Earth Simulator (pink) were made with the scientific assistance of the NCAR program.

The PCM and the CCSM3 IPCC runs are being performed at the NSF/NCAR, DOE/ORNL and DOE/NERSC supercomputing sites. (We recently hired Haiyan Teng through supplemental funds to assist in running the experiments and diagnosing the results. An additional set of parallel runs, using the same version of CCSM3 with forcing datasets prepared by the NCAR program, was run on the Japanese Earth Simulator (ES). Focused model development support from the ORNL and LANL science and software engineering teams, significant dedicated computing resources at NCAR and ORNL, a large computing allocation at NERSC, and 24 hour/7 day run monitoring/ support by NCAR staff have kept the IPCC runs on track for completion in time to meet IPCC data submission and paper publication deadlines Most recently, NERSC consultants assisted the NCAR team to run the NERSC A2 5 member ensemble as one single 1020 processor massively-parallel run.

This figure shows PCM IPCC simulations for the AR4: Globally averaged surface air temperature anomalies from the BAU, Stab, A1F1, B1, A1B, B2, and A2 scenarios are shown along with simulation in which the 20th century greenhouse gases are frozen at year 2000 values ("20thC freeze"), as well as simulations where A1B and B1 concentrations are frozen at year 2100 values and the model is run to the year 2200. The shading shows the range of ensemble members and the heavy line is the mean of the ensemble. Note for the 20th century freeze simulation surface temperature warms by 0.3-0.4 ^{0} C.

The data products from the PCM and the CCSM3 IPCC simulations will be used for climate change impact studies and as boundary conditions to drive regional-scale models. To support DOE and NSF regional modeling efforts, we are outputting two additional subdaily data streams for each of the CCSM IPCC scenarios. By design, the raw and post processed data products from the different IPCC scenarios are being kept at the DOE and NSF sites where they were computed. This large distributed dataset is being freely served to the U.S. climate research and education community via the DOE Earth System Grid (ESG).



This figure shows CCSM3 DOE/NSF IPCC scenario runs as of 4 October 2004: Observed forcings (solar, volcanoes, greenhouse gases, sulfate aerosols, carbon aerosols, and ozone) are used during the historical period, from years 1870-2000. A variety of future forcing scenarios (20th Century freeze, B1, A1B, and A2) are used from years 2000-2200 to simulate the most likely range of future climates. Two of the commitment scenarios (A1B and B1) will be executed out to year 2300.

The results of this project will be submitted as the U.S./DOE contribution for the IPCC AR4. The integrated picture formed by these scenarios will be the basis for long-term energy and resource use policies. By the use of higher resolution studies, we are providing data to the climate impacts community that will be more useful than previous studies. Performing simulations in the 2003-2005 timeframe is a high priority for the DOE and the national effort.

Research Projects

Land-Atmosphere Interaction and the Water Cycle

Global climate models are often employed to investigate whether and how soil moisture anomalies affect weather and climate in the current and in a potentially different future climate. A recent model intercomparison by Lawrence demonstrated that the degree of land-atmosphere interaction varies widely between current state-of-the-art AGCMs. Models with different inherent coupling strengths can lead to vastly different conclusions about climate sensitivity. Land-atmosphere coupling strength, or the extent to which a precipitation-induced soil moisture anomaly influences the overlying atmosphere and thereby the evolution of weather and the generation of precipitation, is reasonably strong in the (CAM2/CLM2) but is very weak in the Hadley Centre modeling system (HadAM3/MOSES2). The notable differences in behavior between these two models may enable the precise mechanisms that control land-atmosphere interactions to be ascertained. Key aspects of the indirect soil moisture-precipitation feedback have been evaluated and compared in both models. While the study is not yet complete, preliminary results indicate that it is relatively unlikely that differences in the land surface schemes can explain the large differences in coupling strength. Instead, it appears that the simulation of the diurnal cycle, particularly the simulation of boundary layer moist static energy and the relationship between moist static energy and convection, are likely the largest factors contributing the considerable differences in coupling strength. In CAM2/CLM2, moist static energy builds differently during the day over moist and dry soils, which leads to heavier precipitation over wet soils. In contrast in HadAM3/MOSES2, soil moisture exerts virtually no control on moist static energy in the boundary layer and henceforth convection is essentially unaffected by the soil moisture characteristics. Research aimed to identify how differences in the boundary layer and convection schemes between the two climate models affects the diurnal buildup of moist static energy is ongoing.

Climate Variability Associated with Atlantic Thermohaline Circulation

Aiguo Dai (CAS) has analyzed a 1200-yr unforced control run and climate change simulations under projected greenhouse gas forcing during the next two centuries for changes in Atlantic Ocean circulations as simulated by the PCM. The strength of the Atlantic thermohaline circulation (THC) shows large variability (amplitudes » 1.5-3.0 Sv) at 15-40 year time scales, with a sharp peak of power around 24 years in the control run. Associated with the THC oscillation, there are large variations in the North Atlantic SST, sea surface salinity (SSS), sea-ice fraction, and net surface water and energy fluxes, all of which lag the THC by 2-3 years. However, the net effect of the SST and SSS variations on upper ocean density in the midlatitude North Atlantic leads the THC by ~6 years or 90^{o} in phase. This density vs. THC phase lag provides a direct mechanism for the 24-year cycle to oscillate through density's effect on North Atlantic deep water formation. The PCM-simulated SST and sea-ice variations resemble observed spatial patterns associated with the NAO. This suggests that the THC multi-decadal variability is coupled with the NAO in the model. Forced by projected CO_2 and other trace gases for the next two centuries, the PCM shows significant weakening (by ~12%) of the THC during the 21st century, even after removing the un-forced THC drift during the period. In the 22nd century, the THC continues to weaken (by additional ~10%) if atmospheric CO_2 keeps rising, but stabilizes if the trace gases level off.

Southern Annular Mode Trends

Arblaster and Meehl have investigated the trend in the Southern Annular Mode during recent decades that has involved an intensification of the polar vortex. The source of this trend is a matter of scientific debate with stratospheric ozone losses, greenhouses gas increases, and natural variability all possible contenders. Since it is difficult to separate the contribution of various forcings to the observed trend, the PCM is utilized here to isolate the responses of the climate

system to single forcings. Ensembles of 20th Century simulations forced with the observed time series of greenhouse gases, tropospheric and stratospheric ozone, sulfate aerosols, volcanic aerosols, solar variability, and various combinations of these are used to examine the annular mode trends in comparison to observations. We find that ozone changes are the biggest contributor to the observed summertime intensification of the southern polar vortex in the second half of the 20th century, with increases of greenhouse gases also a necessary factor to reproduce the observed trends. Although stratospheric ozone losses are expected to stabilize and eventually recover to pre-industrial levels over the course of the 21st Century, these results suggest that the observed trends in atmospheric circulation will continue into the future.

Development of the Earth System Grid (ESG)

During the last year, the ESG was taken into full production, serving as the primary online data distribution mechanism for the DOE/NCAR PCM and CCSM runs. The extensive PCM climate experiment collection, the new CCSM3 control runs, as well as the initial results from the IPCC runs with CCSM3, are now being served to the US and international scientific community via the ESG. Gary Strand was instrumental in moving the ESG from a pilot project to a production facility, working with the ESG development team, building the initial metadata catalogs, and supervising the large-scale production of CCSM and PCM ESG metadata catalogs.

Effects of Land Cover Changes as Part of the IPCC Assessment

Johannes Feddema (University of Kansas) used the PCM to assess the sensitivity of a fully coupled climate model to changes in land cover. By comparing three simulations representing present day land cover from different data sources, we conclude that there is significant model sensitivity to land cover characterization, with an observed average global temperature range of 0.21K between the simulations. These results show that careful consideration needs to be made of the land cover boundary conditions used in land cover change experiments.

In addition, we compare the variability in the three present day simulations to the differences observed between comparable potential vegetation (pre-human) and present day land cover simulations to assess the potential historical impacts of land cover change on climate. The historical change simulation is significantly different from all the present day simulations with a 0.386K higher average global temperature and, perhaps of greater importance, regionally up to 2K. From these results we conclude that land cover change could play a significant role and should be included in future climate change simulations. With respect to the IPCC, changes of land cover as a forcing of the climate system have not been fully explored. This study provides some quantitative measure of the impact. Several NCAR scientists were involved in this research: Linda Mearns (ESIG), Keith Oleson (TSS) Gordon Bonan (TSS), Meehl, and Washington.

20th and 21st Century Climate

Collaborative work by Meehl, Dai, Washington, Tom Wigley (CAS), Arblaster, and Ping Liu (International Pacific Research Center, University of Hawaii) examined the influences of various anthropogenic forcings over the 20th and 21st centuries in the PCM. These experiments show that the response of globally averaged temperature in the model to individual forcings is mostly additive, and that only by the addition of anthropogenic forcing mainly from greenhouse gases can the model produce the large warming observed in the second half of the 20th century. They also studied the effects of increasing CO_2 emissions on the magnitude of future global warming and the effects of global warming on the extent of the Sahara desert. The latter study showed that the PCM, along with several other models in the Coupled Model Intercomparison Project (CMIP), reproduced a decreasing rainfall trend during the 20th century in the Sahara region as observed, and in future climate the Sahara becomes smaller, moves north and west, and continues to dry. Meehl and Washington collaborated with Ammann and others to document the effects of a new volcanic forcing dataset now being used in the PCM and CCSM3 20th century simulations.

Meehl and Arblaster completed a study on the processes that affect changes in precipitation in the Indian monsoon. They used the PCM to document increases in mean monsoon rainfall and enhanced interannual variability with increased CO_2. Regional increases in Indian Ocean SSTs played a role in these changes, but influences from the tropical Pacific were even more important for future increases of interannual variability in the monsoon.

Ben Santer (LLNL) collaborated with a team of scientists, including DOE funded NCAR scientists Meehl, Washington, and Arblaster, and used the PCM to show that trends in the lower tropospheric temperatures from satellite data were consistent with a global coupled model that included known anthropogenic forcings for the period of the Microwave Sounding Unit (MSU) data (including aerosols from Mt. Pinatubo). The model and observed data analyses indicate that tropopause height is a valid new index to monitor global warming. They also addressed the issue of large El Niño events and their influence on trends in short data records such as the MSU, where the 1997-98 El Niño event at the end of the record induced a warming trend that was absent prior to that event. They showed that the models with El Niño

amplitudes comparable to observations can produce trends nearly as large due to sampling of 20-year records similar to the observations.

There is ongoing collaborative work at NCAR by Meehl with Tebaldi and Doug Nychka (GSP) to analyze changes in variability and extremes in ensembles of future climate projections. This work is using statistical analyses of extremes, as well as threshold methods to study changes in weather and climate extremes in the PCM. They have shown that the change in base state atmospheric circulation, due to the increase of greenhouse gases in the PCM, affects the pattern of future changes in frost days (nighttime minimum temperatures below freezing) and heat waves. For example, frost days decrease most over western North America due to an anomalous ridge of high pressure over that region that is caused by changes in tropical SSTs and convective heat sources. Heat waves become more intense over the western and southern U.S. in the 21st century due to positive 500 hPa height anomalies caused by the increase of greenhouse gases. These circulation anomalies are again related to changes in tropical SSTs and convective heating anomalies.

Meehl with Washington, Wigley, Arblaster, and Dai have analyzed the solar forcing ensemble runs with the PCM for 20th century climate compared to the ensemble runs without solar forcing. Results show that the observed early century warming is only simulated when solar forcing is included. A main difference in climate system response in the solar runs compared to the runs without solar forcing is that tropical precipitation regimes are more intense due to early century solar forcing compared to late century greenhouse gas forcing, suggesting for the first time that solar forcing could affect the climate system in some regions through coupled ocean-atmosphere interaction and consequent precipitation processes.

Dai, Hu, Meehl, Washington, and Strand analyzed the ensemble simulations of the 20th and 21st century climate by the PCM under greenhouse gas and sulfate aerosol forcings. Over the midlatitude North Atlantic Ocean, the model produces a moderate surface cooling (1-2°C, mostly in winter) over the 21st century. This cooling is accompanied by changes in atmospheric lapse rates over the region (i.e., larger warming in the free troposphere than at the surface), which stabilizes the surface ocean. The resultant reduction in local oceanic convection contributes to a 20% slowdown in THC. Dai and collaborators also documented results from the ACPI pilot project, where the PCM was used to force a regional model, as well as streamflow models, to examine the effects of global warming on water resources in California.

Arblaster and Meehl collaborated with David Karoly (University of Oklahoma) and a team of scientists to use a set of simple indices in a detection/attribution study for North America. The PCM was one of a set of models used in this study to show that humans have indeed influenced the climate over North America.

Meehl collaborated with Harry van Loon and Ralph Milliff (Colorado Research Associates) and addressed onset of warm events in the Southern Oscillation in the early 1990s. Two aspects of the onset of a warm event in the Southern Oscillation are 1) the subtropical South Pacific High is weakened in early southern winter which weakens the trade winds and reduces upwelling along the equator, and 2) in the months that follow, and particularly during the mature phase of the warm event during southern summer, the negative SST anomalies in the equatorial eastern Pacific cold-water tongue are displaced by positive anomalies. Based on these criteria, Meehl and collaborators identified two warm event onsets that occurred during the early 1990s, in 1991 and 1994. This result refutes earlier work that the early 1990s may have been one long ENSO event and has implications for understanding and interpreting anthropogenic influences on ENSO in climate change simulations.

van Loon also collaborated with Meehl and Arblaster to follow up on the analysis of solar forcing in the PCM, but to look for similar signals in satellite and reanalysis data. Results show that comparable processes are at work in the observations and model in that greater solar forcing enhances climatological patterns of precipitation in the tropics, resulting in higher amplitude precipitation over the monsoons and ocean convergence zones.

Meehl and Arblaster worked with Johannes Loschnigg (University of Hawaii) and a team of scientists to study recent variations in Indian Ocean circulation related to interannual variability associated with the Tropospheric Biennial Oscillation (TBO). Results showed that the Indian Ocean plays an active role in monsoon and tropical Pacific interannual variability that is important to understand for interpreting the processes that contribute to 20th century climate variability.

Meehl worked with Duane Waliser (State University of New York) and a team of scientists to document intraseasonal variability in global coupled climate models including PCM. They showed that such variability is generally weak in current models, but that ocean coupling seems to improve the simulations of intraseasonal variability somewhat.

Meehl collaborated with Washington and Arblaster to analyze four recent NCAR global coupled models (PCM, CSM, PCTM, and CCSM) to show that the relevant feedbacks for climate system response to increasing CO_2, (ice/albedo, water vapor, and clouds) are managed by the atmospheric model. The ocean, sea ice, and land surface play secondary roles for the globally averaged response. Two models with identical atmospheres but different ocean and sea ice

components (PCM and PCTM) have the most similar response to increasing CO_2, followed closely by the CSM with comparable atmosphere and different ocean and sea ice. The model that is most dissimilar, the CCSM, has a different response from either of the other three, and in particular is different from PCTM in spite of very similar ocean and sea ice but different atmospheric model components. The role of ocean heat uptake is also crucial to understand the response of the respective models, and depends on the THC in the Atlantic Ocean.

Porting of the PCM on to the CRAY and Linux Computer System

Although the PCM is not being developed further there are still several science groups that are interested in performing simulations. The reason for the continued use is that we have an extraordinary archive of previous simulations with various climate forcings. For example we are still exploring different solar forcing, carbon aerosol, and land cover changes for researchers at several universities. Since the model is still in use, Vince Wayland is making the model available on the CRAY and Linux machines. The status is that the PCM has ported to the Cray X1 this past year; however, there are still software problems to be solved. Preliminary performance results showed good scaling on 4 to 16 processors without any Cray specific additional optimization (vectorization). Additional work will be done to enable the use of up to 64 processors. Some Cray specific optimization may also then be undertaken. The PCM is currently being ported to a Linux cluster named Bangkok in the NCAR CGD environment. This cluster consists of Dell workstations containing Intel chips. As soon as the NCAR SCD IBM Linux cluster, Lightning, is made available to users, the PCM will be ported there also. These ports should provide a general framework for additional Linux ports as they are required.

Examination of Future Abrupt Climate Change

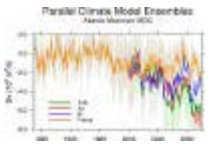
Hu, with Meehl and Weiqing Han (at Program in Ocean and Atmospheric Sciences, University of Colorado), worked on detecting the THC changes from ocean properties using NCAR's CCSM2 model, since significant changes of the THC are likely to cause abrupt climate change. Here we intend to find a simple measure to detect changes in THC through examining several factors proposed to control the THC variations using a coupled climate model. These factors are Equatorial-South Atlantic upper ocean temperature, Southern Ocean freshening, inter-basin sea surface salinity contrast, and meridional steric height gradient. Three experiments are analyzed: a present-day control run, a freshwater hosing run, and a 1% CO_2 run. Results show that, if freshwater flux is the primary cause, all examined factors can predict the THC changes. If both thermal and haline forcings are involved, only the Atlantic meridional steric height gradient gives a consistent measure of the THC variations. A new result presented here is that the inter-basin sea surface temperature contrast between North Atlantic and North Pacific is found to be an indicator of THC changes.

Understanding Recent Past North Atlantic Ocean Circulation

Hu worked on understanding the changes in North Atlantic Ocean and the relationship with the meridional overturning circulation in the last 50 years of the 20th century using the PCM. Observations show a freshening and cooling sub-polar North Atlantic in the last 50 years of the 20th century. This trend is related to the changes on the NAO pattern. In PCM historical runs, the observed trend in North Atlantic is realistically simulated. However, the model didn't capture the observed NAO trend. By analyzing the changes of the oceanic meridional overturning circulation and the surface heat and freshwater fluxes into the northern North Atlantic in our model, we found that it is the slowing of the meridional overturning circulation that induces a reduced meridional freshwater divergence responsible for the freshening, and a reduced meridional heat convergence is responsible for the cooling. Those surface fluxes and the sea ice volume flux into this region work towards reducing the effect induced by a slower meridional overturning circulation.

Hu also worked on analyzing the THC, sea level, and heat content changes in 20th and 21st centuries from PCM IPCC runs. Preliminary results show that the THC weakens about 1 Sv in the last 25 years of the 20th century. And it stays at roughly the same strength in the 21st century for the 20th century freeze scenario, and by the end of the 21st century; it weakens by 3 to 5 Sv for B1 scenario, 5 to 6 Sv for A1B scenario, and 6 to 8 Sv for A2 scenario. The simulated changes of upper 300-meter ocean heat content in the last 50 years of the 20th century are equivalent to an increase of upper 300-meter ocean temperature by about 0.2 ^{o}C, agreeing well with the observations (Levitus et al, 2000). For the projected scenarios, the upper 300-meter ocean temperature will additionally increase 0.2 ^{o}C, 0.45^{o}C, 0.9^{o}C, and 1.05 ^{o}C for 20th century freeze, B1, A1B, and A2 scenarios, respectively. The upper 3 km ocean heat content changes also agree well with the observations, with about a 0.05^{o}C increase in upper 3 km ocean temperature in the last 50 years of the 20th century. The global mean sea level change in the 20th century is about 4 cm, roughly 25% of the changes suggested by observations. The projected sea level change by the end of the 21st century in comparison with year 1999 is 6 cm, 13 cm, 17.5, and 19 cm for 20th century freeze, B1, A1B, and A2 scenarios. Changes in the THC due to increased CO_2 are important in future climate regimes. Using the PCM, regional responses of the THC in the North Atlantic to increased CO_2 and the underlying physical processes are studied here. The Atlantic THC shows a 20-year cycle in the control run, qualitatively consistent with observations. Compared with the control run, the simulated

maximum of the Atlantic THC weakens by about 5 Sv or 14% in an ensemble of transient experiments with 1% CO_2 increase per year at the time of CO_2 doubling. The weakening of the THC is accompanied by reduced poleward heat transport in mid-latitude North Atlantic. Analyses show that oceanic deep convective activity strengthens significantly in the Greenland-Iceland-Norwegian (GIN) Seas, but weakens in the Labrador Sea and the south of Denmark Strait Region (SDSR). The strengthening of deep convective activity in the GIN Seas is mainly caused by an increased salty North Atlantic inflow, reduced sea ice volume fluxes from the Arctic into this region, all of which lead to a saltier (denser) upper ocean. The weakening of deep convective activity in the SDSR is induced by a reduced sea ice flux into this region and a reduced heat loss to the atmosphere, which leads to a warmer (lighter) upper ocean. On the other hand, the weakening in the Labrador Sea is mainly attributed to increased precipitation that freshens the surface ocean. These regional changes produce the overall weakening of the THC in the Labrador Sea and SDSR, and more vigorous ocean overturning in the GIN Seas. The northward heat transport south of 60^{o}N is reduced with increased CO_2, but increased north of 60^{o}N due to the increased North Atlantic water across this latitude.



This figure shows Atlantic maximum meridional overturning circulation evolution from 1870 to 2099.

More information may be found at www.cgd.ucar.edu/pcm/ and www.ccsm.ucar.edu/working_groups/Change/.

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Community Climate System Model Narrative

Scientific Objectives

The scientific objectives of the Community Climate System Model (CCSM) project are as follows:

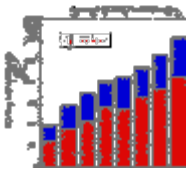
- develop and continuously improve a comprehensive climate modeling system that is at the forefront of international efforts to understand and predict the behavior of Earth's climate;
- use this modeling system to investigate and understand the mechanisms that lead to interdecadal and interannual variability in Earth's climate;
- explore the history of Earth's climate through the application of versions of CCSM suitable for paleoclimate simulations; and
- apply this modeling system to estimate the likely future of Earth's climate to provide information required by governments in support of national and international policy determination.

The project is organized and conducted so as to involve a large community of scientists and stakeholders in the scientific and technical design, evaluation, and use of the ultimate product, CCSM.

Overall Activities and Accomplishments of the CCSM Project

The major objectives of the CCSM project during FY04 were to develop and validate a new version of CCSM called CCSM3. This model is designed to support the CCSM project's contributions to the Fourth Assessment Review (AR4) of the Intergovernmental Panel on Climate Change (IPCC). The development was completed by the late fall of 2003 through an intensive effort by the CCSM scientists and software engineering teams. The project then conducted and evaluated a large series of control runs to establish the basic characteristics of the climate as simulated by CCSM3. The Climate Change Working Group performed an extensive series of emission scenario experiments using CCSM3 for submission to the IPCC. The scientists and engineers generalized the CCSM3 code to produce realistic climate simulations across a wide range of spatial resolutions. There are also extensive control runs for each of the configurations to provide the basic documentation of the simulated climate system via the Web (www.ccsm.ucar.edu/experiments). The code, documentation, and standard experiments for CCSM3 were released to the community on June 23, 2004.

The CCSM Project Office organized and supported several working group meetings, CCSM Scientific Steering Committee and CCSM Advisory Board meetings, and the 9th annual CCSM Workshop. This workshop was held in Santa Fe, whereas all previous workshops had been held in Breckenridge. The 2004 Workshop set a new record for numbers of participants with a total of 331 attendees, 237 from universities and laboratories and 94 from NCAR.



This figure shows the growth in participants (NCAR and non-NCAR) at the annual CCSM workshops from 1996-2004.

The project office was also responsible for the administration of a number of Small Grants for Exploratory Research (SGERs) from NSF. These small grants produce major benefits to the CCSM project, particularly by attracting new talent and investment in the CCSM enterprise. Results from the SGER program include an outreach grant that was crucial in supporting and re-energizing a coordinated regional climate modeling program at NCAR. Another grant supported a PhD student (Lucinda Shellito) from the University of California, Santa Cruz, investigating paleoclimate regimes using CCSM. The SGER awarded to Ilana Wainer (visitor, University of Sao Paulo) supported short-term visits to NCAR for collaborative analysis of the behavior of the southern Atlantic Ocean in the coupled model. She has published her findings in several papers in both Brazilian journals in Portuguese, as well as English-language refereed journals. The SGER support provided to James Hack (CMS) and David Bader (visitor, Department of Energy, DOE) was used to hire a student assistant and to purchase a Linux dual-processor Xeon computer system for the purpose of running the cloud model and analysis software. The project successfully ported the University of Wisconsin Non-hydrostatic Modeling System to NCAR for use in parameterization studies with the CCSM Community Atmosphere Model (CAM) single column model. The group developed analysis procedures for examining output from the cloud model and the infrastructure required to allow for direct comparisons of cloud resolving model simulations with CAM3 single column model simulations. Follow-on work will continue under separate funding. A grant was awarded to Natalie Mahowald (TSS) and Andrew Gettelman (CMS) to hold a community workshop on the modeling and use of isotopes in CCSM. The workshop was held in January 2004, and the participants included 24 scientists from universities and other research institutions and 16 scientists from NCAR. The workshop attendees reviewed the science of isotopes as a tool to understand climate processes, the state of the science of isotope transport, and the transformation in climate models. They also addressed the issue of modeling isotopes in the CCSM and formulated a work plan and priorities for the development and testing of the capability in CCSM. A copy of the workshop report is available from the CCSM Project Office.

Present Scientific Capabilities of the CCSM Modeling System

The new version of the model, CCSM3, includes a number of important scientific and technical enhancements. These improvements are designed to facilitate a greater range of scientific experimentation by a larger community of climate modelers than any previous release. CCSM3 can be integrated over a wide range of spatial resolutions depending upon the goals of a specific application. The model can be run at a low resolution suitable for lengthy simulations of paleoclimate regimes and biogeochemical interactions, an intermediate resolution for development, and a high resolution for climate change assessments.

The major enhancements for the atmospheric model include new treatments of cloud and ice-phase processes; improved representation of the interactions among water vapor, solar radiation, and terrestrial thermal radiation; new treatment of the effects of aerosols on shortwave and longwave radiation; and new dynamical frameworks suitable for atmospheric chemistry. The updates to the land model are new methods to enable simulation of the terrestrial carbon cycle, dynamic vegetation, and improvements in land-surface physics to reduce temperature biases. The ocean component incorporates improvements to the representation of the ocean mixed layer, inclusion of solar heating by chlorophyll, and a new infrastructure for studying vertical mixing in the ocean. The enhancements for the sea ice model include a more accurate representation of surface stresses on ice, inclusion of salt in ocean-ice mass exchanges, and significant improvements in the numerical ice advection scheme.

In general, the climate for present-day conditions produced by CCSM3 has greater fidelity to the observed climate than simulations from previous generations of CCSM. The magnitude of the cold bias in the equatorial east Pacific has been halved in the new version. The warm bias in the winter land-surface temperatures at high northern latitudes has also declined, which will facilitate studies of the polar amplification of global warming using CCSM3. The thickness and spatial distribution of the Arctic sea ice are much more realistic in this new version due in part to better gradients in sea level pressure across the Arctic basin and to a much more realistic polar surface radiation budget. The snow climatology has improved because of better low-level moisture transport and atmospheric temperatures. The greater fidelity of the snow and sea ice for present-day conditions are important for studies of climate feedbacks in the cryosphere. The ocean exhibits better sub-surface zonal currents in the eastern and equatorial Pacific and smaller biases in shallow-ocean mixing and ocean heat uptake. Several aspects of the simulated El Niño-Southern Oscillation (ENSO) cycles are also more realistic, including the teleconnections between the equatorial and northern Pacific and the cloud radiative feedbacks.

Despite the improvements in the model fidelity, several significant challenges remain. The next CCSM workshop in June 2005 will include an integrated assessment of the systematic biases in the climate simulated with CCSM3. The excessive mass transport through the Drake Passage is directly related to the overestimate of surface wind stress over the southern oceans. The warm sea surface temperature (SST) biases off the western coasts of Africa and South America are due to an underestimate of stress and an overestimate of surface insolation. Preliminary studies indicate that the coastal SST errors affect the surface state over large areas of

the Pacific and Atlantic Oceans. Other issues in the tropical climate include a double Intertropical Convergence Zone (ITCZ) in the Pacific and Atlantic, excessive precipitation in the western Indian Ocean, a semi-annual SST cycle in the eastern Pacific, and representation of the major modes of variability including ENSO. With the introduction of biogeochemical cycles in CCSM, it has become more urgent to address long-standing biases in continental precipitation and temperature, particularly over tropical Africa and the Amazonian basin. The CCSM Scientific Steering Committee is committed to focusing future development and experimentation on amelioration or elimination of these systematic errors.

Control Runs Accomplished and Data Available

The new version of CCSM3 was released to the community in June 2004. All source code and input data are freely available via the CCSM Web site (www.ccsm.ucar.edu/experiments). This model is significantly different from any previous version with major changes made to all the CCSM components. CCSM3 can also run on a much larger number of machines and associated platforms than previous releases, including vector machines and Linux clusters. The portability to Linux clusters, which are widely available in the university community, should help users run CCSM3 at their home institutions. The reintroduction of a vector capability will allow CCSM scientists to perform demanding simulations on the fastest computers available to the climate community.

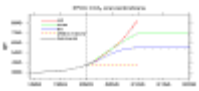
New user-friendly scripts for building and running the system were introduced, producing easy-to-use methods to run the IPCC climate change experiments, as well as the flexibility to simulate climate over a wide range of spatial resolutions. The new build/run scripts also permit the straightforward porting of the model system to new machines by providing the user with the ability to easily tailor the scripts for their particular machine environment. The release was also accompanied by new built-in test facilities suitable for validating installation and verifying some types of model changes. CCSM3 was accompanied by a completely new flux coupler with new infrastructure that improves its performance and scalability on parallel supercomputers and accelerates multi-way communication among the component models. CCSM3 also includes the introduction of "dead" models, which provides the ability to easily test the CCSM3 software infrastructure. In conjunction with the release of the new CCSM3 model, the project produced the most comprehensive suite of control runs ever provided to the CCSM community. The following table indicates the number of simulated years for a variety of standard forcing scenarios. Each scenario was run at three resolutions (low, medium, and high). In addition, there are ensembles for some of these scenarios. For example, the T85_gx1v3 20th century control has a seven-member ensemble. The total volume of control simulations is approximately 4,000 simulated years. A large subset of output data from each control run has been made available on the Web via the Earth System Grid (www.earthsystemgrid.org), which is a DOE project to distribute large collections of climate research data.

Run Length In Years			
Scenario	**T85_gx1v3**	**T42_gx1v3**	**T31_gx3v5**
1990 control	700	1000	880
1% increasing CO_2	150	150	180
2xCO_2	150	150	150
4xCO_2	150	150	150
1870 control	750	300	150
20th century	100	100	100

The scenarios are:	
1990 control	constant 1990s forcing
1% increasing CO_2	starting from a 1990 control, applies 1% annual increasing CO_2 forcing
2xCO_2	starting from where a 1% increasing CO_2 reaches 2 times 1990 levels, CO_2 held constant
4xCO_2	starting from where a 1% increasing CO_2 reaches 4 times 1990 levels, CO_2 held constant at 4x levels
1870 control	constant 1870s forcing
20th century	starting from an 1870 control, a time series of 20th century forcing is applied

The IPCC Simulation Production Process

The application of CCSM to IPCC represents a multi-institutional, distributed effort by scientists and software engineers at NCAR, Oak Ridge National Laboratory (ORNL), National Energy Research Supercomputing Center (NERSC), Lawrence Berkeley National Laboratory (LBNL), and partners in the Kyosei Consortium using the Japanese Earth Simulator (ES).



This figure shows IPCC CO_2 concentrations. In addition to CO_2, the simulations are run with solar, volcanoes, sulfate aerosols, ozone, and other greenhouse gases for the period 1870-2000. A spread of CO_2 concentrations for future forcing scenarios is used from years 2000-2200 that also include sulfate aerosols and ozone.

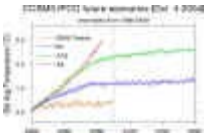
CCSM3 (T85 version) has been run to perform a suite of 20th, 21st, 22nd, and 23rd century climate simulations. These simulations are the CCSM contribution to the IPCC AR4. The experimental design and list of experiments was suggested by IPCC Working Group 1 and coordinated by the World Climate Research Program/Climate Variability and Prediction Program (WCRP/CLIVAR) Working Group on Coupled Models (WGCM).

The IPCC scenarios that are being run can be categorized into two groups: a set of "commitment scenarios" and a number of "science scenarios" that explore alternative future emissions outcomes. The IPCC Special Report on Emissions Scenarios (SRES) that were recommended to the global coupled climate modeling groups by IPCC Working Group 1 include B1 (a low forcing scenario), A1B (a medium forcing scenario), and A2 (a large forcing scenario). The A2, A1B, and B1 scenarios consist of eight-member ensembles run from the year 2000 to the year 2100. Then, commitment scenarios are run with the concentrations of all atmospheric constituents in A1B and B1 held constant at year 2100 values, and the model continues to the year 2200 with five-member ensembles. One of the ensemble members from each is continued for an additional 100 years to the year 2300 with constant year 2100 concentrations. There is also a 20th century commitment scenario that freezes concentrations at levels observed in the year 2000, and the model is run to the year 2100. A limited number of experiments performed on the ES examined the implications of future reductions in CO_2 concentrations.

This figure shows the CCSM3 IPCC Run Plan: The IPCC scenario runs have been done at NSF/NCAR (blue), DOE/ORNL (green), and DOE/NERSC (red). Parallel runs on the ES (pink) were made with the scientific and technical assistance of the Kyosei Consortium.

The CCSM3 and Parallel Climate Model (PCM) IPCC runs are being performed at NSF/NCAR, DOE/ORNL, and DOE/NERSC supercomputing sites. An additional set of parallel runs, using the same version of CCSM3 with forcing data sets prepared by NCAR, was run on the ES. Focused model development and significant dedicated computing resources provided by NCAR, DOE, and the Kyosei Consortium have kept the IPCC runs on track for completion in time to meet IPCC data submission and paper publication deadlines. Most recently, NERSC consultants assisted the CCSM team in running the NERSC A2 five-member ensemble as one single 1020 processor massively-parallel run.

The data products from CCSM3 and PCM IPCC simulations will be used for climate change impact studies and as boundary conditions to drive regional scale models. To support NSF and DOE regional modeling efforts, we are outputting two additional sub-daily data streams for each of the CCSM IPCC scenarios. By design, the raw and post-processed data products from the different IPCC scenarios are being kept at DOE and NSF sites where they were computed. This large distributed data set is being made freely available to the U.S. climate research and education community via the DOE Earth System Grid (ESG).



This figure shows CCSM3 DOE/NSF IPCC scenario runs as of October 4, 2004. Observed forcings (solar, volcanoes, greenhouse gases, sulfate aerosols, carbon aerosols, and ozone) are used during the historical period, from years 1870-2000. A variety of future

forcing scenarios (20th century freeze, B1, A1B, and A2) are used from years 2000-2200 to simulate the most likely range of future climates. Two of the commitment scenarios (A1B and B1) will be executed out to year 2300.

The IPCC experiments are intended to address several outstanding climate simulation issues. First, how well can the CCSM3 simulate 20th century climate if most of the dominant forcings are included over that time period? In this regard, forcings used previously included natural forcings (solar and volcanoes) and anthropogenic forcings (greenhouse gases, sulfate aerosol direct effect, and ozone). It also included an important new forcing by carbon aerosols, using a present-day distribution of carbon aerosols that scaled the geographical pattern over the 20th century by population as an approximation of their varying effect with time. Future experiments already planned will examine the role of carbon aerosols in much more detail. The 20th century simulations with the CCSM3 show that the time evolution of globally averaged temperatures track the observed time series very well, indicating that the forcings we have included are relevant for simulating 20th century climate.

Second, given three SRES's for 21st century climate change, what possible changes could occur by the end of the 21st century? Results show that the global temperature increases are proportional to the forcing as could be expected, with the pattern of temperature changes showing greatest warming at the high latitudes of the Northern Hemisphere and over land areas, with least warming over the North Atlantic and Southern Oceans.

A third major issue is the nature of climate change that is committed by previous emissions and by emissions occurring during the 21st century. The analysis is based upon idealized experiments where all concentrations are held fixed, first at year 2000 values, and then at year 2100 values for the A1B and B1 scenarios. Results show that global temperatures continue to rise on the order of a couple of tenths of a degree for the next 100 years after concentrations are fixed, but the much greater commitment comes from sea level rise. Subsequent sea level increases from thermal expansion alone 100 years after fixing concentrations are on the order of a couple hundred percent. These results demonstrate that the threat from future climate change after stabilization comes more from sea level rise we are already committed to, rather than future increases of temperature.

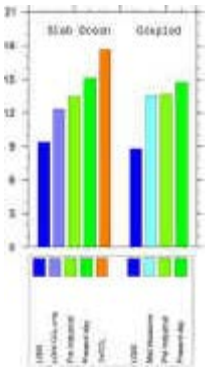
The CCSM3 experiments for the IPCC AR4 involve the most extensive and highest resolution multi-member ensemble ever performed with a global coupled climate model at NCAR, with five-member ensembles for all of the experiments. We also have been coordinating a parallel set of runs with CCSM3 on the ES. Combining the multi-member ensembles run on the ES, the CCSM3 will have by far the largest multi-member ensemble data set of any of the international global coupled models run for the IPCC AR4. Thus, the CCSM3 has assumed a leadership role in the performance and analysis of these high profile climate change simulations for the AR4. The model simulations have been completed and a subset of requested model data is being shipped for archival at DOE's Program for Climate Model Diagnosis and Intercomparison (PCMDI). This data will become part of the largest multi-model climate analysis project ever attempted, as over 200 researchers from around the world have registered to analyze the multi-model data set, of which CCSM3 is a part, for the IPCC AR4. After the deadline for submission of manuscripts for the *Journal of Climate* special issue on CCSM3 in fall 2004, the entire CCSM3 data set will become available for analysis to the CCSM3 community.

Some Highlights of Scientific Results Using CCSM Models

a) Estimating Climate Sensitivity from Last Glacial Maximum

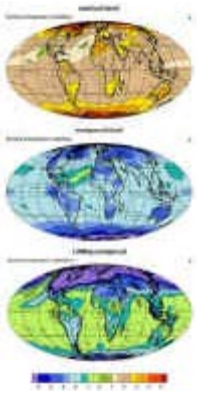
The second phase of the Paleoclimate Modeling Intercomparison Project (PMIP2) is coordinating simulations and data syntheses for the Last Glacial Maximum (LGM, 21,000 years before present) to improve the assessment of climate sensitivity. The important forcing for the LGM is not the direct effect of insolation changes, which are minor, but instead results from the large consequential changes in various elements of the climate system, including greenhouse gases, aerosols, ice sheets, and vegetation change. The changes in greenhouse gases are fairly well known but the others are not. Global climate sensitivity can in principle be estimated from the difference between LGM and present, from $Q=\alpha\,\Delta T$, where Q is the radiative forcing, ΔT; the global average surface air temperature change, and α; the climate feedback parameter. The climate feedback parameter is related to equilibrium climate sensitivity according to $\Delta T_{2x}=Q_{2x}/\alpha$. While Q and ΔT are uncertain, fortunately the signal associated with the changes between LGM and present-day conditions are large.

Using measurements from ice cores, atmospheric CO_2 concentrations at the LGM are estimated to be 185 ppmv, approximately 50% of present-day values. Global, annual mean surface temperature simulated by the slab ocean version of the CCSM3 shows a cooling of -2.8°C for LGM CO_2 levels and a warming of 2.5°C for a doubling of CO_2 (see figure below). Slab and coupled CCSM3 simulations that include the reductions of the other atmospheric trace gases and the large ice sheets covering North America and Eurasia at LGM give cooling in agreement with proxy inferences. The simulations indicate that atmospheric CO_2 concentration change explains about half of the global cooling at LGM.



This figure shows global, annual surface temperatures as simulated by slab ocean and fully-coupled versions of CCSM3 for past and future climate states.

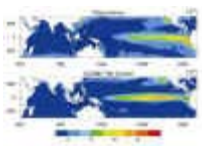
Regional signatures of the climate response to changed LGM forcing are also an important measure of climate sensitivity and are key for understanding the processes governing global sensitivity. Patterns and amplitudes of annual surface temperature change are similar but opposite in sign between the LGM CO_2 and $2xCO_2$ simulations with the CCSM3 slab ocean model (see figure below, top vs. middle). Cloud feedbacks, particularly feedbacks involving low clouds, play an important role in determining the surface temperature response in the model and show comparable patterns of change in the $2xCO_2$ and LGM CO_2 simulations. Additionally, a LGM CCSM3 slab ocean simulation that includes the reductions of the other atmospheric trace gases and the large northern ice sheets indicates that the cooling over the oceans in the tropics and Southern Hemisphere subtropics are primarily (~85%) due to the reductions of atmospheric CO_2 (see figure below, middle vs. bottom). Comparisons of PMIP2 model simulations of surface temperature changes for these regions and paleoclimatic proxy data may allow the LGM to be used as a metric to identify estimates of climate sensitivity that are outliers. Other regions of scalable response will also be identified and quantified as part of the PMIP2 model-data comparisons for the LGM.



This figure shows the surface temperature change simulated by the slab ocean version of CCSM3 for doubled CO_2 compared to present (top), LGM CO_2 compared to present (middle), and Full LGM compared to LGM CO_2 (bottom).

b) The ENSO Phenomenon in CCSM3

The ENSO phenomenon is a natural irregular oscillation of the coupled tropical ocean-atmosphere system on interannual time scales. ENSO is manifest primarily as a warming of the equatorial Pacific Ocean and a redistribution of precipitation within the tropics. However, the effects of ENSO are felt worldwide due to the global atmospheric circulation response to tropical rainfall changes.

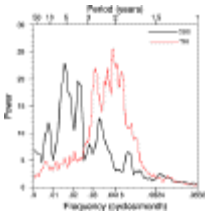


This figure shows the variance of monthly SST anomalies from (top) observations during 1900-1999 from the Hadley Centre Sea Ice and SST (HadISST) data sets and (bottom) the T85 CCSM3 control run during model years 400-499.

The ENSO phenomenon in the CCSM3 at T85 resolution exhibits a realistic spatial pattern and amplitude of SST variability in the

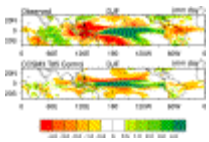
tropical Pacific and Indian Oceans, with maximum variability in the eastern equatorial Pacific and along the South American coast. This represents a considerable improvement over the previous version of the model (CCSM2), which greatly overestimated the amplitude of the SST variability and its zonal extent (not shown). The T42 version of CCSM3 exhibits a similar pattern and amplitude of SST variability as the T85 version (not shown).

A commonly used index of ENSO is the area-averaged monthly SST anomaly (defined as the departure from the long-term monthly mean) in the equatorial eastern Pacific (5ºN-5ºS, 170ºW-120ºW). A power spectrum of this index shows that the ENSO period in the model is approximately 2 to 3 years (also in the T42 version of CCSM3), considerably shorter than the observed period (approximately 3 to 8 years based on years 1900-1999). The peak amplitude of the power spectrum is comparable in the model and observations.



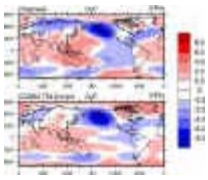
This figure shows the power spectrum of the monthly equatorial eastern Pacific SST index from observations during 1900-1999 (black curve) and the T85 CCSM3 control run during model years 400-499 (red curve).

The spatial distribution of the tropical precipitation changes during December-February for a composite "warm-minus-cold" ENSO event is shown in the figure below, where "warm" and "cold" years are identified using a one standard deviation criterion of the equatorial eastern Pacific SST index. In the model, warm events are accompanied by rainfall increases in the central and western equatorial Pacific and decreases directly to the north and south; rainfall decreases are also seen in the tropical Atlantic and eastern Indian Oceans (a similar pattern and amplitude of precipitation anomalies is seen in the T42 version of CCSM3; not shown). The simulated rainfall changes show good overall agreement with the observed changes, although nature exhibits more pronounced rainfall decreases over the western Pacific and maritime continent.



This figure shows the warm-minus-cold ENSO composite of precipitation anomalies during December-February from (top) observations during 1979-2000 based on the Xie-Arkin data set and (bottom) the T85 CCSM3 control run.

The global atmospheric circulation responds to the redistribution of tropical precipitation during ENSO events via Rossby waves and their interaction with the midlatitude storm tracks. The global sea level pressure (SLP) response to ENSO during December-February is well simulated in the model compared to observations (see figure below). Below normal SLP is found in the eastern tropical Pacific, with above normal SLP in the remaining tropical areas. In the extra tropics, a deepening of the Aleutian Low over the North Pacific is well simulated in the model, with maximum values of approximately 8-10 hPa for the warm-minus-cold ENSO composite. SLP teleconnections to the Southern Hemisphere are also well simulated both in terms of location and amplitude. The T42 version of CCSM3 exhibits a similar SLP response to the T85 version over the tropics, but the amplitude of the Aleutian response is considerably weaker (~5 hPa) than the T85 version (not shown).

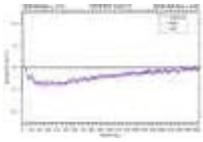


This figure shows the warm-minus-cold ENSO composite of sea level pressure anomalies during December-February from (top) observations during 1948-2003 based on the National Centers for Environmental Prediction (NCEP)-NCAR Reanalysis and (bottom) the T85 CCSM3 control run.

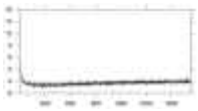
c) Simulating the Climate of the Late Permian

The boundary between the late Permian and the Early Triassic at 251 Ma is one of the most remarkable time periods in Earth's history. At this point in time, the largest known extinction of life took place, with approximately 95% of species extinguished. Geologic data indicate this was a time of global warming and very low oxygen levels in the oceans. Jeff Kiehl (CCR) and Christine Shields (CCR) have configured the CCSM3 to simulate the climate of this period. To study ocean conditions at depth, the fully coupled model has to

be run for thousands of years for the system to come to a new equilibrium state. The Late Permian simulation is forced with a ten-fold increase in present-day CO_2 concentrations. The simulation has been run for over 2000 years, the longest integration of CCSM to date.

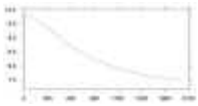


This figure shows the time series of the net energy flux at the top of the atmosphere (red) and surface (blue) for the Late Permian simulation. The initial forcing to the system was 14.5 Wm^{-2} due to a 10x increase in atmospheric CO_2.



This figure shows the time series of the global mean annual mean energy flux (Wm^{-2}) into the oceans.

Given the large heat capacity of the ocean, the long time scale for the model to attain equilibrium is governed by the heat uptake of the oceans as shown in the figure above. Note that around year 1900, the energy flux into the system has reached a very small value (-0.04 Wm^{-2}). This flux of energy is proportional to time rate of change of the volume averaged ocean temperature, shown in the figure below.



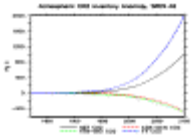
This figure shows the time series of the volume averaged ocean temperature (°C) from the Late Permian simulation.

The near equilibrium solution indicates a dramatic decrease in the overturning circulation in the deep ocean. The present-day high latitude pathways of deep water formation, i.e., in the North Atlantic and off the coast of Antarctica, are shut off in the warm climate of the Late Permian. This is the first comprehensive coupled simulation of this time period, and it indicates the need for substantial computational resources to study scientific questions involving deep ocean circulations.

d) Coupled Carbon Cycle Results

A suite of multi-century fully coupled carbon-climate integrations have been performed using a modified version of the Climate System Model version 1.4 (CSM1.4). Several century-long spin-up runs were done to adjust the modeled carbon cycle incrementally to the coupled model climate. These spin-up runs led to a stable multi-century (1000 years) carbon-climate pre-industrial control run.

Additionally, multiple 180-year historical and 100-year future scenario fossil fuel emissions experiments have been completed. These experiments are being analyzed to understand connections and feedbacks between the carbon cycle and the physical climate.



This figure shows the CSM1.0 simulation of atmospheric carbon dioxide in peta grams of carbon from the pre-industrial to future climate using the SRES A2 scenario. This simulation includes both ocean and terrestrial carbon response to climate and changes in carbon dioxide.

Plans for the Use of CCSM3

The CCSM project will continue to follow a research and development program to enhance the capabilities of the modeling system. The research will be directed toward providing a more complete, more useful, and more accurate CCSM. Representations of new physical and chemical processes will be formulated and tested within the CCSM framework to make the modeling system closer to what is termed an earth system model. Development will take place to provide increased resolution of climate change projections for impact assessment. As well, increased emphasis will be placed on improving the simulations of the hydrological cycle on continents. Software development will be directed to make the modeling system more portable, more reliable, and easier to use. Considerable effort will be put toward making the modeling system more accurate through a concerted attack on the long standing biases and continued examination of the fidelity of the representations of the physical and dynamical processes of the basic components of the

model, atmosphere, ocean, ice, and land.

The recently released version of the model, CCSM3, will be used to tackle a large number of interesting scientific questions. One of the most interesting questions has to do with the physical processes that can lead to abrupt climate change (ACC). In general, climate change is viewed as a gradual process taking place over centuries or millennia. However, observations of past climates indicate that large changes can occur over a few decades. There are hypotheses about physical processes involving ice, air, and ocean interaction particularly in the North Atlantic that, when perturbed, appear to have the potential to lead to rapid changes as a new equilibrium is sought by the climate system. CCSM3 will be used to investigate these physical mechanisms from a basic science point of view. The ad hoc CCSM group for ACC will also attempt to reproduce the characteristics of periods of ACC that have been observed in the paleoclimate record.

CCSM3 will be used to address a rather important question about the effects of human-induced land-use change on climate. Most people think of the emission of greenhouse gases as the substance of human effects on climate. However, in the past 150 years human activity has transformed the land surface. For example, farms have replaced forests in most of the eastern half of the U.S. and southern Canada. There is instrumental evidence of the changes in local climates produced by changes in land use. It is important to address the question of the impact on the climate on at least the continental scale by land-use changes in the 19th and 20th centuries.

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Climate Dynamics and Predictability Narrative

The objective of the Climate Dynamics and Predictability Section (CDP) is to further develop the scientific understanding of the dynamics and predictability of large-scale atmospheric variability and coupled variability on time scales of days to decades. This process will allow construction of the scientific basis for predicting the transient, global circulation in the atmosphere beyond the present practical limits. CDP scientists take three approaches to their research: (1) numerical and theoretical experimentation with a hierarchy of physical models ranging from the non-divergent, barotropic model to coupled atmosphere-ocean models, (2) diagnostic analyses of the cause of atmospheric climatic variability and its theoretical and practical predictability in simulation and forecast experiments using the NCAR Community Atmosphere Model (CAM) and Community Climate System Model (CCSM), and (3) sensitivity analyses of numerical prediction models to atmospheric initial and boundary conditions using ensemble techniques that will aid in the design of improved methods of data assimilation, for both conventional and non-conventional meteorological data, e.g., precipitation and sea surface temperature (SST).

Predictability and Prediction Studies of Weather and Climate Variations

The studies described below are highlights of the research in CDP devoted to the prediction and predictability of climate variations and extreme events. These studies are integral to our section goals of extending and defining the spatio-temporal domain over which scientifically and societally useful forecasts can be made. CDP scientists have continued their interest in the inherent predictability of atmospheric phenomena and have utilized their expertise gained in ensemble prediction techniques to address the prediction of extreme events.

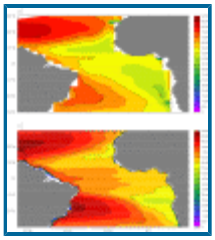
A focused research effort centered about the goals of the United States Navy predictability initiative was the impetus to reinvigorate CDP efforts in the predictability of synoptic time and space scales with particular emphasis on the predictability of nonlinear events. Cognizance of the nonlinearity of climate models is necessary if model predictions are to capture sensitivity seen in nature, and yet models are frequently run in a 'deterministic' mode. Exploitation of (nonlinear) model sensitivity to initial conditions may enable a model to demonstrate behavior observed in nature but not seen in a single, deterministic run; further, information from such ensembles of runs can help in distinguishing system sensitivity and model error.

Dave Baumhefner (CDP) and JosephTribbia (CDP), along with Ron Errico (NASA-Global Modeling and Assimilation Office) and Steve Mullen (University of Arizona), tackled the problem of modeling the initial uncertainty in atmospheric ensemble prediction through the development of statistical model of analysis error. To develop this model six-hourly reanalysis fields from European Centre for Medium-range Weather Forecasts (ECMWF) and National Centers for Environmental Prediction (NCEP) were compared for the 1990-1991 boreal winter (DJF) and 1991 boreal summer (JJA). Differences between geopotential height, temperature, rotational and divergent wind components, and specific humidity were compared for 16 isobaric levels from 1000 hPa to 10 hPa, with the goal being a statistical documentation of analysis uncertainty. Synoptic maps, horizontal spectra, vertical correlations, and spatial variations in the amplitude were examined for differences with seasonal biases removed. Horizontal spectra of these differences revealed that the analysis differences exhibit strong scale dependencies. The horizontal wavenumber at which the ECMWF-NCEP perturbation variance first exceeds the variance of the ECMWF analysis, the saturation cutoff, was relatively high for

geopotential height and the rotational wind, with an implied cutoff occurring near total wavenumber T40-T50 (equivalent wavelengths in range 1100-800 km). Temperature saturated at a larger scale, near T30 (1400 km wavelength), while divergent wind and specific humidity saturated near T25 (1600 km wavelength). Moisture stood out as a particularly uncertain field, with perturbation variances exceeding the variability of the ECMWF analyses over the lower troposphere equatorward of 40 degrees. The differences decorrelate rapidly with height, possessing e-folding scales of 1-2 km for all fields except height and rotational wind, which were 2-3 times deeper. They appear equivalent barotropic to first order over the tropics and vast regions of the extratropics. The statistics for this study, and from future analysis of more years of data, should prove useful as guidance for the construction of an analysis difference simulator and a baseline to compare statistics from emerging ensemble Kalman filter methods.

One of the important research areas in CDP is predictability on seasonal-to-interannual timescales. On the global scale, the largest source of such predictability is the El Nino-Southern Oscillation (ENSO) phenomenon. The second largest source of predictability on seasonal-to-interannual scales lies in the tropical Atlantic region. Ramalingam Saravanan (CDP) and Ping Chang (Texas A&M) have been carrying out collaborative research on tropical Atlantic variability (TAV) to understand this source of predictability.

To better study the mechanism of TAV and the role of air-sea interaction, Saravanan and Chang have developed a regional coupled ocean-atmosphere model for the Atlantic basin. The atmospheric component of this coupled model is CAM3, the NCAR atmospheric general circulation model (GCM). The oceanic component is a high-resolution, eddy-permitting Atlantic sector ocean model derived from Geophysical Fluid Dynamics Laboratory's (GFDL) Modular Ocean Model 3 (MOM3). The ocean model's spatial domain contains 480 points in longitude and 340 points in latitude spanning the region from 100 degrees west to 20 degrees east and from 35 degrees south to 50 degrees north with a fixed resolution of 1/4 degree in both longitude and latitude. The portion of this region that includes part of the eastern Pacific Ocean west of Central and South America is not included in the modeled domain. The model has 25 vertical levels with 15-meter resolution in the upper 150 meters. The horizontal resolution was selected as a compromise that is fine enough to be “eddy permitting” but also computationally efficient. The oceanic and atmospheric components are fully coupled in the Atlantic domain without the use of explicit flux adjustment. Outside the Atlantic Ocean model domain, climatological SSTs are specified as the surface boundary condition for the atmospheric model. Saravanan and Chang have completed spin up of the ocean model over an 80-year period. For the spin-up simulation, Figure 1 compares the simulated upper 400m mean heat content (deg.C m) to XBT observations for the period of 1979-1999. The model is able to capture the spatial structure of the heat content variability along with its magnitude in the western tropical Atlantic.



This figure shows long term mean heat content (deg.C m) from the surface to 400m from a) XBT observations for the period 1979-1999, and b) Regional Atlantic ocean model.

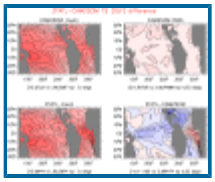
Just as the seasonal forecast community uses concepts and methodologies developed by the climate dynamics community to diagnose, interpret, and further develop its prediction capabilities, there is the potential for climate change researchers to apply these same concepts and techniques to climate change scenarios. Conversely, climate change scenarios provide a fertile testing ground for ideas developed by the climate dynamics community. With assistance from Grant Branstator (CDP), Caspar Ammann (CCR) and Bette Otto-Bliesner (CCR), during the summer of 2003 a team of Dutch scientists performed an unprecedented climate change experiment using NCAR's CCSM Version 1.4. This version of CCSM was originally configured for studies of paleoclimatology and has also been used for simulations of the last millennium. The new experiment consisted of producing a 62-member ensemble of simulations for the years 1940-2080, with each realization being forced by the identical observed forcing functions during the first 61 years, and the same projected business-as-usual rampup in greenhouse gas concentrations during the last 80 years of the integrations. The ensemble members differed only in their initial conditions, so that at each stage of the climate change a large sample of states produced under identical conditions was being produced. This has made it possible to analyze features of the changing climate that cannot be studied with statistical confidence in conventional experiments. In collaboration with colleagues at the Royal Netherlands Meteorological Institute (KNMI) and Colorado State University (CSU), Branstator has used this experiment to study the interplay between the natural modes of variability of the atmosphere and long-term trends in the mean atmospheric circulation resulting from the secular forcing trends. The large sample size has made it possible to detect and diagnose the two-way interaction between modes and trends. For example, calculations with a stochastically forced planetary wave model linearized about mean states from the

experiment indicate that centennial changes in the mean circulation are responsible for subtle modifications in the structure of intrinsic interannual modes that occur on the same timescale in the ensemble. On the other hand the structure of the mean circulation trends correspond to one of the dominant intrinsic modes of the coupled system. One of the unexpected outcomes of the experiment is that the intrinsic mode that most influences secular circulation trends is not the North Atlantic Oscillation (NAO), as is often assumed, but rather the Circumglobal Waveguide Pattern. This is a pattern that Branstator recently identified when studying interannual variability. Results indicate that understanding the mechanisms that produce this pattern are key to understanding the regional character of climate change in this and other experiments.

Diagnostic and Theoretical Studies of Variability and Validation

Within CDP the purpose of diagnostic analyses is twofold: diagnosis is used to test theoretical ideas concerning the mechanisms responsible for climate variations and their relative import and also test (i.e., validate) the behavior of comprehensive climate models like the NCAR CCSM against that of the observed climate system. Naturally, the aforementioned prediction studies can also be viewed in this latter context. Additionally, several particularly insightful examples of past CDP studies exemplifying these two types of diagnoses are detailed below.

Saravanan and Chang have been studying the causes of the persistent cold biases in the simulated tropical Pacific SST in the CCSM coupled model. They find that these biases can be attributed, at least in part, to the remote influence of tropical Atlantic SST biases, as demonstrated by coupled experiments using CAM2/CCM3 coupled to a slab ocean model. As shown in Figure 2, simulated ocean heat transport errors in the tropical Atlantic can have a significant effect on SST throughout the tropical Pacific region. This remote influence is quite sensitive to the depth of the slab ocean, with increasing depth leading to decreased remote influence. In addition to being relevant for understanding systematic errors in coupled models, this remote influence could also play a role in explaining paleoclimatic teleconnections in the tropical regions.



This figure shows sea surface temperature (SST) diagnostics during the boreal winter (Dec-Feb) for two integrations: CAM2SOM (CAM2 coupled to slab ocean) and ZTATL (CAM2 coupled to slab ocean, but with implied oceanic heat transport QFLX set to zero in the tropical Atlantic). Setting QFLX to zero simulates errors in oceanic meridional heat transport. Top-left: Mean SST for the CAM2SOM integration. Top-right: Root-mean-square deviation of SST for the CAM2SOM integration. Bottom-left: Mean SST for the ZTATL integration. Bottom-right: SST difference between ZTATL and CAM2SOM integrations. Note the significant cold bias in tropical Pacific SST in the bottom right panel, which is caused solely by the simulated ocean heat flux errors in the tropical Atlantic.

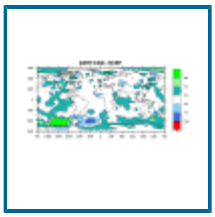
Theoretical ideas from other fields of physics, most often statistical physics, are occasionally beneficial in the study of climate. Climate scientists generally use one of two methods for estimating how the climate system will react to a given change in external forcing. Either they search the observational record for earlier occurrences of the conditions of interest, or they build a numerical model of the system and determine how it reacts to altered forcing. But neither approach is able to answer a whole class of problems, namely optimization problems that in effect concern all possible responses of the system to external forcing. For example, one might want to ask with respect to some measure, what is the strongest possible global response to a unit change in atmospheric heating? To answer questions of this type, one needs a linear operator that maps infinitesimal forcing anomalies into response anomalies. In the 1970s while at NCAR, Chuck Leith pointed out that by application of the Fluctuation-Dissipation Theorem (FDT), one might be able to construct such an operator simply from observations of the lag-covariance structure of naturally occurring, unforced perturbations to the state of the climate system. In collaboration with Andrei Gritsoun and Valentin Dymnikov of the Russian Academy of Science's Institute for Numerical Mathematics, Branstator has been testing this idea and has found that, even though the conditions of the FDT are not strictly met, it can be used to construct a remarkably accurate response operator for the atmosphere. In this investigation the operator is constructed from data generated by a long integration of a GCM in which external boundary conditions are kept constant. Then the accuracy of the operator is determined by comparing its response to local steady heat sources to the response of the GCM to the same heat sources. Because these tests indicate the operator is very accurate, it is now being applied to various optimization problems. These range from determining what is the optimal means of exciting the NAO to finding what tropical heating anomalies produce the largest change in North American mean surface temperature. To date the operator has only been constructed for the first generation NCAR atmospheric community climate model (CCM), CCM0, but plans are to now generate it for the latest version of this model.

Data Assimilation and Numerical Model Development Studies

Data assimilation studies have been a component of CDP research for many years. In the past year a more coordinated NCAR-wide activity has been developed with CDP a focus of activities within CGD. Jeffrey Anderson (CDP/MMM), Kevin Raeder (CDP), and Hui Liu (CDP) have been teaming with Alain Caya (MMM), Chris Snyder (MMM), Dale Barker (MMM), Syed Rizvi (MMM), Tim Hoar (GSP), Doug Nychka (GSP) ,and Tribbia in an NCAR strategic initiative. The NCAR Data Assimilation Initiative (DAI) is creating and leading a research community for data assimilation where individuals benefit from sharing ideas, methodologies, and software tools, as well as access to a data assimilation research testbed (DART). The DART facility is used to provide focus to both internal and external collaborations related to data assimilation. Improved self-calibrating and scalable variants of ensemble filter algorithms were two of many enhancements found in new releases of DART made during FY04.

Several new important models were added to DART including the Massachusetts Institute of Technology's General Circulation Model, ACD's ROSE model of the middle atmosphere, and the operational Global Forecast System that is used to make operational global predictions at the NCEP. The last model will allow fair comparisons between ensemble filter and operational variational assimilation algorithms to be made during FY05.

DART is now able to assimilate real observations from the Binary Universal Form for the Representation of Meteorological Data (BUFR) files used as input to both operational analyses and reanalyses at numerical weather prediction centers. Any DART compliant model can be tested as a forecast / prediction model using radiosonde, aircraft, satellite cloud drift wind, and other standard observations. To test this capability, CGD's CAM 2.0 GCM was combined with an 80-member ensemble filter to generate analyses and short-term forecasts for January 2003. Despite significantly lower resolution (T42 for CAM), this ensemble assimilation system was able to produce analyses that were of nearly the same quality as those produced by the operational global prediction system at NCEP. Figure 3 shows a snapshot of the differences in 500 hPa height analyses for 00GMT on 08 January 2003 from the two systems. In general, the differences are less than 25 geopotential meters over much of the globe demonstrating that the two analysis systems have roughly comparable capabilities (large errors in the southern hemisphere result because the DART CAM analysis does not use satellite radiance observations).



This figure shows a snapshot of the differences in 500 hPa height analyses for 00GMT on 08 January, 2003 between an 80-member ensemble filter with T42 CAM and the operational NCEP system. In general, the differences are less than 25 geopotential meters over much of the globe demonstrating that the two analysis systems have roughly comparable capabilities (large errors in the southern hemisphere result because the DART CAM analysis does not use satellite radiance observations).

The ability to simulate radar reflectivity and Global Positioning Satellite (GPS) occultation observations has been added to DART. This allows researchers to evaluate the real or potential value of observations of these types. The ability to simulate the assimilation of GPS observations is particularly interesting as UCAR prepares for the launch of an array of new low earth orbit satellites that will produce GPS occultation observations.

During the next year the DART facility will be further refined, culminating in a software release that will support a joint GSP/DAI workshop with the statistical community in June. DART's ability to use assimilation to estimate the value of model parameters will be put to the test with several projects. In particular, assimilation will be used to obtain appropriate values for free parameters associated with CAM's gravity wave drag parameterization. It is conjectured that assimilation may be able to improve model performance by providing better values for a variety of model parameters.

One of the great challenges for ensemble assimilation in regional atmospheric models is to deal with introducing uncertainty at the model's horizontal boundaries. With the global CAM and Global Forecast System (GFS) models and the regional Weather Research and Forecast (WRF) model now available in DART, tests on using global ensemble assimilations to provide boundary conditions for WRF will be undertaken. It is possible that this will lead to significantly improved assimilation capability in WRF.

In data assimilation work funded through the NSF Collaboration between Mathematics and Geophysics (CMG) program, Greg Duane (CDP) and Tribbia have been examining the relationship between synchronization and assimilation. It has been recently established that a pair of chaotic dynamical systems can synchronize when loosely coupled in a variety of

ways. This suggests that the synchronization phenomenon, with one system representing ‘truth' and the other system representing 'model', could provide a new approach to data assimilation in high-dimensional systems. Duane and Tribbia have thus been led to search for low dimensional subspaces through which the two systems can be synchronously coupled, such as a subspace defined by a small number of local bred vectors. Using a pair of 2-layer quasigeostrophic channel models, the efficacy of a bred vector basis for data assimilation has been compared to that of other bases.

They also examined whether the synchronization approach differs qualitatively from the standard approaches to data assimilation. An equation for synchronously coupled dynamical systems was obtained for continuous data assimilation in a linearized model, with coupling strength given in terms of observation and background errors in the usual way, and with observation error taken to correspond to noise in the coupling channel. Background error was computed from an assumption of stationarity of the probability distribution function (PDF) that satisfies the corresponding Fokker-Planck equation, for the case of a perfect model. An optimal coupling, in contrast, was defined as one that minimizes the spread of the PDF. The analysis was used to demonstrate that the synchronization approach to computing the optimal coupling for a linear model gave the same criterion as assimilation, but a fully nonlinear model synchronization may improve upon more empirical methods.

In addition to advances in assimilation, the next generation of atmospheric model dynamical cores will in all likelihood span a range of scales that will include those for which the hydrostatic approximation is questionable. This will require new understanding of global non-hydrostatic effects. In search of a more refined formulation of the dynamical models for global weather prediction and climate projection, Kasahara continues his research to understand the basic dynamics of a deep nonhydrostatic atmospheric model that is more general than the primitive-equation model for weather and climate. One notable aspect of this general model is the role of Coriolis forces arising from the horizontal component of the earth's rotation. These additional forces together with the traditional Coriolis forces due to the vertical component of the earth's rotation, give rise to a unique kind of oscillation modes that have frequencies close to inertial (Coriolis frequency) and are referred to as “boundary-induced inertial” (BII) modes, because without the horizontal boundary of domain these modes are absent. Moreover, their structures are highly variable in the vertical in a large, thermally stratified environment, such as mixed-layers in the oceans. In fact, it is likely that the well known near inertial-period oscillations that are observed prominently worldwide in the oceans can be better explained from the standpoint of adjustment involving the joint action of traditional inertio-gravity and BII modes. Toward the goal of investigating a geostrophic adjustment involving this joint action, Kasahara is extending his research from analytical means to numerical modeling, so that more realistic situations, such as the response of external forcing in inhomogeneous media, can be handled.

Tribbia has also been investigating the limitations of the hydrostatic balance approximation in a different context--that of limited area modeling. With Roger Temam (Indiana University) and Antoine Rousseau (Universit'e Paris-Sud), he has been continuing the examination of approximate equations that break the strong constraint of hydrostatic balance. The reason for their interest is the well-known deficiency of the hydrostatic primitive equations, ill-posedness as an initial-boundary value problem.

The ill-posedness of the system imposes severe restrictions on the applicability of the system for limited area regional climate modeling and the use of adaptive mesh methods. Temam and Tribbia developed a simple alternative, designated the delta model. In the extension of this work with Rousseau, they have examined the limit in which delta, which regularizes the initial-boundary value problem, approaches zero to better understand the nature of the boundary layer behavior that ensues. In the recent work they have studied a linear differential system consisting of two coupled scalar evolution equations in one space dimension that was derived from a modal analysis of the primitive equations of the ocean. They have shown numerically that, by adjunction of a small viscosity, the system converges to an unusual, unexpected limit system thus producing boundary layers and reflections of waves at the boundary. They proposed an alternate set of boundary conditions of transparent type for the viscous systems and, in this case, the viscous system does not produce boundary layers or reflections of waves at the boundary. For the primitive equations of the atmosphere, the implication of this study is that a mild friction term can produce unexpected spurious waves in a model with a limited domain.

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Climate Modeling Section Narrative

The mission of the Climate Modeling Section (CMS) is to improve understanding of the global atmosphere and its role in the climate system, through modeling and observational studies, and to represent that understanding in the form of improved numerical models of the atmosphere and broader climate system. The principal modeling tool in CMS is the Community Climate System Model (CCSM) Community Atmospheric Model (CAM). CAM is the global atmospheric model employed in the CCSM, where CMS scientists play a primary role in its ongoing development.

Climate Modeling

Members of CMS (Byron Boville, William Collins, James Hack, Philip Rasch, and David Williamson), in collaboration with colleagues in the university and national laboratory community, contributed broadly to the development of the new Community Atmosphere Model, CAM3. The new model was formally released in June 2004. CAM3 includes a large number of significant improvements and enhancements to the treatment of physical processes, new capabilities such as a Slab Ocean Model (SOM) configuration, and additional improvements to the software engineering implementation of the model. Some of the improvements to the physics include: a substantially revised prognostic cloud water parameterization that includes separate phases for ice and liquid condensate, advection and sedimentation of condensate, and a consistent treatment of condensate in the microphysics and radiative transfer parameterizations. The representation of direct shortwave aerosol forcing is incorporated using an annually repeating aerosol distribution for sulfate, dust, sea salt, and carbonaceous aerosols. Improved representations of shortwave water vapor absorption, longwave absorption, and emission by greenhouse gases are also included. The latent heat of fusion is included in all aspects of the thermodynamics involving the phase transformation of water substances, where the model now conserves energy exactly in all physical parameterizations. The shallow/frontal convection parameterization now interacts more closely with the prognostic cloud parameterization by detraining condensate directly into the stratiform clouds. The new CAM represents a concerted effort by CMS scientists to address several of the more important systematic biases identified in the coupled and uncoupled simulations with CAM2. CAM3 is incorporated as the atmospheric component of CCSM3, which will be used for NCAR's participation in the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report. The new model provides three dynamical cores, including the spectral Eulerian dynamical formulation, which uses a semi-Lagrangian transport scheme, the NASA Data Assimilation Office (DAO) finite-volume dynamical core that was incorporated via a collaboration with Shian-Jiann Lin (NASA Goddard Space Flight Center, GSFC), and a two-time-level, semi-Lagrangian dynamical formulation employing a linear transform grid. For the first time a single-column modeling capability (Single Column Community Atmosphere Model, SCAM) is fully integrated with the evolving CAM physics package and is included in the standard model distribution. This modeling framework also exploits new capabilities in the CAM3 to sample arbitrary columns, or regions of columns, for later exploitation by the SCAM (John Truesdale, CMS). This capability will be essential for the Climate Variability and Predictability program (CLIVAR) Atmospheric Climate Process Team (CPT) work currently underway with the Geophysical Fluid Dynamics Laboratory (GFDL), NASA, and university collaborators. The model continues to be capable of running on a variety of computer architectures popular for climate research applications, and is in the process of being extended to once again exploit re-emerging vector architectures.

Hack, in collaboration with Julie Caron (CMS) and Christine Shields (CCR), has developed climate configurations of the

new CAM3 at multiple resolutions. These include T31, T42, T85, and T170 truncations for the spectral dynamical core, where the T85 model will serve as the flagship configuration of the atmospheric model. This will be the highest resolution atmospheric model configuration ever released by NCAR, and leads the way for other global modeling activities. Slab Ocean Model simulations have been completed for the T31, T42, and T85 configurations. Hack continues to work internally and with external collaborators to develop higher resolution configurations of the finite-volume version of the atmospheric model, including 1.0°x1.125° and 0.5°x0.625° configurations of the dynamical core.

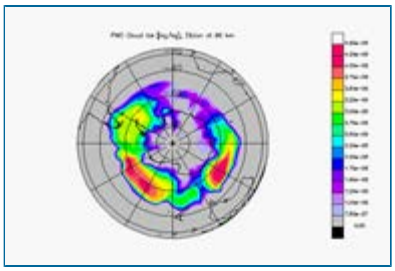
Collins has served as the co-chair of the CCSM Scientific Steering Committee, and coordinated the final scientific development of CCSM3 and the preparation of the model for its release in June 2004. A description of the new CCSM3 and some of the initial scientific work has been completed. The new atmospheric component CAM3 of the coupled system is described in the NCAR technical note NCAR/TN 464+STR. Collins is now working on a program plan for the near-term scientific exploitation and extension of the CCSM system, including the development of a 1st generation coupled chemistry-climate model.

In support of the upcoming Fourth Assessment Report (AR4) for IPCC, Collins and V. Ramaswamy (GFDL) have organized a radiative transfer model intercomparison project (RTMIP). This project was commissioned by Susan Solomon, one of the co-chairs for the Working Group 1 volume on “Climate Change 2007: The Physical Science Basis.” Estimates of radiative forcing by well-mixed greenhouse gases obtained from coupled atmosphere-ocean general circulation models (AOGCM) are being compared against benchmark forcing calculations from line-by-line (LBL) codes. The goal is to characterize the accuracy of the codes used in all of the model integrations submitted for the Fourth Assessment. NCAR is contributing calculations using the radiative parameterizations in CCSM3 and using the General line by line radiative transfer model (GENLN) LBL code developed in the NCAR Atmospheric Chemistry Division (ACD). Details on the experimental protocol and overall design of the intercomparison are available from ftp://science.arm.gov/outgoing/IPCC-rt. Preliminary results from the intercomparison were presented at the IPCC Workshop on Climate Sensitivity and indicate a wide disparity in estimates of forcing by CH_4 and N_2O at the tropopause and by CO_2 at the surface. Collins will present the results in invited talks at the 85th meeting of the American Meteorological Society, the 2005 Annual Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) Program, and the IPCC workshop on multi-model analysis in May 2005. Collins served as a co-chair for the IPCC Climate Sensitivity Workshop and led a breakout group to further refine estimates of radiative forcing for climate simulations submitted for the AR4.

In addition to the research invested in completing the development, documentation, and application of the CAM3, scientists in CMS have been involved in a wide variety of other research activities related to modeling of the climate system.

Collins and David Fillmore (CMS) have continued work on aerosol assimilation and participated in the international Aerosol Model Intercomparison (AEROCOM) program. Their assimilation using new aerosol retrievals from NASA’s MODIS (Moderate Resolution Imaging Spectroradiometer) has been formally adopted for the NASA CERES (Clouds and the Earth's Radiant Energy System) project. The CERES products include vertical profiles of radiation in the atmosphere and at the surface computed using our assimilation results. Collins gave an invited presentation on the effects of aerosols on the coupled climate system at the International Radiation Symposium in August 2004.

Andrew Gettelman, in collaboration with Steve Massie (ACD), Douglass E. Kinnison (ACD), Cora Randall (University of Colorado, CU), and Michael Mills (CU), has been pursuing several avenues to modify and improve the representation of thin clouds in global models. Most of the efforts center on thin cirrus clouds in the upper troposphere. This work includes multi-scale modeling validated with aircraft and satellite observations from detailed box and process models to global models. First steps this year have included detailed satellite validation and preparation for using large data sets. One aspect includes adding supersaturation to global models starting with the Whole Atmosphere Community Climate Model (WACCM) in an investigation of the impact of water vapor changes on climate and chemistry of the upper troposphere and stratosphere. Another avenue of investigation is understanding model representations of polar mesospheric clouds (PMC's) and developing a climatology of them in WACCM.



This figure shows the distribution of clooud ice mass mixing ratio (or ice water content) in Polar Mesospheric Clouds

(PMCs) around the south pole at 86km from the WACCM3 GCM. The plot is a instantaneous snapshot from a model simulation. PMCs form at the cold summer mesopause, and due to a combination of mesospheric cooling due to antropogenic greenhouse gases and increases in water vapor at the mesopause (also due to an anthropogenic greenhous gas- methane), these clouds are sensitive indicators of climate change, and possibly also solar cycle influences on climate.

Hack and Truesdale have completed development of the second generation of the single column model version of the NCAR Community Atmosphere Model, SCAM. The entire software package, including the redesigned Graphical User Interface (GUI), has been fully incorporated in the CAM development library. As such, the SCAM is now routinely distributed as a part of the CAM3, where maintenance responsibility has been transferred to the NCAR CCSM Software Engineering Group (CSEG) and the CCSM Atmospheric Model Working Group (AMWG) liaison.

With help from NCAR initiative funding, Hack and Caron have accelerated the development of a more comprehensive turn-key diagnostic framework to support process studies using the SCAM. The initial focus has been on the examination and improvement of the diurnal representation of warm season convection over the southern central great plains. This work exploited the infrastructure investment that allows for routine high-temporal regional sampling of state and process behavior in the global CAM. This data can also be used to force the single-column version of the respective CAM physics package in order to allow more detailed investigations of process behavior. Initial work documenting the processes involved in regulating moist convection focused on the CAM3 physics package near the ARM Southern Great Plains (SGP) observational facility. CAM3 convection is much more vigorous, is much less persistent throughout the day, and the maximum in convective precipitation rate occurs later in the day. The cloud field is also quite different, with a nighttime maximum in total cloud cover and considerably more lower tropospheric liquid water cloud throughout the day. We also note that the surface forcing is quite different in the new model, where the latent heat flux plays a much greater role in the total surface turbulent heat flux. Experiments to isolate and understand the role of cloud and land surface improvements to the model in altering the behavior of the diurnal cycle have been conducted.

High-resolution configurations of the spectral dynamical core version of CAM3 are extremely expensive to run in terms of computational resources. The principal reason for this is related to the inability to sub-cycle the dynamics calculation, i.e., the physics and dynamics computations are tightly linked to each other, and the dynamics is strongly constrained by Courant-Friedrichs-Lewy (CFL) linear stability requirements. Hack, Williamson, and James Rosinski (CMS) explored ways to decouple the physics and dynamics time steps, as is done in the two-time-level, finite-volume version of the atmosphere. The goal is to identify a suitable strategy for implementing such a decoupling without exciting the computational mode associated with the three-time-level scheme employed by the spectral dynamical core . Hack, Williamson, and Rosinski have also revived the reduced-grid form of the spectral model and are in the process of testing the configuration at multiple resolutions. This configuration of the model will save approximately 25% in computer time. The hope is that this configuration will allow efficient exploration of resolution parameter space up to the equivalent of a T341 spectral truncation if computational resources can be identified.

Work over the last year continued to confirm the results of previous studies, which demonstrated a strong simulation sensitivity to horizontal resolution. Strong sensitivities to horizontal resolution of time-mean features of the simulation are observed, like extratropical cloud forcing, as well as transient behavior and climate sensitivities. Similar sensitivities are also seen to the choice of dynamical cores. Hack, Caron, Truesdale, and Williamson are working with Jeffrey Kiehl (CCR) and Cecile Hannay (CCR) to better understand the reasons for this behavior.

Rasch has been working on the diagnosis and understanding of relatively short time scale phenomena associated with variations in cloud processes. This work, in collaboration with Aiguo Dai (CAS), Lucrezia Ricciardulli (Remote Sensing Systems), Rob Wood (University of Washington), and Patrick Minnis (NASA Langley), has focused on understanding diurnal variability and partitioning between convection and stratiform cloud processes radiation and precipitation properties. Rasch and Ben Johnson (NCAR Advanced Study Program ASP) have also collaborated on the development of a new formulation for cloud fraction based on probability distribution functions for subgrid-scale variability of clouds.

Rasch is also collaborating with Kerry Emanuel (Massachusetts Institute of Technology, MIT) on the exploration of alternate formulations of parameterized convection for climate modeling, and the impact of these alternate formulations on the distribution of tracers. Two schemes in particular, the Emanuel convection scheme and the Kain/Fritsch convection scheme, are now working in the context of both SCAM and CAM.

Rasch, in collaboration with David Mitchell (Desert Research institute) and Paul Lawson (SPEC Incorporated, Boulder), worked on new formulations for ice particle formation, sedimentation, and cloud optical properties. New formulations have been proposed for each of these processes, based on measurements in a number of field campaigns, including bimodal size distributions representative of both tropical and midlatitude cirrus regimes.

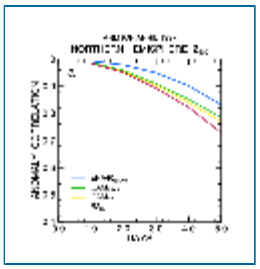
Rasch, in collaboration with Steve Ghan (Pacific Northwest Laboratory, PNL), worked on the development of a

prognostic cloud drop number density distribution for CAM that extends the formulations currently in use in CAM. These formulations allow a much improved representation for the first and second indirect effect of aerosols on cloud radiative and precipitation properties.

Rasch, in collaboration with Natalie Mahowald (TSS) has been working on improving representations of dust and sea salt. Others involved in this scientific work include Chao Luo (University of California, Santa Barbara) and Tami Bond (University of Illinois), who are focused on carbonaceous aerosol emissions, and their space and time evolution particularly from Asia. A major emphasis of this work is understanding the sensitivity of aerosols to scavenging and the interaction of scavenging and cloud precipitation processes.

Rasch, Boville, and James McCaa (CMS) have been exploring the Finite Volume (FV) version of CAM in coupled and uncoupled simulations with the goal of moving it closer towards becoming the next generation CCSM. The focus has been on exploring the differences in heat and moisture distributions in the FV version of the model, and its impact on the distribution of surface fluxes of heat and moisture. These differences subsequently effect the sea ice distributions in the coupled simulations. Formulations of form and wave drag, along with their impacts on the momentum budget and systematic biases in the simulated stationary wave structure, are also being explored.

Williamson and Jerry Olson (CMS) continue to work on developing the capability to apply CAM3 in forecast mode. The objective is to gain insight into errors in parameterizations by directly comparing parameterized variables, such as clouds and precipitation, early in the forecasts with observations from field campaigns. They are working in collaboration with scientists from the Program for Climate Model Diagnosis and Intercomparison at Lawrence Livermore National Laboratory (PCMDI/LLNL), and the project has been labeled the Climate Change Prediction Program (CCPP)-ARM Parameterization Testbed (CAPT). Their approach is to run CAM in forecast mode using analyses or reanalyses from National Weather Prediction (NWP) centers for recent years. By using analyses from several centers, information becomes available on the sensitivity of the parameterized variables to the initial conditions. Parameterization and the Community Land Model (CLM) initial conditions are obtained by spinning up the land and parameterized atmospheric variables to be consistent with the evolution of the analysed atmospheric state variables. They established that, for the large scales contained in climate models, the forecasts are actually comparable to operational NWP forecasts as demonstrated using skill scores. This is important to demonstrating that the parameterizations under investigation are not being driven by grossly incorrect atmospheric states. Several other in-depth studies of the CAM for several ARM Intensive Observing Periods (IOPs) have been completed and can be found at http://www-pcmdi.llnl.gov/projects/capt/publications.php.



This figure shows the anomaly correlations for forecasts with CAM and with reanalyses models. It illustrates that the CAM forecasts of the large scales are comparable to those from the operational NWP models used to produce the reanalysis. The green and yellow curves are from CAM2 starting from ERA40 and NCEP R2 reanalyses respectively. The blue and red curves are form the ECMWF and NCEP models used to produce the ERA40 and NCEP R2 reanalyses respectively.

Williamson continued to organize a coordinated Aqua-Planet Experiment (APE) under the auspices of the Working Group on Numerical Experimentation (WGNE) with Richard Neale (NOAA Climate Diagnostics Center), Brian Hoskins and Mike Blackburn (University of Reading), and Peter Gleckler (PCMDI/LLNL). The project is intended to provide a benchmark of current model behaviors, and more importantly, to stimulate research to understand the cause of differences arising from different models, different subgrid-scale parameterization suites, different dynamical cores, and different methods of coupling the two. Groups that have announced their intention to participate to date include the UK Meteorological Office, the Australian Commonwealth Scientific and Industrial Research Organization (CSIRO), the Department of Numerical Mathematics, Russian Academy of Sciences (DNM), GFDL, NASA GSFC, the Institute of Atmospheric Physics at the Chinese Academy of Sciences (LASG), Frontier Research System for Global Change, the European Center for Medium Range Weather Forecasts (ECMWF), NCAR, the Centre for Global Atmospheric Modelling, University of Reading (CGAM), the Main Geophysical Observatory, St. Petersburg, Russian Federation (MGO), and the Institut fur Physik der Atmosphere, Universitat Mainz, although not all have run the experiments and

submitted data. Details of APE can be found at the APE Homepage. Williamson and Olson have carried out the standard APE experiments with CAM3 and submitted the data to PCMDI. They have also carried out a variety of experiments in addition to the standard APE experiment to determine the affect of resolution, parameterization tuning, dynamical core, and time step on the aqua planet simulations. They are just beginning to examine these experiments, but have already discovered a very intriguing low-frequency wavenumber five mid-latitude phenomenon in the aqua-planet simulations.

Climate Research

Using observations from aircraft and global chemical and climate models, Gettelman, in collaboration with Kinnison, Timothy Dunkerton (Northwest Research Associates, NWRA) and Guy Brasseur (Max Planck Institute for Chemistry, Hamburg), has examined in detail the transport characteristics of the Asian monsoon complex on the upper troposphere and lower stratosphere. This work is continuing by incorporating observations from satellites. He has also proposed specific satellite validation activities surrounding the Asian monsoon in conjunction with colleagues at University of Colorado and in Japan.

Hack and Caron, in collaboration with Kiehl, have applied the Microwave Sounding Unit (MSU) channel 2 temperature retrieval technique to three different global climate models: CSM1, Parallel Climate Model (PCM), and CCSM3, to quantify the extent to which stratospheric temperature trends contaminate tropospheric temperature retrievals. The modeling results confirm earlier hypotheses that the channel 2 MSU retrieval of tropospheric temperature trends is likely to be significantly contaminated by the stratospheric cooling trends, a signature of global warming in response to increasing levels of greenhouse gases. A recent retrieval algorithm proposed by Qiang Fu (University of Washington) does a very good job of eliminating this contamination and accurately capturing the true middle-tropospheric temperature trend. The results suggest that the technique is quite robust, and produces similar ratios of tropospheric warming to surface warming when compared with what has been derived from the observational record by Fu and colleagues.

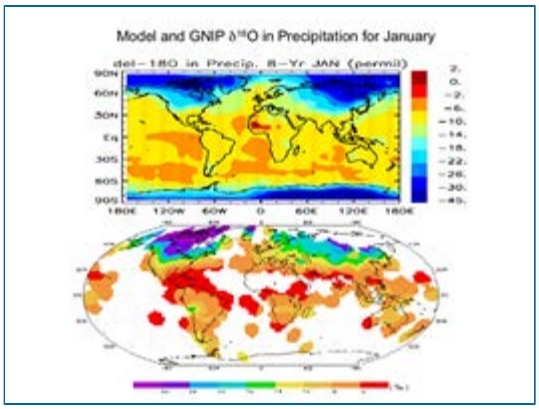
Climate and Chemistry

Rasch, in collaboration with Mahowald, Williamson, and Lin, has developed a suite of tests in CCSM for understanding the mechanisms that affect trace constituent distributions in the atmosphere. These constituents provide a framework in which changes to CCSM and CAM can be evaluated with respect to relevant problems in chemistry, biogeochemistry, and climate. An ozone-like constituent is used for studying differences in the stratosphere-troposphere exchange. Emissions similar to those of CO_2 from the neutral biosphere provide an important test of the rectification associated with correlations between transport and sources and sinks with strong diurnal and seasonal variation.

Rasch has been working on mechanisms for convective transport of chemical species in collaboration with Mark Lawrence (Max Planck Institute for Chemistry in Mainz). They have shown that two formulations (bulk and ensemble formulations) used to represent convective transport can have a significant effect on subsequent tracer evolution in atmospheric models. These formulations have historically been viewed as equivalent in the meteorological community. This work has shown that the assumptions of equivalence of formulation is not true for many important constituent distributions in the atmosphere, and that it is important to acknowledge and attempt to understand these differences in the picture of atmospheric convection.

Rasch has been collaborating with Peter Hess and Francis Witt of ACD on the development of an offline transport modeling capability for CAM. The intention is to produce a model that can replace the Model of Atmospheric Transport and Chemistry (MATCH) and the Model for OZone And Related chemical Tracers (MOZART) offline transport models, and allow the CCSM to be used for a variety of new chemistry/climate transport problems.

A multi-pronged investigation of the isotopic composition of water in the atmosphere has been extended in the past year. Gettelman, in collaboration with Christopher Webster (NASA-Jet Propulsion Laboratory), David Noone (CU), Andrew Dessler and Sun Wong (University of Maryland), and Mahowald, has extended an analytic model of the tropical tropopause layer to include isotopes of water and compared against observations of isotopes from in-situ aircraft. The agreement is quite good, indicating that the observations can be explained using existing isotopic physics. This group has been working as part of a team with university collaborators to put isotopes in the CCSM. The atmospheric portion of this work is nearly complete. Isotopes will also be integrated into WACCM. As part of this work, Gettelman and Mahowald coordinated a workshop on “Isotopes in the Earth System” at NCAR in January 2004, which brought in 25 international experts on modeling isotopes.

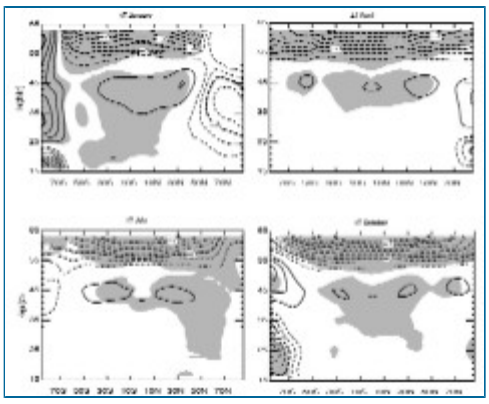


This figure shows the monthly mean Oxygen-18 isotopic composition of precipitation from CAM3 with isotopes (top panel) and from the GNIP observations database for January. The model reproduces the basic features, with more depleted air at higher latitudes, and over continents. This correspondence makes the model useful for paleoclimate studies and comparisons to ice cores.

WACCM Development

Boville and Fabrizio Sassi (CMS) have worked closely with ACD and the High Altitude Observatory (HAO) colleagues toward the implementation of interactive chemistry and of a solar module in WACCM. Implementation of the interactive chemistry includes the in-line calculation of heating rates to 120 nm, which has been led by Kinnison in ACD. This extension to WACCM is now completed, and a study investigating the effect of interactive ozone chemistry in stratosphere has been presented at the 3rd Stratospheric Processes And their Role in Climate (SPARC) General Assembly by Sassi and will soon to be submitted for publication. In collaboration with Raymond Roble (HAO), the solar cycle module has now been tested and will be ready shortly.

A large number of scientific studies using WACCM are now well underway or completed. They include impacts of El Niño/Southern Oscillation (ENSO) on the middle atmosphere (Sassi, Kinnison, Boville, Rolando Garcia (ACD), and Roble), seasonal variability of trace species in the Upper Tropospheric-Lower Stratospheric region (Mijeong Park (Seoul National University), Kinnison, Boville, Garcia, and W. Choi (Seoul National University)), stratospheric influence on seasonal cycles of tropospheric tracers (Cynthia Nevison (ACD), Kinnison, R. Weiss (Scripps Institution of Oceanography)), monsoon impacts on stratosphere/troposphere exchange (Gettelman, Kinnison, Dunkerton, and Brasseur (MPI-Hamburg)), parameterization of gravity wave fluxes due to convective excitation (Jadwiga Beres (ASP), Boville, Garcia, Sassi), stratospheric trends in temperature and water vapor (Daniel Marsh (ACD), Garcia, Kinnison, and Sassi), chemical transition across the extratropical tropopause (Liwan Pan (ACD), J Wei (Goddard SFC), Kinnison), structure and variability of the SE Asia monsoon system (Park, William Randel (ACD), Kinnison, and Garcia), and the effect of interactive ozone chemistry in simulations of the middle atmosphere (Sassi, Boville, Garcia, and Kinnison).



This figure illustrates the temperature difference between two 20-year simulations of WACCM3. Ozone is fully interactive in the first simulation. A zonal mean and monthly mean ozone climatology is constructed from the interactive simulation. This ozone climatology is used for the radiative heating rate calculations in the second simulation. The temperature difference is for the fully interactive minus the not-interactive ozone simulation. Contour interval is 1 K. Shading indicates the regions where differences are statistically significant at least at the 90% level, based on a t-test with 20 degrees of freedom.

With the help of software engineers Stacy Walter (ACD) and Jeff Lee (CDP) and other members of the WACCM

development team, plans to release to the community WACCM version 3 around the beginning of 2005. Work to study the effects of the solar cycle on the middle atmosphere, and to explore improvements to tropical wave variability (in collaboration with Ricciardulli), is also underway with the new version of WACCM.

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Geophysical Statistics Project Narrative

The mission of the Geophysical Statistics Project (GSP) is to encourage the application of statistical analysis and the development of new statistical methods in the geophysical sciences. To fulfill this goal GSP must also be engaged in basic statistical research including mathematical statistics and probability theory. Although GSP is administered through the Climate and Global Dynamics Division, this project is an NCAR-wide effort, and the research reported in the following sections reflects this breadth of scientific collaboration across the Center's divisions. A large part of GSP's impact is through multi-year projects with substantial scientific involvement. For this reason many of the research results below are based on efforts continuing from last year's report. Project leadership is provided by Douglas Nychka (GSP). Co-Principal investigators for the project are Richard Katz (Environmental and Societal Impacts Group, ESIG), Joseph Tribbia (Climate Dynamics and Predictability, CDP) and Jeffrey Anderson (Data Assimilation Initiative, DAI).

Spatial and Spatio-Temporal Processes

Multiresolution covariance models

Tomoko Matsuo (GSP/DAI), in collaboration with Nychka, has developed a parametrization for a family of covariances based on a wavelet representation and implemented an algorithm to estimate the covariance from irregularly sampled spatial data. Flexible classes of nonstationary covariance functions are important for the analysis of historical climate data or atmospheric soundings, sparse measurements of the upper atmosphere, and as a background (or prior) covariance in data assimilation. The basic idea behind a wavelet representation is that the random field is a composition of basis functions with localized support multiplied by random coefficients. The main contribution of this modeling project is the construction of a covariance among the wavelet coefficients that is much simpler than the covariance of the original field, can be adaptive over space, and has many zero elements. One result of this project is a statistical parametrization of the square root of the coefficient covariance matrix (H) that can accurately approximate the shape/scale Matern family of one dimensional covariances. Preliminary results also suggest that this parametrization can be extended to a two-dimensional family including anisotropy. The sparsity of the H matrix makes it possible to compute the likelihood of the

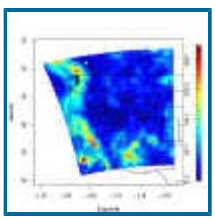
covariance efficiently for large spatial datasets using sparse matrix algorithms. Moreover, a Monte Carlo Expectation/Maximiation (EM) algorithm has also be shown to work for irregularly sampled data. Here the E step is accomplished using conditional simulation from the spatial model to estimate the missing values of the field on a regular grid. The M step takes advantage of fast wavelet algorithms for regular grids, and unlike Fourier techniques, does not require tapering at the boundaries.

Precipitation Extremes

Daniel Cooley (GSP and University of Colorado), in collaboration with Ulrike Schneider (GSP) Linda Mearns (ESIG), and Philippe Naveau (University of Colorado), is developing statistical models to characterize the spatial distribution of extreme rainfall. The behavior of univariate extremes can be easily modeled parametrically, but little is known how the univariate distribution can vary over space. In addition, no parametric model exists to describe the family of multivariate extreme value distributions. This problem is exacerbated when considering processes of extreme values, such as a field of annual maximum precipitation across a region.

As a joint project with ESIG, new statistical methodology is being developed for extreme precipitation data from Colorado's Front Range. The goal is to improve on methods currently in use by the United States Weather Service in the construction of regional precipitation atlases. A Bayesian hierarchical model is proposed in which the parameters of the extreme value distribution at each location are spatially dependent and possibly dependent on other covariates (such as the annual precipitation, slope and elevation). From this model one obtains a spatial prediction of precipitation return levels, along with ensemble-based measures of uncertainty. Another data motivated project arises from regional climate model (RCM) experiments. Unlike observational data, the RCM output is a complete field, but due to limited computing resources, does not cover a long period of time. The goal is to quantify the extreme behavior of the RCM simulations of daily precipitation based on statistical extreme value distributions. One important scientific issue is how extremes change according to the spatial scale of the output grid. Preliminary results for the Pacific Northwest Laboratory (PNL) RCM, forced by the NCAR Parallel Climate Model, show coherent spatial patterns of return levels for simulations of current climate.

Some theoretical questions related to spatial dependence extremes have also been investigated. Spatial dependencies are often modeled with the variogram; however, use of the variogram requires that second moments be finite, which is often not the case with extreme value distributions. However, the madogram (an L1 version of the variogram) only requires that first moments be finite, and it also has convenient relationships with maxima. Preliminary results suggest that the madogram can be used to estimate spatial dependence parameters for fields of stationary max-stable random fields.



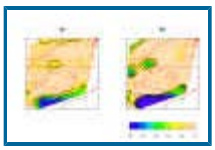
This figure shows the estimated 50-year return levels based the PNL RCM simulation of current climate. The 50-year return level is the value that has a 1/50 probability of occuring in a given year and is estimated for each grid cell of the RCM model grid. These quantiles

were found by fitting a generalized Pareto distribution (GPD) using maximum likelihood to the grid cell time series. To reduce the variability of estimating the GPD parameters across the grid, a local smoothing approach was taken. For a given location a local likelihood was used that weighted the log likelihood of the central grid cell by 1/2 and the log likelihoods of the neighboring grid cells by 1/8. Maximizing this criterion results in more stable parameter estimates across space.

Determining Extremes in Daily Ozone

Eric Gilleland (Research Applications Program) and Nychka have studied the problem of estimating the spatial field comprising the ozone standard proposed by the United States Environmental Protection Agency (EPA). The standard for an ozone monitoring station is an extreme order statistic (fourth highest) of the daily ozone averages observed over the summer season. When the fourth highest daily average (FHDA) exceeds 84 parts per billion, EPA deems that air quality standards have been violated. This is a nonlinear statistic that has different spatial structure from daily ozone measurements and is possibly not normally distributed. Despite these difficulties, the goal is to estimate the spatial field of the standard at unmonitored locations.

In this period previous work was extended to include a spatial model for the tail of the daily ozone distribution. A generalized Pareto distribution (GPD) was used to model ozone extremes as a function of spatial. Here the region had a common shape parameter, and the scale parameter varied according to a spatial model. To reduce the complexity of the model, the spatial covariance for the GPD scale was thin-plate spline model. The posterior modes for the GPD parameters have been determined for the North Carolina study region during the 1997 ozone season. Given the GPD distribution one can calculate the probability that a given location will have an FHDA statistic exceeding 84. The probability surface estimated through this model is very similar in structure to a spatial analysis obtained by a space-time model applied to the daily ozone measurements (These results are reported in the 2003 GSP Annual Science Report.). The fact that an extremes approach agrees with a more conventional space time model is surprising and reinforces the credibility of each method.



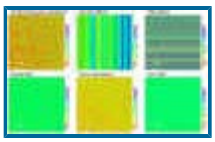
This figure summarizes the probability of the FHDA ozone statistics exceeding 84 PPB based on two statistical methods and estimated from monitoring data for 1997. The right image is based on a space-time model for daily values and the distribution of the FHDA statistics is inferred using a Monte Carlo conditional simulation. The left image is the probability of exceedance based on a generalized Pareto distribution where the scale parameter is allowed to vary smoothly over space.

Regression and Classification

Analysis of microarray data

Reinhard Furrer (GSP) and Stephan Sain (University of Colorado at Denver) applied techniques based on sparse matrix methods for tapered covariances to genomic microarray data. This is a technology transfer project that showcases the use of methods developed for large geophysical datasets to an important area in the life sciences. Microarrays are an array of DNA or protein samples that can be hybridized with probes to

study patterns of gene expression. They provide a powerful assay to determine how a large number of genes within a cell interact with each other. Typically, a single microarray includes over 400,000 individual observations, too much data for classical analysis techniques. To estimate the effects of different genes, it is appropriate to use a statistical mixed model with a random spatial component. Tapering the covariance matrix in statistical calculations is known to be an accurate approximation and makes the analysis feasible. By taking advantage of the sparse nature of such tapered covariance matrices, back-fitting is used to estimate the fixed and random model parameters. Results are demonstrated on an experiment using microarrays to build a profile of differentially expressed genes relating to cerebral vascular malformations, an important cause of hemorrhagic stroke and seizures. This approach can also be applied to other problems in the environmental and biological sciences that involve the analysis of large and spatially structured data.



This figure illustrates the decomposition of log gene expression of a single microarray. Each pixel in these images represents a single location on the microarray, and images decompose the response into an overall mean, column and row effects, a spatial field, the gene expression itself, and a remaining error field. Here the spatial field is seen to represent a large amount of the variability compared to the error field.

Stochastic Multiresolution Models for Turbulence

This project is a collaboration among Brandon Whitcher (formerly of GSP, now with GlaxoSmithKline), Jeff Weiss (University of Colorado at Boulder), Thomas Lee (Colorado State University, CSU), and Curtis Storlie (CSU). With the current state of computing technology, it is relatively straightforward to generate high-resolution numerical integrations of the Naiver-Stokes (N-S) equations, the fundamental physical equations that describe (nonreactive) fluid motion. One feature in the simulation of geophysical type fluids is the presence of eddies and vortices. It has become of interest in the past five years to describe these coherent structures (i.e., the number, size, shape, amplitude of vortices), and our goal is to formulate a statistical model for these structures. The initial statistical problem is to segment the time slices from a numerical simulation of turbulence to reliably identify vortices. The statistics estimated from the vortices allow one to verify some of the assumptions made by Weiss and James McWilliams (University of California at Los Angeles) in the derivation of scaling arguments. The vortex field (vorticity is the curl of velocity) is decomposed as a sum of individual models for the vortices where the individual modes use a multi-resolution basis. This model for the field is formulated as a multivariate multiple linear regression in the wavelet domain, and individual vortex models are isolated through a model selection strategy. The identification procedure depends on the usual kind of truncation ideas in wavelet regression and has been implemented on a parallel computer architecture to make analysis of a reasonable numerical experiment feasible. The amount of truncation is determined by generalized cross-validation, in which the number of effective parameters is obtained via a thresholding rule.

A second problem is to use sequences of images to track the movements of vortices. A novel likelihood-based approach is currently being investigated that allows for the birth, death, and emerging of vortices. Results from small-scale numerical experiments demonstrate the promising empirical properties of this new approach. Future research

focuses include the studies of (i) the empirical performance of the approach for large scale tracking problems, and (ii) the statistical properties of the estimated movements of the vortices. Several scientific goals from this extension are to quantify the interactions among vortices in simulations of turbulence and to track storms and eddies from more realistic numerical experiments for the atmosphere and ocean.

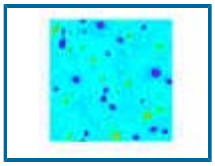


Figure 1

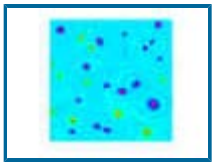
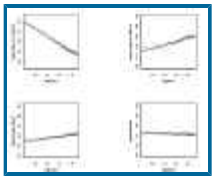


Figure 2

These two figures (figure 1 and figure 2) are snapshots of the vorticity field from a simulation of 2-d quasi-geostrophic flow taken at two different times. The statistical problem is to readily identify the vortices in this image as distinct coherent elements and to track the movements of the identified coherent elements. The crosses mark the locations of all the detected structures and agree with a subjective visual inspection of the images.



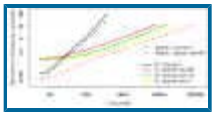
This figure summarizes the properties of vortices from different time slices of a numerical simluaton of 2-D turbulence. Here the vortices have been identifed from the vorticity field using the methods illustrated in the previous figures. From scaling arguments one expects that the number of vortices, the average vorticity (circulation), the average radius, and the maximum vorticity to have a linear relationship when the variable and time are logged. The empirical slopes of these linear relationships are useful for characterizing dynamics due to coherent structures such as vortices.

Statistical Computing

The KriSp package for large spatial datasets

Furrer has written a package called 'KriSp' (**Kri**ging with **Sp**arse matrices) for the high-level language R. The functions are based on similar methods and classes of the well-established package 'fields' (Nychka, et al.). The package allows one to handle large spatial prediction problems where observations occur at irregular locations. The approach is to introduce sparsity in the covariance matrix by tapering with a compactly supported (positive definite) kernel (e.g., one finds the direct product of the covariance matrix and the tapering matrix). Although this technique is common in atmospheric data assimilation, it is not well used in general. The theoretical background was established in the previous year stating that, given the correct choice of a taper (e.g., matching the tail behavior of the spectral density of the covariance function), the approximation is asymptotically optimal. The potential speedup, based a sparse approximations and implemented KriSp, is striking suggesting that a spatial prediction (Kriging) can be computed for several thousand points interactively in the R environment. Also, the tapering approximation is quite accurate

sacrificing little statistical efficiency compared to the exact calculation.



This figure is an example of the computational time for the key step in a spatial prediction problem. Different lines indicate the time for solving ten linear systems for a 1-d Kriging problem based on two different high-level languages (Matlab and R) and different levels of tapering. For the R package the time difference between the exact solution verses using a tapered, sparse approximation is more that a factor of 100 for 1000 spatial locations.

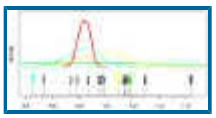
This figure is a copy of the KriSp homepage and gives downloading instructions and a concise tutorial.

Model Validation and Synthesis

Combining multi-model regional climate projections

This project is a collaboration among Furrer, Nychka, Sain, and Tom Wigley (Climate Analysis Section). The objective is to develop a Bayesian mixed effects model to combine the results of different climate model simulations and quantify the uncertainty. This research is in the context of synthesizing the numerical experiments from different climate modeling centers in a way that produces credible probabilistic forecasts of future climate change. The novelty of this approach is the use of gridded, high-resolution data within a spatial framework, and is a generalization of Claudia Tebaldi's (ESIG) former work (with collaboration with Mearns, and Richard Smith, University of North Carolina). This single hierarchical Bayes model can be used to quantify uncertainty of atmosphere-ocean general the circulation model's (AOGCM) responses on different scales, from regions of several hundred miles up to continental size. A pilot dataset used for this work is the set of 16 AOGCM experiments runs contained in the SCENGEN/MAGICC (A Regional Climate Scenario Generator/Model for the Assessment of Greenhouse-gas Induced Climate Change) package and has a resolution of 5 x 5 degrees.

The posterior distributions are obtained with computer-intensive Markov Chain Monte Carlo (MCMC) simulations with present and future mean temperatures from the periods 1971–1990 and 2031–2050. Preliminary results suggest that the AOGCM results are quite heterogeneous to the extent that spatial models for the model disagreement have significant nonstationary and possibly non-Gaussian components. It is planned to switch to the new high-resolution data used for the Fourth Intergovernmental Panel on Climate Change report and to extend the model to the bivariate case (temperature and precipitation). The coding of this model in the R statistical language will facilitate the use of these methods by a wide audience.



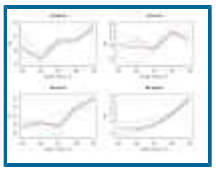
This figure gives posterior density estimates of the 20-year average temperature climate

change between 2031–2050 and 1971–1990 of a 5 x 5 degree region centered in eastern Colorado. The red curve represents the posterior density of mean climate change synthesize from all 16 models and borrowing information from adjacent grid points. The tick marks locate the actual differences for the models, the "data" for this grid box. As an example, the light blue (CAR Climate System Model) and yellow (ECM4) are the posterior densities for two models.

Parameter estimation for intermediate climate models

This project is collaborative research among Chris Forest (Massachusetts Institute of Technology, MIT), Bruno Sanso (University of California at Santa Cruz), Nychka, Tebaldi, and Dorin Drignei (GSP) and is intended to revise the method for estimating the uncertainty in climate system properties from Forest, et al. (2002). From a statistical point of view, the goal is to estimate the parameters of a nonlinear regression model where the regression function is expensive to evaluate and the response has correlated errors. Some of this work draws on the design and analysis of computer experiments, but has the additional complexity that a run of the climate model only yields a realization of the climate and so contains some sampling error. To apply a fully Bayesian approach, we first approximate the response of the MIT intermediate climate model with a statistical model that provides a response surface in the uncertain parameter space. The three-dimensional parameter space is defined as climate sensitivity (CS), rate of deep-ocean heat uptake (KV), and the net aerosol forcing (FA), and covers the three major uncertain quantities that affect the ability to simulate accurately the 20th century climate record. The availability of this response surface permits one to sample the joint posterior distribution of the parameters using a MCMC technique. This approach facilitates the testing of methodologies for performing a more computationally intensive project using the complete MIT climate model, which is infeasible with current computer resources. Currently, the choice of parameters to evaluate the climate model is not driven by knowledge of the regression response surface. This statistical approach would lead to computational designs that specify a minimal number of physical parameter vectors required to achieve a desired precision of the parameter estimates.

Previous work has used an error covariance estimated from long control runs for all other combinations of the above physical parameters. It is possible that the error covariance is dependent on these parameters and a better approach would be to construct a global statistical model that allows the error covariance to vary as a function of the climate model parameters.



This figure is an example of output of temperature change from MIT model and the interpolated temperatures, showing the performance of the interpolation algorithm. The plotted quantity is surface temperature change, averaged over 4 zonal bands (4 plots), and 5 decades (along the x-axis of each plot). Black solid line, MIT model ensemble mean, dashed lines individual ensemble members, red line interpolated temperatures. This specific case corresponds to the setting CS=0.5° C, KV=40cm^2/s and FA=-0.5 W/m^2

Oceanography Section Narrative

The mission of the Oceanography Section (OS) is to understand the large-scale ocean circulation and the dynamics of climate through studies of the important processes in the ocean and sea-ice, in air-sea-ice interactions, and in coupled systems.

Global Ocean and Sea-Ice Modeling

Every member of the OS has spent a large fraction of their time on work towards the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). This includes the final parameter choices that went into defining the IPCC version of the Community Climate System Model, Version 3 (CCSM3) and executing the many integrations at various computing centers. Most important, however, is the analysis of these integrations and writing of papers for a special issue of the *Journal of Climate* dedicated to CCSM3. The papers in preparation are:

- *Attribution and implications of upper ocean biases in CCSM3* by William Large (OS), Gokhan Danabasoglu (OS), and Ilana Wainer (Universidade de Sao Paulo, Brazil). The specific purpose of this work is to expose some of the largest and potentially most important upper ocean biases in the CCSM3 fully coupled simulation of the present day climate. These biases include not only sea surface temperature (SST) and sea surface salinity (SSS), but also the mean and seasonal cycle of equatorial temperature, salinity, and velocity. Of particular interest are attribution and impact determinations. Biases that are merely the end product of cumulative forcing and model errors and that do not feedback into the large scale, multi-component solution are perhaps tolerable, and less of a priority than those that significantly impact extensive elements of the solution.

- *Diurnal coupling in CCSM3* by Danabasoglu, Large, Joseph Tribbia (CDP), Peter Gent (OS), and James McWilliams, University of California, Los Angeles (UCLA). The primary purpose of this work is to evaluate the standard, once-a-day air-sea coupling implemented in the CCSM3 relative to possible alternatives. These alternatives include one-hourly and three-hourly coupling, as well as an idealized diurnal cycle parameterization, which distributes the daily net solar radiation received from the coupler over a day. With this scheme the ocean model is still coupled once a day. The short wave heat flux is zero between 6 p.m. and 6 a.m., and in between it follows a cosine function attaining its peak value at noon. The paper documents the effects of these alternatives on the coupled model drift, deep cycle turbulence, rectification of SST, the atmospheric mean state, and El Niño Southern Oscillation (ENSO) variability. It is demonstrated that the idealized diurnal cycle significantly reduces the cold bias in the equatorial Pacific and improves the ENSO variability.

- *Thermocline and deep ocean ventilation during the 20th Century in the CCSM3* by Gent, Frank Bryan (OS), Danabasoglu, Keith Lindsay (OS), Daisuke Tsumune (OS), a visitor from the Central Research Institute of Electric Power Industry (CRIEPI) in Japan, Matthew Hecht, Los Alamos National Laboratory (LANL), and Scott Doney, Woods Hole Oceanographic Institution (WHOI). An assessment of the ocean component is performed by evaluating the ventilation rate of the thermocline and deep-ocean in simulations of the 20th Century. An ensemble of these simulations from 1870–2000 has been made with the CCSM3 using the best estimates of

solar, volcanic, and greenhouse gas forcing variations over the 20th Century. Results from the ocean component are compared to observations from the second half of the 20th Century. These comparisons include the uptake of chlorofluorocarbon (CFC) and heat, changes in ocean salinity, and sea level.

- *Transient response of the thermohaline circulation and ocean ventilation* by Bryan, Danabasoglu, Tsumune, and Nori Nakashiki (CRIEPI). This work concentrates on the response of the thermohaline circulation (THC) to the transient climate forcing, primarily focusing on the dominant physical processes affecting the THC. The effects of the atmospheric resolution on the strength and variability of THC are also considered. The ideal age tracer is used to analyze how the changes in ventilation relate to the THC changes. Implications of the ventilation rate changes on CO_2 uptake are also discussed.

- *The low resolution version of CCSM3* by Stephen Yeager (OS), Christine Shields (CCR), James Hack (CMS), and Large. A description of the new developments and the accompanying (coupled and uncoupled) control simulations of the low resolution ocean component of CCSM3 is given. An assessment of these results is presented in comparison with those from higher resolutions versions. The primary focus is to determine if this low resolution version can address the needs of the paleoclimate, biogeochemistry, and climate change communities. The metrics include the overturning circulation of the North Atlantic, SST biases, equatorial circulation, and ENSO variability.

In addition, Gent and Danabasoglu have finished a study of heat uptake in the ocean component of the CCSM2. They used results from the 1000-year control run, the 1% per year increasing CO_2 run, and the doubled CO_2 run. They analyzed heat content changes in the upper 300 m and the upper 3 km and compared them to an analysis of ocean observations published by Levitus et al. in *Science* in 2000. They conclude that the rate of heat uptake is about right in CCSM2, and conclude that this supports the climate sensitivity value, which is quite low. They also documented a weak decline in the North Atlantic THC in the 1% CO_2 run, in a paper published in *Journal of Climate*.

Tsumune, Lindsay, Doney, Bryan, and Hecht have completed a study of the variability in the North Pacific using CFC ages and ideal age in a CCSM Parallel Ocean Program (POP) experiment with realistic forcing data from 1958 to 2000. The simulated CFC concentrations are in good agreement with World Ocean Climate Experiment (WOCE) observations in shallow layers. The CFC tracer ages are computed using the partial pressure approach and the ratio approach. The relationships of pCFC-11, pCFC-12 age, ratio age, and ideal age are as expected from previous studies by simple models. Temporal changes and the spatial distribution of the difference between these age measures have been described for the first time in a manuscript that is ready for submission.

Wanli Wu (OS), Large, Danabasoglu, and Gent are the co-investigators of the two funded Climate Process Team (CPT) proposals. These are highly collaborative projects bringing observationalists, process modelers, and modeling centers (NCAR, NOAA's Geophysical Fluid Dynamics Laboratory, GFDL, and NASA's Goddard Space Flight Center, GSFC) together. A goal is to expedite the incorporation of some new discoveries into the climate models. The funded proposals concern the deep gravity currents and entrainment with particular emphasis on their role in water mass formation, and hence, the THC, and the interaction between meso-scale eddies and mixed layers. Among the objectives are to develop new or modified parameterizations that can be reliably used in ocean models and to assess their impacts on the climate model simulations. The gravity current proposal should be particularly challenging for the CCSM3 z-coordinate ocean model. Wu has implemented a version of the Price and Baringer overflow model and obtained improvement in the representation of the Mediterranean Outflow. He has also implemented making the eddy parameterization coefficient depend on the buoyancy frequency, also with encouraging initial results.

High Resolution Ocean Simulations

A major effort in high resolution (0.1 degree) global ocean modeling in collaboration with oceanographers at CRIEPI, LANL, and the Naval Postgraduate School (NPS) continues using computational resources at the Earth Simulator in Yokohama, Japan. To address some of the biases that were observed in an initial control integration, an extensive series of sensitivity experiments surveying a broad range of parameter space has been carried out. A combination of anisotropic viscosity and an anisotropic generalization of the Gent-McWilliams (GM) eddy parameterization were found to provide the best representation of the Kuroshio region, ameliorating an unrealistically steady large meander off of the Japanese island of Shikoku. An unrealistic path of the North Atlantic Current has proven to be more difficult to correct. The adiabatic nature of the anisotropic GM formulation is an important element of preparing the high resolution model for long running climate simulations. Analysis and further experiments are ongoing to prepare an ocean component of a very-high resolution coupled climate system model.

Richard Smith (LANL) and Gent have developed an anisotropic generalization of the GM parameterization for eddy-induced tracer transport and diffusion in ocean models. They focus on its application in high-resolution eddy-permitting and eddy-resolving models, where it provides an adiabatic alternative to the more commonly used biharmonic horizontal diffusion operator. A series of numerical simulations of the North Atlantic Ocean are conducted at 0.2 degree resolution using anisotropic viscosity, anisotropic GM, and biharmonic mixing operators to investigate the effects of the anisotropic forms, and to isolate changes in the solutions specifically associated with anisotropic GM. They then conduct a high resolution 0.1 degree simulation using both anisotropic forms and compare the results with a similar run using biharmonic mixing. Modest improvements are seen in the mean wind-driven circulation with the anisotropic forms, but the largest effects are due to the anisotropic GM parameterization that eliminates spurious diapycnal diffusion and leads to significant improvements in the model THC. These improvements include the meridional heat transport, overturning circulation, and deep water formation and convection in the Labrador Sea. A manuscript on this work is about to be published the *Journal of Physical Oceanography*.

Ocean Biogeochemical Modeling

Oceanic biogeochemical processes, as they relate to the global carbon cycle and climate system, are being studied by Lindsay and external collaborators, including Doney, Jefferson Keith Moore, University of California, Irvine (UCI), and Mathew Maltrud (LANL). Two paths currently being pursued are: (a) global ocean biogeochemical and tracer modeling and, (b) the study of the relationship between the ocean carbon cycle and the global carbon cycle.

Work on (a) has primarily consisted of continued studies on the incorporation of alternative tracer advection schemes into the CCSM POP. This research is building on the experience of other ocean modeling centers, notably the Massachusetts Institute of Technology (MIT) and GFDL. The work is focusing on flux limited schemes that are based on the work of Peter K. Sweby. In the coming year alternative advection schemes will be evaluated on their performance on a variety of tracers, including the potential temperature and salinity, and passive tracers.

With respect to (b) above, a suite of multi-century, fully coupled, carbon-climate integrations has been performed using a modified version of the Climate System Model, Version 1.4 (CSM1.4). These experiments include a stable 1000 year pre-industrial control run and multiple 180 year historical and 100 year future scenario fossil fuel emissions experiments. These experiments are being analyzed to understand connections and feedbacks between the carbon-cycle and the physical climate.

Air-sea-ice Interactions

Analysis of the CCSM2 control integration has been performed to examine variations in the southern hemisphere ice cover. This is collaborative work between Marika Holland (OS), Cecilia Bitz (University of Washington) and Elizabeth Hunke (LANL). The dominant mode of ice variability exhibits a dipole pattern with positive anomalies in the Pacific associated with negative anomalies in the Atlantic. This variability compares well to the observations. The mechanisms driving this variability and the atmosphere and ocean conditions associated with this variability have been investigated. The influence of ENSO variability and the southern annular mode on variations in southern ocean sea ice extent and thickness have also been considered. A manuscript documenting this research is under review at *Journal of Climate*.

In related work, in collaboration with Richard Cullather (ASP, now at Lamont Doherty Earth Observatory, LDEO), an evaluation of the CCSM3 Antarctic sea ice simulation compared to observations has been performed. This includes an analysis of the simulated interannual variability. Additionally, an appraisal is performed by Cullather of the recently released European Center for Medium-Range Weather Forecasts (ECMWF) 40-Years Re-Analysis data set in Antarctic latitudes.

Work has continued to investigate mechanisms forcing the relatively high Arctic amplification simulated by the CCSM3 model. Sea ice model parameterizations which may affect the simulation of high latitude feedbacks are being assessed by Holland, Julie Schramm (OS), Bitz, Bill Lipscomb (LANL) and Hunke. More specifically, an evaluation of the influence of the sub-gridscale ice thickness distribution (ITD) on climate sensitivity is underway. The ITD parameterization has a significant effect on the simulated climate, and there are indications that this parameterization also enhances the albedo feedback by resolving thin ice categories that are easily melted away under a climate change scenario. A manuscript discussing the influence of the ITD on the simulated climate is in preparation for *Journal of Climate*.

Work is underway to determine the conditions and consequences of a seasonally ice-free Arctic Ocean. This involves collaborative research between Holland, Laurence Hamilton (University of New Hampshire), Gifford Miller (University of Colorado), Don Perovich (Cold Regions Research and Engineering Laboratory, CRREL), Bruce Peterson (Marine Biological Laboratory, MBL), and Gavin Schmidt (NASA Goddard Institute for Space Studies, GISS). Climate model projections suggest that the Arctic may become seasonally ice-free in the not too distant future (in approximately the next 100 years depending on the forcing scenario). However, there are many feedbacks, which may influence how and

when an ice free Arctic state is reached. Many of these, such as the potential for changes in Arctic Ocean stability to affect ice formation, are not well understood. For this study, evidence from multiple sources, including numerical model experiments, the instrumental record, process studies, and paleoclimate analogues, is used to develop a conceptual model of a seasonally ice-free Arctic system. Uncertainties in the projected climate state and processes that may lead to considerably different conditions are assessed. Additionally, the consequences that an ice-free Arctic state might have on socio-economic and biological systems are being explored.

In collaborative research between Hugues Goosse (University Catholique de Louvain) and Holland, the mechanisms forcing simulated interdecadal climate variability in the Arctic have been assessed from the CCSM2 control simulation. In previous studies a number of mechanisms have been proposed to explain natural climate fluctuations in the Arctic. These mechanisms and their interrelation were assessed within the context of the CCSM2. It was found that changes in ocean ice exchange and heat transport in the Barents Sea dominate in forcing the large-scale Arctic surface temperature variability. Changes in atmospheric circulation are consistent with a wind forcing of this variability, while changes in the THC are more weakly related. A manuscript discussing these results has been submitted to *Journal of Climate*.

The fresh water budgets of the Arctic Ocean, and the mechanisms that drive variability in the budget terms, including the transport of fresh water from the Arctic to the North Atlantic, are being investigated within the CCSM3 control integration. This work is a collaborative effort between Holland, and Joel Finnis and Mark Serreze of the University of Colorado (CU). The primary goal of this project is to explore the progressive integration of the impacts and processes of Arctic freshwater cycling on the local, pan-Arctic, and global scales. This includes the study of processes that modify the Arctic freshwater budgets in the terrestrial, atmospheric, and oceanic environments; the integration of these processes to produce the exchange of freshwater between the Arctic and North Atlantic; and ultimately, the influence of these processes on northern North Atlantic deep water formation.

Forcing of the Ocean Circulation

The development of a complete set of global forcing fields for ocean and sea-ice models is described in Large and Yeager (2000, NCAR/TN-460+STR). The forcing is based primarily on the International Satellite Cloud Climatology Project – Flux Data (ISCCP-FD) surface longwave and solar radiation (Zhang et al., 2004), the National Centers for Environmental Prediction (NCEP) reanalysis (Kalnay et al., 1996), and a blend of satellite precipitation products. Ancillary data sets of higher quality have been used to objectively correct the surface winds, air temperature, and humidity to produce a globally balanced heat and freshwater flux. The interannually varying forcing (IVF) is complete from 1983 through 2000, and the NCEP based fields vary all the way back to 1958. In response to an expressed community need to force ocean and sea-ice models with a repeating annual cycle of forcing, these datasets have been processed into such a form. The criteria were to preserve the 43-year mean fluxes, to have realistic storm events, and to transition smoothly from December 31 to January 1, all without changing the standard forcing infrastructure. Since this forcing is not overly biased to any particular year, it is referred to as "Normal Year Forcing" (NYF).

The two CCSM3 ocean model configurations, with respective nominal horizontal resolutions of 1 and 3 degrees, have both been forced with several cycles of IVF and about 100 years of NYF. This standard forcing has also been applied to coupled ocean and sea-ice models as part of the Coordinated Ocean Reference Experiments (CORE). Several national and international groups have adopted this forcing for their CORE integrations, so that solution differences can be compared with minimal consideration of forcing contributions.

Investigations are still continuing to study the transfer of wind energy to the ocean through resonant inertial forcing. One aspect of this work, in collaboration with Robert Stockwell and Ralph Milliff of Colorado Research Associates (CoRA), has found that everywhere, but especially at 30 degrees latitude, ocean surface winds do have a preferential anticyclonic rotation at inertial frequencies making them predisposed to resonate with inertial ocean currents (Stockwell et al., 2004). The other research path in collaboration with Patrice Klein, French Research Institute for Exploitation of the Sea (IFREMER) and Hecht aims to quantify the role of ocean meso-scale eddies in extracting wind energy by broadening the resonant frequency band. Two simulations of a 0.1 degree North Atlantic model shows that, although the mean energy input is not much affected, there is a much broader distribution of energy input, so that non-linear processes, such as vertical mixing, could be much more vigorous in eddy-resolving models forced by high frequency (e.g., 6 hourly) winds. The hypothesis is that both eddies and near-inertial wind forcing will need to be parameterized in non-eddying climate models to mix as deep as observed in eddy rich regions of the ocean, such as the Atlantic Circumpolar Current.

Terrestrial Sciences Section Narrative

The goal of the Terrestrial Sciences Section (TSS) is to increase scientific understanding of land-atmosphere interactions, in particular surface forcing of climate, through model development, application, and observational analyses and to represent that understanding in climate models. Research in TSS spans a broad knowledge of the relationships among the biosphere, hydrosphere, cryosphere, and atmosphere. Scientists in TSS develop and use appropriate multi-scale models, remote sensing, advanced analytical techniques, and observations to study the role of the terrestrial biosphere in the climate system. Topics of study include the regulation of planetary energetics, planetary ecology, and planetary metabolism through exchanges of energy, momentum, and materials (e.g., water, carbon, mineral aerosols) with the atmosphere and ocean and the response of the climate system to changes in land cover and land use.

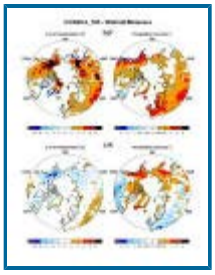
Scientists in TSS are involved in developing the land model used in the Community Atmosphere Model (CAM) and the Community Climate System Model (CCSM). This model, the Community Land Model (CLM), includes biogeophysics and hydrology, the traditional physical core components of land models, and is being further developed to include river routing, biogeochemistry (carbon, nitrogen, mineral aerosols, biogenic volatile organic compounds, water isotopes), and vegetation dynamics. Gordon Bonan co-chair's the CCSM Land Model Working Group, Natalie Mahowald co-chairs the CCSM Biogeochemistry Working Group, and other TSS scientists actively participate in both working groups, providing strong input to model development and implementing and testing model parameterizations. Model development is based on process studies of the relevant physical, chemical, and biological mechanisms and the numerical modeling techniques required to represent these mechanisms. TSS scientists compare model output with observed atmospheric, ecological, and hydrological data to validate and improve the model on a wide range of spatial and temporal scales. TSS provides a focal point for CGD and university ecological and hydrological research and serves as a resource to these communities in their use of CCSM.

Members of TSS participate in NCAR initiatives in Biogeosciences, Weather and Climate Impact Assessment, Water Cycle, and Wildland Fire.

Community Land Model

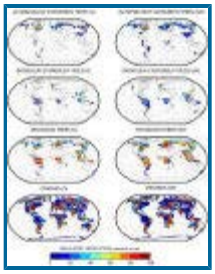
Mariana Vertenstein (TSS), Keith Oleson (TSS), Sam Levis (TSS), Forrest Hoffman (Oak Ridge National Laboratory), Peter Thornton (TSS), and Gordon Bonan (TSS) oversaw the release of the third version of the CLM3 for the CCSM3. The model includes a new under-canopy turbulence scheme developed by Xubin Zeng (University of Arizona) and colleagues, which significantly reduces excessively warm daytime ground temperatures in sparsely vegetated areas. The model also includes a dynamic global vegetation model that allows plant community composition to change over time in response to fire and climate change, as well as new capabilities that facilitate implementation of the terrestrial carbon cycle. Model source code, datasets, technical descriptions, and user guides can be found at http://www.cgd.ucar.edu/tss/clm/distribution/clm3.0/index.html.

Oleson and Robert Dickinson (Georgia Tech) analyzed the control CCSM3 simulations for the present-day climate. The model has a prominent winter (DJF) warm temperature bias in Siberia, Alaska, and western Canada. This same region has a cold temperature bias in summer (JJA). Eastern and central United States and the Amazon have pronounced annual dry biases in terms of precipitation.

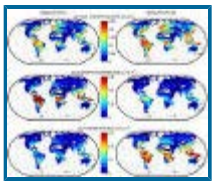


This figure shows surface air temperature (left) and precipitation (right) biases in CCSM3 at T85 resolution.

Levis and Bonan analyzed the vegetation simulated by the dynamic global vegetation model in CCSM3. Their analyses showed that the prominent dry biases in the United States and the Amazon result in an inability to grow the expected forest vegetation. Changes to CLM3 that reduce the interception of water and increase transpiration result in a better simulation of vegetation.



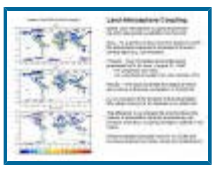
This figure shows vegetation simulated by CLM3 with its dynamic global vegetation model. Left: CLM3. Right: CLM3 with modifications that reduce interception and increase transpiration. The modifications allow for more extensive forests in eastern U.S. and tropical South America.



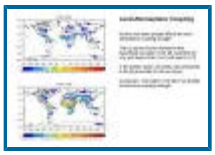
This figure shows relative soil water wetness, canopy evaporation, and transpiration simulated by CLM3 (left) and a modified CLM3 (right). The modifications result in relatively wetter soil, reduced interception and canopy evaporation, and increased transpiration.

Hydrology

As part of the NCAR Water Cycle initiative, Oleson, Bonan, and David Lawrence (CCR) participated in the Global Land Atmosphere Coupling Experiment (GLACE). This intercomparison of several atmospheric models has the goal of quantifying and documenting the degree to which the atmosphere responds to anomalies in the land surface states, especially soil moisture. Climate model experiments in which soil water is either prognostically simulated or prescribed from a dataset were compared to determine the degree to which soil moisture influences precipitation. Results from the CAM and the CLM show that land-atmosphere coupling strength is highest in the tropics.



Surface soil water greatly influences the land-atmosphere coupling strength. The model has much greater coupling strength when the top 5 cm of soil is included in the analysis than when only the deeper soil layers are considered.



Biogeochemistry

As part of the NCAR Biogeosciences Initiative, TSS scientists conducted several projects to implement biogeochemistry in CLM and CCSM. This research broadly addresses how biogeochemical coupling of carbon, nitrogen, iron, and sulfur cycles affect climate, air quality, radiative forcing, and ecosystem function on regional to global scales. It involves two specific research agendas related to mineral aerosols and the terrestrial carbon cycle.

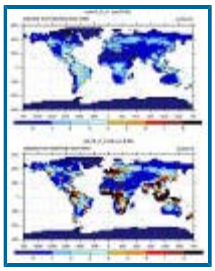
Natalie Mahowald's (TSS) work has focused on three main issues: understanding the anthropogenic portion of desert dust, the climate and biogeochemical impacts of desert dust, and incorporating desert dust into the CCSM. In collaboration with university researchers (Jean-Louis Dufresne (UCSB/CNRS France), Chao Luo (University of California, Santa Barbara), Masaru Yoshioka (University of California, Santa Barbara), Mahowald contributed to two papers (one submitted, one published) on the relative proportion of anthoropogenic mineral aerosol sources to the total sources, using Total Ozone Measuring Spectrometer Absorbing Aerosol Index (TOMS AII) and comparisons to observations. Additionally, she has one submitted article with a SOARS student (G. Rivera) and a university researcher (Chao Luo (University of California, Santa Barbara)) using desert dust storm data to constrain the land use fraction of current desert dust concentrations. Additionally she contributed to a paper looking at the importance of diurnal (surface energy flux processes) and synoptic processes in modulating the desert dust cycle (with Chao Luo (University of California, Santa Barbara) and Charles Jones (University of California, Santa Barbara).

Mahowald contributed to two papers dealing with the biogeochemical implications of mineral aerosols (with Greg Okin (Virginia), Ed Boyle (Massachusetts Institute of Technology) and many others). She authored an additional paper evaluating the atmospheric phosphorous sources over the Amazon (with university collaborators) which is in preparation. She worked with Jenny Hand (ASP) to develop the first modeling study of atmospheric iron in mineral aerosols as it is processed in the atmosphere, and has a paper published on this topic, of great importance to the ocean biogeochemistry community. Mahowald's research also examined the impact of desert dust on African easterly waves as derived from observations with Charles Jones (University of California, Santa Barbara) and Chao Luo (University of California, Santa Barbara).

Mahowald has continued to improve the CCSM desert dust modeling codes and has looked at the the response of atmospheric mineral aerosols and seasalts to climate change, using the CCSM in slab ocean model mode, for the current climate, preindustrial, doubled-CO_2 and the last glacial maximum. This work is being done in collaboration with Phil Rasch (CMS), Charlie Zender (University of California, Irvine), Sam Levis (TSS), Masaru Yoshioka (University of California, Santa Barbara) and Bette Otto-Bliesner (CCR).

Peter Thornton (TSS) continued research to develop the carbon and nitrogen biogeochemical algorithms for CLM. The core biogeochemical capabilities for carbon and nitrogen cycling were implemented in CLM during FY 2003. Over the past year these capabilities have been extensively evaluated and expanded, and long offline and coupled simulations have now been executed in a number of different configurations to demonstrate the readiness of the new model (CLM3-CN) for research applications.

Offline simulations driven by the National Center for Environmental Prediction NCEP/NCAR reanalysis surface weather fields have demonstrated that the new land biogeochemistry behaves reasonably under prescribed atmospheric forcing. The first long simulations coupling the new land model to the atmosphere in CCSM3 (with prescribed ocean and ice boundary conditions) have just been completed. The results suggest that both the improved canopy integration scheme and the prognostic carbon and nitrogen cycles have a significant impact on the coupled climate simulation. A major contributor to climate feedback in the new model is the prognostic canopy leaf area, which causes the seasonal, interannual, and long-term dynamics of the canopy to respond directly to the model climate, in contrast to the default land model which prescribes the seasonal cycle and spatial distribution of canopy leaf area from satellite observations. Next steps include simulations to quantify the climate feedbacks due to greenhouse forcing from prognostic carbon fluxes on land, and fully coupled simulations including the carbon cycle biogeochemistry of the oceans.



This figure shows comparison of annual average leaf area index (LAI) for the default implementation of CLM3 in CCSM3 (top), and for the new implementation of CLM3-CN which includes prognostic carbon and nitrogen cycles (bottom). The CLM3 LAI is derived from remote sensing observations and does not respond in any way to the modeled climate. The CLM3-CN LAI is a product of the prognostic development of vegetation canopy carbon and nitrogen state variables, with strong seasonal, interannual, and climatological responsiveness to the modeled surface weather and climate fields. The CLM3-CN result in this example is an intermediate result with nitrogen limitations turned off to achieve more rapid canopy development.

Thornton is participating in the Coupled Climate Carbon Cycle Model Intercomparison Project (C4MIP) experiments. For this effort, he defined new requirements for the data atmosphere component of CCSM3 and defined the spinup protocol for the C4MIP experiments. He used the C4MIP protocol for prescribed transient landuse changes to define the requirements for the input datasets and the implementation of changing landcover within CLM. All of the raw datasets have been assembled and processed to produce a preindustrial potential vegetation map and a timeseries of landcover from 1900-1990 that includes the fractional gridcell coverage for crops and pasture and their changes through time.

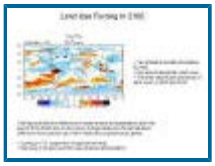
Thornton is Principal Investigator on a project sponsored by the NASA Earth Science Technology Office to develop and implement a research-quality user interface for high-resolution carbon cycle simulation, using the Daymet and Biome-BGC models as technology components. The project involves a close collaboration with researchers in Scientific Computing Division (SCD) to implement this interface as a web-based tool that can connect remote users to not only a set of state-of-the-art modeling tools, but also the high-end computational and data storage resources required to perform and analyze high-resolution simulations over large regions.

Thornton led an effort with Nan Rosenbloom (TSS) and Sylvia Murphy (CCSM Software Engineering Group (SEG)) to produce an updated diagnostics package for CLM that includes new variables for the CN code.

Land Cover and Land Use Change

A major research focus for TSS is natural and human-mediated changes in land cover and ecosystem functions and their effects on climate, water resources, and biogeochemistry. TSS scientists worked on several projects to implement land cover and land use change in CLM and to use climate models to study the impact of these processes on climate. This work contributes to the NCAR Weather and Climate Impact Assessment Science Initiative and the NCAR Biogeosciences Initiative.

Johannes Feddema (University of Kansas), Bonan, Oleson, and Mearns (Environmental and Societal Impacts Group (ESIG)) studied the effects of historical and future land cover change on global climate. Climate model simulations were performed with the Parallel Climate Model (PCM) and examined the sensitivity of simulated climate to different specifications of present-day land cover and natural potential vegetation. Uncertainty in the classification of present-day vegetation can produce large differences in the simulated climate. Present-day vegetation has generally cooled surface climate, especially in the mid-latitudes due to the higher albedo of croplands compared to natural vegetation. Climate model simulations using land cover for the year 2100 showed that the land cover forcing of climate can be large, especially in tropical South America and in the United States, where agricultural land is projected to become more extensive by the year 2100.



Bonan, Oleson, and Feddema also worked to develop and implement an urban land cover parameterization for CLM. The parameterization uses concepts from urban canyon models to simulate the radiative balance of a city, turbulent energy fluxes, and the hydrologic cycle.

Agroecosystems differ from other terrestrial ecosystems due to their intensive management. Levis and Bonan worked to implement a crop model in CLM. The CLM is being modified from one crop type with prescribed leaf area index to include corn, wheat, and soybean, and to allow leaf area to grow in response to prevailing atmospheric conditions and management practices. The crop model is based on a model developed by Chris Kucharik, Jon Foley, and colleagues at the University of Wisconsin. This will provide a first order look at the sensitivity of climate to better specification of croplands.

Carbon Data Assimilation

Through the activities of Dave Schimel (TSS), the section holds a leadership position in the development of data assimilation techniques for biogeochemistry and carbon cycle studies.

The carbon cycle is an important and dynamic part of the Earth System. Recent experiments as part of the C4MIP program of model intercomparison have revealed the potential for significant feedbacks between the carbon cycle and the climate system, yet at large scales, the carbon models remain essentially unvalidated. While some aspects of the carbon models can be tested at local (hectare-kilometer) scales, few techniques exist for either estimating parameter values or testing model performance at scales comparable to model grid resolution. We are conducting an integrated program that focuses on combining measurements and innovative modeling techniques at regional scales. This program, the Airborne Carbon in the Mountains Experiment (ACME) focuses on quantifying carbon fluxes in mountain and mountain-valley complex landscapes using airborne and ground-based flux measurement techniques. Mountains might seem like a challenging choice meteorologically, but we selected this region for two reasons. The first consideration is importance. In the mid-latitudes of the Northern Hemisphere, much of the actively growing forests occur in complex landscapes, and so techniques are urgently required. The second consideration is methodological. Much of the uncertainty in carbon models is in the respiratory processes or the release of photosynthetically fixes carbon back to the atmosphere. In level landscapes, this measurement is challenging as eddy covariance fails in (common) stable nighttime conditions. In the mountains, concentration measurements in nighttime drainage flows allows “scaling up” respiratory fluxes to airshed or “carbonshed” scales. This gives access to a key unknown at a range of large scales.

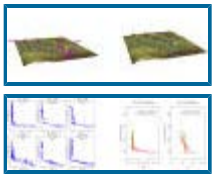
The overall ACME program was carried out in summer 2004 and involved 54 flight hours using the NCAR C-130 and a four-month deployment of the Integrated Surface Flux Facility (ISSF), complementing long term measurements made by the University of Colorado at Niwot Ridge. The project involves Principal Investigators from the University of Colorado, Colorado State University, collaborators from the University of Miami-Florida, University of Montana, and guest scientists from the University of Utah, Scripps Institution of Oceanography, and Washington State University. The project is part of NCAR’s Biogeosciences Initiative, and contributes to the National Science Foundation (NSF) Biocomplexity Program, the NASA Interdisciplinary Science Program, and is part of the interagency North American Carbon Program.

The airborne program explored a number of techniques for estimating carbon fluxes, and focused on separating nighttime and daytime fluxes. Nighttime fluxes were estimated by early morning profiling into the nocturnal boundary layer, while daytime fluxes were estimated using semi-lagrangian experiments and airborne eddy covariance. Results showed clear accumulation of CO_2 in the nocturnal boundary layer and strong daytime drawdown. Results are currently being analyzed using a mesoscale data assimilation system based on the CSU RAMS (RAMDAS) coupled atmospheric-land surface model. The ground-based component, the Carbon in the Mountains Experiment (CME) deployed three ISFF towers on Niwot Ridge, Colorado from July-October 2004, extending a permanent 4-tower flux array maintained by University of Colorado and the US Geological Survey (USGS). All of the towers measure CO_2 concentrations and physical parameters. Two of the ISFF towers also made flux measurements. The towers allow quantification of nighttime advective fluxes and can be inverted to estimate respiration. Each ACME flight included overpasses of the CME site and allow extension of the results across scales.

The CME tower studies will be analyzed using a unique carbon process data assimilation model developed by University of New Hampshire and NCAR scientists which allows forest carbon fluxes from eddy covariance and advective techniques to be inverted into estimates of ecosystem model parameters. Preliminary studies have already demonstrated that key ecosystem parameters can be retrieved using this method. The model is being extended to include satellite vegetation estimates, water cycle measurements and isotopes. The current process model being used is highly simplified from the CLM but includes a number of common process formulations and structure. As the information content of the flux data are better understood, we will move from assimilating into a model of reduced dimensionality (SPACENET) into assimilation of parameters and states in the full CLM. Results from the SPACENET and CLM assimilations can be compared to fluxes estimated from the airborne program using RAMDAS.

Taken together, the experiment provides an innovative way of estimating landscape-scale parameters for land surface models, and a way of validating these models against regional airborne measurements. The separation of the airborne program into daytime (photosynthesis-respiration) and nighttime (respiration alone) fluxes allows the model to be tested much more rigorously than in previous studies where 24-hour measurements were made. This study is a pathfinder for

upcoming intensives of the North American Carbon Program where this and other approaches for analyzing large-scale observations, model development, and model testing will be explored.



This figure shows morning and afternoon flight segments of a typical ACME day. On the upper left, early morning vertical profiling and low-level survey flights, along with the upwind segment of a semi-lagrangian flight (extension to the Northwest). Upper right, afternoon flights showing the downwind segment of the semi-lagrangian experiment and low-level eddy covariance surveys. The lower left panel shows typical morning profiles indicating large accumulation of respired CO_2 in the nocturnal boundary layer. These accumulations, also evident in low-level survey flights, suggest that large-scale drainage flows may be used to develop integrated estimates of respiration in the mountains. The lower right panel shows morning and afternoon profiles of CO_2 from the semi-lagrangian experiment, together with the CO profiles used to correct for pollution signals.

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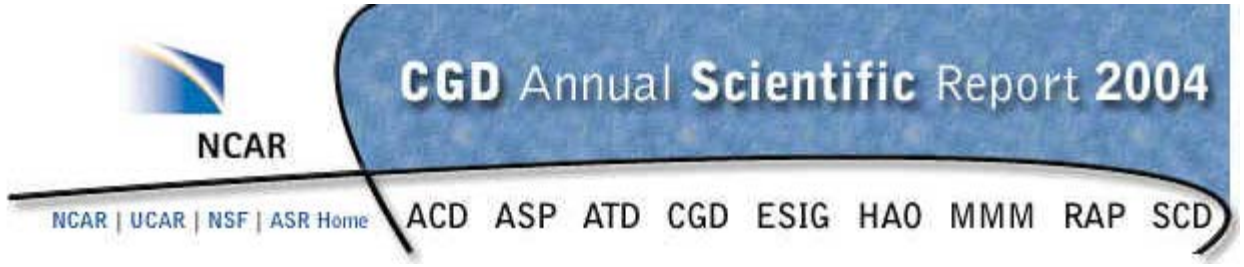

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Education and Outreach

CGD is a strong supporter of educational activities at NCAR, the scholastic arenas and the general community. We have a broad range of participation as shown in the table below.

Staff Appointments to NCAR:	Total
Postdoc Fellowships	5
Graduate Research Assistants	2
Undergraduate Students	0
Teaching Appointments	13
Advising on Graduate Research	7
Member of Thesis Committee	10
Other Activities:	
Seminars, Presentations, and Workshops	
Technical	192
Non-Technical	21

The Geophysical Statistics Project continues. This project encourages the application of statistical analysis and the development of new statistical methods in the geophysical sciences. The overriding programmatic strategy is to bring in young postdoctoral fellows to collaborate with resident NCAR geophysical scientists. Also, the statistics visitors supported by this project provide statistics guidance to the fellows. This structure allows for growth in the careers of the young statistics postdoctoral fellows as well as providing additional research tools to the geophysical sciences. For more information, please see GSP section in the Narratives of the ASR04.

Sylvia Murphy (SEWG) and Dennis Shea (CAS) continue to participate in development of a free, general purpose, public domain software data processing tool based on SCD's NCAR Command Language (NCL). This tool can be used to access, process and visualize data in a variety of formats. They support and teach UCAR and university users how to use the NCL tool. To facilitate outreach, they have used three approaches: (i) a World Wide Web (WWW) portal (http://www.cgd.ucar.edu/csm/support/) (ii) tutorial workshops and (iii) downloadable reference manuals. The WWW portal contains numerous examples based upon 'real-world' applications. Separate links are provided for file input/output, data processing and visualization. Examples are based upon structured training methods which proceed from simple to more complex applications. The free, three-day tutorial workshops are offered at NCAR three to five times per year. In addition to NCL, these workshops offer instruction in special CCSM related processing tools and the netCDF operators. The classes have been attended by NCAR, university and government personnel. Upon request, as part of university outreach, workshops have been held at universities. In FY04, six NCL workshops were conducted. Three were invited workshops, and they were held at Purdue University (15 attendees), Naval Research Laboratory (14 attendees), and NOAA’s National Ocean Service’s Laboratory (13 attendees). Three workshops ere conducted at NCAR with a total of 23 attendees.

Each year CGD holds a CCSM Workshop which brings together CCSM users throughout the community. At the workshop, participants present findings based on either model output from simulations or model development

CGD continues to support strongly, seminars, presentations and workshops, both technical and non-technical in nature.

In FY04 the technical talks range from in house seminars to invited talks at international symposiums. This was a workshop for nineteen highly qualified high school teachers who, during a two-week period explored many aspects of the geosciences related to climate and global change. Examples of non-technical talks range from climate change presentations to undergraduates at the University of Colorado to CGD scientists being interviewed on National Public Radio. The number of CGD's technical seminars, presentations, and workshop tops 200, exemplifying CGD's strong interaction with its peers and outreach to the community.

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Community Service

Editorships

Clara Deser, Associate Editor, *Journal of Climate*, 1996

Peter R. Gent, Associate Editor, *Journal of Physical Oceanography*, 1992

James Hurrell, Editor, *The North Atlantic Oscillation: Climatic Significance and Environmental Impact.* Geophysical Monograph Series Volume 134, 279 pp.; Co-editor, *Ecological effects of climatic variations in the North Atlantic Ocean.* Oxford University Press, in press. Co-editor: *Marine Ecosystems and Climate Variation: The North Atlantic.* Oxford University Press, 2004, 227 pp.

James C. McWilliams, Editorial board of the *Journal of Turbulence*; Associate Editor of *Physics of Fluids*, 2001

Doug Nychka, Editor, *Statistical Science*, 1999–2003

Bette Otto-Bliesner, Guest Editor, *Palaeogeography, Palaeoclimatology, Palaeoecology*, Glacial-Interglacial Climate of the Past 160,000 Years: New Isights from Data and Models

Philip Rasch, Editorial Panel Member, *Tellus*, 1992

David Schimel, Consulting Editor, *Global Change Biology*, Editor-in-Chief, *Ecological Applications*, Associate Editor, *Annual Reviews of Enviornment & Resources*

Joseph Tribbia, Guest Editor, *Handbook of Numerical Analysis*, 2003

Tom M. L. Wigley, Editorial Board, Climate Dynamics, 1994; Global Climate Change Digest, 1989; Mitigation and Adaptation Strategies for Global Change, 1995

Scientific, Policy, or Education Committees and Advisory/Panels/Boards

Jeffrey Anderson, Member, NOAA/NASA Joint Center for Satellite Data Assimilation Science Steering Committee, 2003

Gordon Bonan, Co-Chair, Land Model Working Group for the Community Climate System Model, 1996; Member, Community Climate System Model, Scientific Steering Committee, 2004.

Grant Branstator, Member, Scientific Advisory Committee for the Center for Atmosphere-Land-Ocean Studies, 1999

Frank Bryan, Member, World Climate Research Program Working Group on Ocean Model Development; Coordinator, World Climate Research Programme (WCRP) Pilot Ocean Model Intercomparison Project (POMIP); Member, Ad Hoc committee for a Petascale Earth System Collaboratory; NSF Physical Oceanography Spring 2004 Review Panel

William Collins, Chair, AMS Committee on Radiation, 1999; Member, NASA CERES Science Team, 2000; Chair, NCAR CCSM Scientific Steering Committee, 2003; Co-chair elect, 2005 Gordon Research Conference on Solar Radiation and Climate, 2003; Chair elect, 2007 Gordon Research Conference on Solar Radiation and Climate, 2003; Co-chair, Aspen Global Change Institute Symposium "Aerosols and the Hydrological Cycle", 2004; Member, Organizing Committee, IPCC Working Group I Workshop on Climate Sensitivity, 2004

Aiguo Dai, Member of Advisory Committee on Coupled Model Development at Institute of Atmospheric Physics, Chinese Academy of Science, 2004; Member, NCAR Biocomplexity Steering Committee, 2004

Clara Deser, Program Committee Member, American Geophysical Union, Chapman Conference on the North Atlantic Oscillation, 2000; Member, Climate Observing System Council, 2000-2001, NOAA-OAR; Member, UCAR Steering Committee of the NOAA Postdoctoral Program in Climate and Global Change, 2001-2003; Member, steering committee for the CLIVAR Pacific Implementation Panel, 2003-2005; Co-chair, Climate Variability Working Group, CCSM, 2003-2005

Peter Gent, Member, Working Group on Modeling and Prediction for the International Research Institute; Member, U. S. CLIVAR Ocean Panel

Andrew Gettelman, Organizer, Isotopes in the Climate System Workshop, 2003; Member, SPARC Chemistry Climate Model (CCM) Validation Project Steering Committee, 2004; Organizer for CCM Validation 2005 meeting, 2004; AGU Atmospheric Sciences Communications Secretary, 2002; Member, AMS Middle Atmosphere Committee, 2003

Marika Holland, Member, AMS Committee on Polar Meteorology and Oceanography; Co-Chair, Polar Climate Working Group; Member, NSF Arctic Systems Science Advisory Committee

James Hack, Member, DOE Climate Change Prediction Program (CCPP) Science Team, 1991; Member, Review Panel, Department of Energy Science Graduate Fellowship Program, 1990; Member, DOE Atmospheric Radiation Measurements (ARM) Science Team, 1991; Member, Oak Ridge National Laboratory Computer Science and Mathematics Division Advisory Committee, 1998; Co-Chair Clouds and Climate Program, 1998; Member, CSM Scientific Steering Committee, 2002; Member, Department of Energy Advanced Scientific Computing Advisory Committee, 2003; Member, US Global Water Cycle Scientific Steering Committee, 2002

James Hurrell, Member, Great Plains Regional Center of the National Institute for Global Environmental Change, 1994–2004; Co-chair of the U.S. Climate Variability and Predictability (CLIVAR) Scientific Steering Committee 2003; member 1998); Co-chair of the U.S. CLIVAR Atlantic Implementation Panel, 1999-2003; Member of the International CLIVAR Atlantic Implementation Panel 1999; Member of the NRC Committee on Climate Data Records from Operational Satellites: Development of a NOAA Satellite Data Utilization Plan 2003; Member of the International CLIVAR/PAGES Intersection Working Group 2004; Member of the US CCSP Synthesis and Assessment Team: Product 1.1. Temperature Trends in the Lower Atmosphere: Steps for Understanding and Reconciling Differences 2004; Member of Local Organizing Committee: 1st International CLIVAR Science Conference, Baltimore, MD, June 2004.

Akira Kasahara, Member, Advisory committee for Next-Generation Polar-Orbiting Operational Environmental Satellite System (NPOESS), 1997

Jeffrey Kiehl, Member, DOE Atmospheric Radiation Measurements (ARM) Science Team, 1991; Co-Director, NSF Science and Technology Center for Clouds, Chemistry and Climate (C4), 1997; Chairman, General Circulation Model (GCM) Validation Work Group at the Center for Clouds, Chemistry and Climate (C4), 1994; Member, Scientific Steering Committee, NSF Climate System Model Project, 1996; NRC Committee on Radiative Forcing Effects on Climate, 2003-2004

William Large, Member, CCSM Principal Investigator Group, 1995; Co-Chairman, International Science Steering Group of the World Ocean Circulation Experiment (WOCE), 1997; Co-chair Working Group II on Air-sea fluxes, CLIVAR Ocean Reanalysis, 2004; NASA Scatterometer Science Working Team, 1988; CCSM Science Steering Committee, 2003; Co-chair CCSM Ocean Working Group, 2003; NASA Aquarius Science Working Team, 2002

Natalie Mahowald, Co-Chair, BGC Working Group, NCAR, 2003–; Member, Global Analysis, Integration and Modeling Taskforce of International Global Biosphere Project, (GAIM/IGBP), 2003–; Chair, Ph.D. Thesis Committee, M. Yoshioka, University of California at Santa Barbara; Member, Ph.D. Thesis Committee, D. Toole, T. Westbury, and A. Ballantine, University of California at Santa Barbara.

James C. McWilliams, Member, World Ocean Circulation Experiment (WOCE), 1994; U. S. Steering Committee; Member, San Diego Supercomputer Center User Advisory Council, 1998; Member, Visiting Committee for the Division of Geological and Planetary Sciences, California Institute of Technology, 1999; Member, Climate Change Science,

National Research Council, 2001

Gerald Meehl, Visiting Senior Fellow, University of Hawaii Joint Institute for Marine and Atmospheric Research, 1995; Vice-chair, Climate Variability and Predictability Working Group on Coupled Models (CLIVAR WGCM), World Climate Research Programme, 1997; Member, Japan/U.S. Scientific Advisory Committee for the International Pacific Research Center, University of Hawaii, 1997; Chairman, Coupled Model Intercomparison Project (CMIP), 1995; Member, Steering Committee for Initial Assessment of the Consequences of Climate Variability and Change for the Pacific Islands, 1999; Co-Chair, Community Climate System Model Climate Change Working Group, 2000; Chairman, Working Group on Coupled Models (WGCM) Climate Simulation Panel, 2003; Member, U.S. CLIVAR Scientific Steering Committee, 2001; Member, National Research Council Climate Research Committee, 2004

Philip Merilees served on the Ocean Research Advisory Panel for the National Ocean Partnership Program (ORAP/NOPP); served on the Scientific Committee of the Canadian Meteorological and Oceanographic Society (CMOS); and chaired the Network Review Committee for the Canadian Foundation for Climate and Atmospheric Science (CFCAS).

Doug Nychka, Member Scientific Advisory Board, Center for Integrating Statistics and the Environment, University of Chicago, 2002–; Member, Committee on Applied and Theoretical Statistics, National Academies, 2003.

Bette Otto-Bliesner, Member, Paleoclimate Modeling Intercomparison Project (PMIP) 1995-2002; Co-chair, Paleoclimate Working Group, NCAR Climate System Model, 1997; Chair, Paleoceanography and Paleoclimatology Focus Group, American Geophysical Union, 2002-; Member, Paleoceanography and Paleoclimatology Committee, American Geophysical Union, 1998; Steering Committee Member, PARCS (Paleoenvironmental Arctic Sciences), National Science Foundation, 1999-2003; Member, SCD Advisory Panel, 2000; Program Committee, Fall AGU Meeting, 2002-2004; Science Advisory Committee NCAR Exhibits, 2002; COMET Paleoclimate Educational Module Advisory Committee, 2003; Member, NOAA Paleoclimatology Program Review Panel, 2004; Steering Committee Member, Geosystems Initiative, National Science Foundation 2004-present; Steering Committee Member, PMIP-2, 2004-present

Philip Rasch, Member Coordinating Committee of the International Global Atmospheric Chemistry (IGAC) Project on Stratospheric and Upper Tropospheric Aerosols (SUTA), 1998; Member, Scientific Steering Committee for IGAC, 2002; Co-Chair, Atmosphere Model Working Group, Community Climate System Model, 2003; Member, Steering Committee NASA Global Modeling Initiative (GMI), 2002; Member, Cloud Processing Team, 2002; Member, NASA Microwave Image Satellite Team, 2002

Fabrizio Sassi, Member, Board of Directors of the Atmospheric Systems and Analysis Corporation, 2002

David Schimel, International Geosphere-Biosphere Program: Task Force on Global Analysis, Interpretation and Modeling; NASA Earth Observing System Project, Biogeochemistry Panel, chairman; NASA Topographic Science Working Group SCOPE Working Group on Biogenic Trace Gases; U.S. National Academy Committee on Global Change Working groups on Biological Systems and Dynamics, Earth System Models, Nutrient Fluxes, and Dynamics; Member, U.S. National Academy Committee on Global Change Research, Carbon Science Working Group (USGCRP); National Research Council Committee on Atmospheric Chemistry; National Research Council Committee on Global Change Research; Member, Steering Committee Carbon Europe Program; Member, Komission (Search Committee) to replace Lennart Benngston; Member, technical Advisory Committee, Max-Planck-Institute for Chemistry; Co-organizer, NCAR-CSU Advanced Study Institute on Carbon Data Assimilation; Chair, Intergovernmental Panel on Climate Change (IPCC) Steering Committee for workshop on Terrestrial Carbon Processes, 2003; Invited Expert, IPCC Second Scoping Meeting, 2003; Member, Institute of Arctic and Alpine Research (INSTAAR), Advising Committee, 2003.

Peter Thornton, Invited Member of Oak Ridge National Laboratory Data Active Archive Center (ORNL DAAC) User Working Group; Member, 2003 NCAR delegation to AGU Congressional Visits Day; NASA peer review panelist, 2003; Member, North American Carbon Cycle PI Team, NASA, 2003; Co-Chair, UCAR Members Meeting, Biogeochemistry Forum, October 7, 2003; Member, Ameriflux Network Steering Committee; Co-Chair, North American Carbon Program Data Workshop; Chair, NCAR Early Career Scientists Assembly

Kevin Trenberth, Member, NOAA Panel on Climate and Global Change, 1987–; Member Executive Council 1991–; Member, ECMWF Reanalysis (ERA) Project Advisory Group, 1993; Member, International CLIVAR Scientific Steering Group, 1995; Member, Joint Scientific Committee of the World Climate Research Programme, 1999; Officer (member of Exec. Committee) 2003–; Member, NOAA OAR Climate Observing System Council, 1999; Earth and Sky Radio Science advisor, 1999–; Member NOAA Panel for the Climate Change Data & Detection (CCDD) program. 2001; Member Research Advisory Executive Committee for The Climate Report. Maryam Golnaraghi Editor, 2001; Member AMS Committee on Atmospheric Research Awards Committee, 2001; Member of team of experts to write Second Report on Adequacy of Global Climate Observing System. 2002; Member CLIVAR 2004 Scientific Conference committee, 2002-

2004; NOAA Climate and Global Change Working Group, 2003-; NOAA Climate Monitoring Working Group. 2003; Member ad hoc UCAR panel and invited speaker workshop on "Integrated Earth System Observations," Smithsonian Institute, 2003; Member organizing committee, Workshop on Ongoing Analysis of the Climate System, Boulder, CO, 2003; Member, ad hoc NOAA Paleoclimate Working Group, 2003; Member External Advisory Committee for Atmospheric Technology Division, NCAR 2004-; Member US Interagency Committee on Global Earth Observing System of Systems (GEOSS) 2004-; Member NASA CERES Climate Model and Analysis Advisory Group 2003-; Convening Lead Author IPCC WG-1 for the AR4 assessment; Member Joint Scientific Committee of the World Climate Research Programme. 1999–, Officer (member of Exec. Committee) 2003–, Chair Working Group on Observations and Assimilation (WGOA) 2004-, Member Modelling Panel 2004-, Member Task Force on COPES: Coordinated Observations and Prediction of the Earth System; Lead Author and Member *The Second Report on the Adequacy of the Global Observing System for Climate in Support of the UNFCCC*. 2002-2003, and follow on implementation report 2004; Convener with Jon Overpeck the CLIVAR/PAGES/IPCC Workshop "A multi-millennia perspective on drought and implications for the future", Tucson, AZ November 18-21, 2003; Member organizing committee for International CLIVAR workshop on Ocean Reanalysis 2004.

Warren Washington, Member, Secretary of Energy's Biological and Environmental Research Advisory Committee, 1990; Member, National Science Board, 1995; Chair, Secretary of Energy's Health and Environmental Research Subcommittee on Biological and Environment Research Program in the U.S. Global Change Research Program, 1995; Member, Modernization Transition Committee of the National Weather Service, U.S. Department of Commerce, 1993; Past President, American Meteorological Society, 1994; Member, Executive Committee, American Meteorological Society Council, 1995; Chair, Fellows Committee, American Meteorological Society, 1995; Member, Board on Sustainable Development, National Research Council, 1995; Member, Advisory Panel, National Centers for Environmental Prediction, 1995; Member, The National Committee, American Association for the Advancement of Science, Center for Science and Engineering, 1994; Member, NASA Earth Systems Science and Applications Advisory Committee (ESSAAC), 1998; Member, Board of Trustees of the Bermuda Biological Station for Research, 1998; Member, Executive Committee, National Science Board, 1998; Member, NOAA Science Advisory Board, 1998; Member, American Meteorological Society, History of the Atmospheric Sciences Committee, 1999; Member, Corporation for Woods Hole Oceanographic Institution, 1999; Member, National Energy Research Scientific Computing Center (NERSC) Policy Board of the Lawrence Berkeley National Laboratory, 1999; American Meteorological Society Award Committee, 2000; U.S. Department of Energy Advanced Scientific Computing Advisory Committee, 2000; Member of Los Alamos National Laboratory Computer & Computational Sciences Division Review Committee, (2001); Member of U.S. Commission on Ocean Policy Science Advisory Panel, (2002); Elected Chair of National Science Board, (2002); Member National Academies of Science Coordinating Committee on Global Change, (2003-present); NOAA Research Review Panel (2003); Reelected Chair of National Science Board, (2004)

Tom M. L. Wigley, Member, United Nations Environment Program (UNEP) Scientific and Technical Advisory Panel (STAP) of the Global Environment Facility (GEF), 1995; Member, American Geophysical Union, Atmospheric Sciences Section, Climate and Paleoclimate Committee, 1996; Member, NCAR/ESIG Climate Affairs Module Program Advisory Committee, 1998; Member-at-large, American Association for the Advancement of Science, Atmospheric and Hydrospheric Sciences Section, 1998; Chair, Steering Committee, Natural Environment Research Council (NERC), Swindon, U.K., 1999; Member, Advisory Board, NCAR Weather and Climate Impact Assessment Initiative

David Williamson, Member of CAS/JSC Working Group for Numerical Experimentation (WGNE), 1991; Member, U.S. Department of Energy Climate Change Prediction Program (CCPP) Science Team, 1991; Member, Atmospheric Modeling Inter-comparison Project Panel, 1996; Member, Program Committee for the 2004 Workshop on Numerical Solutions of Fluid Flow in Spherical Geometry, 1999; Organizing Committee for the Aqua-Planet Experiement (APE), 2002; Member, External Advisory Committee for the Center for Ocean/Atmosphere Prediction Studies (COAPS) at Florida State University, 2004

Professional Society Memberships

Caspar Ammann, American Geophysical Union; American Meteorological Society; International Association of Volcanology and Chemistry of the Earth's Interior; European Society for Environmental History; International Space Science Institute; American Quaternary Association; National Geographical Society

Gordon Bonan, American Geophysical Union; American Meteorological Society; Ecological Society of America

Byron Boville, American Geophysical Union; American Meteorological Society; Canadian Meteorological and Oceanographic Society

Esther Brady, American Geophysical Union; The Oceanography Society

Grant Branstator, American Meteorological Society

Frank Bryan, American Meteorological Society; American Geophysical Union; The Oceanography Society

Julie Caron, American Meteorological Society; American Geophysical Union

William Collins, American Geophysical Union; American Meteorological Society; American Physical Society; American Association for the Advancement of Science

Aiguo Dai, American Geophysical Union; American Meteorological Society **Clara Deser**, American Meteorological Society; American Geophysical Union

John Fasullo, American Meteorological Society

Reinhard Furrer, American Statistical Association, Institute of Mathematical Statistics, International Association of Mathematical Geology, Swiss Statistical Society

Peter Gent, American Geophysical Union; American Meteorological Society

Andrew Gettelman, American Geophysical Union; American Meteorological Society

Tim Hoar, American Statistical Association; American Meteorological Society; American Geophysical Union

Marika Holland, American Geophysical Union; American Meteorological Society

James Hurrell, American Meteorological Society; American Geophysical Union; Royal Meteorological Society

Akira Kasahara, American Meteorological Society; American Association for the Advancement of Science; American Geophysical Union; Sigma-Xi Scientific Society; Meteorological Society of Japan

Jeffrey Kiehl, American Geophysical Union; American Meteorological Society

Young-Oh Kwon, American Geophysical Union, Korean Society of Oceanography

David Lawrence, American Geophysical Union; American Meteorological Society

Roland Madden, American Meteorological Society; American Geophysical Union

Natalie Mahowald, American Geophysical Union

Tomoko Matsuo, American Geophysical Union

James C. McWilliams, American Geophysical Union

Gerald Meehl, American Meteorological Society; American Geophysical Union; Pacific Science Association

Carrie Morrill; American Geophysical Union; American Quarternary Association

Chester Newton, American Meteorological Society; American Geophysical Union; American Association for the Advancement of Science

Douglas Nychka, American Statistical Association; Institute for Mathematical Statistics; Royal Statistical Society; International Statistics Institute

Bette Otto-Bliesner, American Geophysical Union; American Meteorological Society

Adam Phillips, American Meteorological Society

Taotao Qian, American Meteorological Society

Philip Rasch, American Geophysical Union; American Meteorological Society; American Association for the Advancement of Science

Ramalingam Saravanan, American Meteorological Society; American Geophysical Union

Fabrizio Sassi, American Geophysical Union; American Meteorological Societ

y**David Schimel**, American Geophysical Union; Ecological Society of America

Ulrike Schneider, American Statistical Association;

Dennis Shea, American Meteorological Society

Christine Shields, American Meteorological Society

Lesley Smith, American Physical Society; American Geophysical Union

Mark Stevens, American Geophysical Union; American Meteorological Society

Peter Thornton, American Geophysical Union; American Association for the Advancement of Science

Kevin Trenberth, American Meteorological Society; American Association for the Advancement of Science; Royal Meteorological Society of New Zealand; American Geophysical Union

Warren Washington, American Association for the Advancement of Science; American Geophysical Union; American Meteorological Society, National Academy of Engineering; American Philosophical Society

Tom M. L. Wigley, American Association for the Advancement of Science

David Williamson, American Meteorological Society

Jeffrey Yin, American Meteorological Society, American Geophysical Union

Fellows of AGU and AMS

Peter Gent, American Meteorological Society, Fellow

Akira Kasahara, American Meteorological Society, Fellow

Jeffrey Kiehl, American Meteorological Society, Fellow

David Williamson, American Meteorological Society, Fellow

Other Activities K-12

Lesley Smith, "Latinas Building Bridges in Education," April 2004. Sponsored by Boulder County Latina Women's League.

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Honors and Awards

Andrew Gettelman, AMS Editor's Award for the Journal of Atmospheric Sciences, 2004

Doug Nychka, Jerome Sacks Award for Cross-Disciplinary Research, awarded by the National Institute for Statistical Sciences.

James Hurrell, Highly Cited Researchers, Thomson-ISI

David Schimel, External Member, Max-Planck Society

Warren Washington; Reed College Vollum Award for Distinguished Accomplishment in Science and Technology

.

Publications

university collaborators (bold) and non-NCAR or other collaborators(*)

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*Ackerman, T. P., **A. J. Braverman**, **D. J. Diner**, **T. L. Anderson**, **R. A. Kahn**, **J. V. Martonchik, J. E. Penner**, P. J. Rasch, *B. A. Wielicki, and **B. Yu**. 2004: Integrating and interpreting aerosol observations and models within the PARAGON framework. *Bull. Amer. Meteor. Soc.,***85**, 1523–1533.

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Kriho	Laura	
Moore	**Mark**	Section Head
Potemkin	Gaylynn	Adm. Asst
Wehrheim	Nicholas	

Oceanography Section

Briegleb	Bruce	
Bryan	Frank	
Butler	Lisa	Adm. Asst
Danabasoglu	Gokhan	
Gent	**Peter**	Section Head
Holland	Marika	
Holland	Bill	
Kauffman	Brian	
Large	William	
Lindsay	Keith	
Norton	Nancy	
Schramm	Julie	
Tsumune	Daisuke	
Weese	Scott	
Wu	Wanli	
Yeager	Stephen	

Vertenstein	Mariana
Yoshioka	Masaru

Visitors

Julie Arblaster; Australia; January 12–28, 2004; Climate Change Research Section

David Baker; Princeton University; October 1, 2003 – November 24, 2004, Climate Change Research Section

Jarrett Barber; Duke University; May 1, 2004 – July 16, 2004; Geophysical Statistics Project

Deborah Battista; University of Colorado; May 15, 2004 – September 30, 2004; Climate Change Research Section

Jorn Behrens; University of Technology, Munich Germany; October 2, 2003 – March 31, 2003; Climate Modeling Section

Thomas Bengtsson; University of California-Berkeley; July 18, 2004 – August 8, 2004; Geophysical Statistics Project

James Bradbury, University of Massachusetts; June 18-23 2004 and July 2-6, 2004; Climate Change Research Section

Amy Braverman; Jet Propulsion Laboratory; October 13, 2003; Climate Modeling Section

Don Boyer; Arizona State University; July 3-6, 2004; Oceanography Section

Christopher Bretherton; University of Washington; December 8, 2003 – January 3, 2004; Climate Modeling Section

Christophe Cassou; CERFACS, France; February 29, 2004 – March 24, 2004; Climate Analysis Section

Clifford Chen; Fujitsu America; October 14-17, 2003; Oceanography Section

Gabriel Clauzet; University de Sao Paolo, Brazil; August 1-31, 2004; Climate Change Research Section

Ben Cook; University of Virginia; July 18-31, 2004; Terrestrial Sciences Section

Daniel Cooley; University of Colorado; May 19, 2003 – June 30, 2005; Geophysical Statistics Project

Stephan De Wekker; Pacific Northwest National Laboratory; February 5-8, 2004 and July 10-22, 2004; Terrestrial Sciences Section

Scott Doney; Woods Hole Oceanographic Institution; November 17-20, 2003; Oceanography Section

Dorin Drignei; Iowa State University; June 1, 2004 – May 31, 2005; Geophysical Statistics Project

Greg Duane; University of Minnesota; October 1, 2003 – November 30, 2004; Climate Dynamics and Predictability Section

Paul Duffy; University of Alaska; September 1, 2003 – September 1, 2004; Terrestrial Sciences Section

Ken Eggert: LANL; February 11-12, 3004; Terrestrial Sciences Section

Johan Feddema; University of Kansas; April 1, 2004 – June 1, 2004; Terrestrial Sciences Section

Joel Finnis, University of Colorado; January 2, 2004 – December 31, 2004; Oceanography Section

Chris Forest; Massachusetts Institute of Technology; July 29, 2004 – August 1, 2004; Geophysical Statistics Project

Baylor Fox-Kemper; Princeton University; March 14-16, 2004; Oceanography Section

Christian Franzke; New York University; June 1-30, 2004; Climate Dynamics and Predictability Section

Reinhard Furrer; Bern, Switzerland; September 1, 2003 – June 30, 2005; Geophysical Statistics Project

Tilmann Gneiting; University of Washington; May 24-28, 2004; Geophysical Statistics Project

Heather Graven; University of California at San Diego; July 19-28, 2004; Terrestrial Sciences Section

David Griggs; Hadley Center; November 17-19, 2003; Climate and Global Dynamics Division

Dale Haidvogel; Rutgers University; June 10 – August 10, 2004; Oceanography Section

Robert Halberg; Princeton-GFDL; November 5-7, 2003; Oceanography Section

James Hansen; Massachusetts Institute of Technology, June 15, 2004 – July 15, 2004; Climate Dynamics and Predictability Section

Matthew Hecht; Los Alamos National Laboratory; November 24-26, 2003; Oceanography Section

Ann Henderson-Sellers; Australian Nuclear Science and Technology Organization; June 23, 2003 – January 1, 2004; Terrestrial Sciences Section

Peter Hildebrand; NASA; July 1-29, 2004; Climate Analysis Section

Matthew Huber; Purdue University; July 23, 2004 – August 31, 2004; Climate Change Research Section

Yanli Jia; University of Hawaii; June 5, 2005 – August 5, 2004; Oceanography Section

Markus Jochum; Massachusetts Institute of Technology; March 17-18, 2004; Oceanography Section

Fortunat Joos; Bern University; July 3-10, 2004; Terrestrial Sciences Section

Cari Kaufman; Carnegie Mellon University; May 15, 2004 – July 17, 2004; Geophysical Statistics Project

David Keith; Carnegie Mellon University; March 9-14, 2004; Terrestrial Sciences Section

Patrice Klein; IFREMER; November 3-15, 2003; Oceanography Section

Zav Kothavala; India; February 15, 2004 – August 15, 2004; Climate Change Research Section

John Kutzbach; University of Wisconsin; July 26, 2004 – August 20, 2004; Climate Change Research Section

Young-Oh Kwon; University of Washington; December 1, 2003 – November 30, 2004; Climate Analysis Section

Emily Lane; University of California, LA; June 8, 2004 – August 2, 2004; Oceanography Section

Peter Hjort Lauritzen; September 1, 2004 – December 1, 2004; Climate Modeling Section

David Lawrence; Los Alamos, NM; December 1, 2003 – September 30, 2004; Climate Change and Research Section

Thomas Lee; Colorado State University; June 30, 2004 – June 30, 2005; Geophysical Statistics Project

Sonya Legg: Woods Hole Oceanographic Institution; October 9, 2003; Oceanography Section

Tomoko Matsuo; HAO, NCAR; October 1, 2003 – June 30, 2005; Geophysical Statistics Project

Jim and Diana McWilliams; UCLA; July 15, 2004 – August 20, 2004; Oceanography Section

David Mitchell; Desert Research Institute; May 1, 2004 – July 31, 2004; Climate Modeling Section

Koki Maruyma; CRIEPI; November 9-13, 2003; Oceanography Section

Michael Montgomery; Colorado State University; November 15, 2003 –December 31, 2003; Oceanography Section

Philip Mote; JISAO/SMA Climate Impacts Group; May 11-12, 2004; Terrestrial Sciences Section

Steve Mullen; University of Arizona; July 6, 2004 – August 6, 2004; Climate Dynamics and Predictability Section

Stefan Muszala; University of Colorado; October 1, 2003 – September 30, 2004; Climate Modeling Section

Antonio Navarra; IMGA-CNR, Italy; July 22, 2004 – August 13, 2004; Climate Dynamics and Predictability Section

David Noone; California Institute of Technology; October 26-31, 2003; Climate Modeling Section and Terrestrial Sciences Section

Hee-Seok Oh; University of Alberta; December 4-14, 2003; April 14-18, 2004 and June 16-21, 2004; Geophysical Statistics Project and Climate Change Research Section

Debashis Paul; Stanford University; June 20-26, 2004; Geophysical Statistics Project

David Parks; NEC-HNSX Supercomputers; November 10-14, 2003; Oceanography Section

Synte Peacock; University of Chicago; October 3- 8, 2003; Oceanography Section

Roger Peng; Johns Hopkins University; May 16-18 2004; Geophysical Statistics Project

Judith Perlwitz; Columbia University; September 1, 2004-December 1, 2004; Climate Analysis Section

Angela Pignotti, University of California at Santa Cruz; June 15, 2004 – September 3, 2004; Geophysical Statistics Project

Lorenzo Polvani; Columbia University, May 26-31, 2004 and August 11-14, 2004; Climate Dynamics and Predictability Section and Scientific Computing Division

Vicky Pope; Hadley Center; November 17-19, 2003; Climate and Global Dynamics Division

Thomas (Zach) Powell; University of California at Berkeley; August 10, 2004 –
August 1, 2005; Oceanography Section

Marilyn Raphael; UCLA; February 19-20, 2004 and June 21, 2004 – December 31, 2004; Climate Modeling Section

Eva Restle; University of Quebec; September 1-15, 2004; Geophysical Statistics Project

Kelvin Richards; University of Hawaii; June 5, 2004 – August 5, 2004; Oceanography Section

David Ruppert; Cornell University; January 17-22, 2004; Geophysical Statistics Project

Bill Sacks; University of New Hampshire; September 30, 2003 – May 30, 2005; Terrestrial Sciences Section

Steve Sain; University of Colorado at Denver; October 1, 2003 – June 30, 2005; Geophysical Statistics Project

Bruno Sanso; University of California at Santa Cruz; February 13, 2004; Geophysical Statistics Project

Takayuki Sasakura; NEC Solutions America; October 14-17, 2003; Oceanography Section

Frank Selten; KNMI, The Netherlands; May 30, 2004 – August 1, 2004; Climate Dynamics and Predictability Section

Bin Shi; Georgia Institute of Technology; June 10, 2004 – August 11, 2004; Geophysical Statistics Project

Tingting Shu; University of Alberta; June 12, 2004 – July 17, 2004; Geophysical Statistics Project

Michael Smyth; Jet Propulsion Laboratory; October 13k 2003; Climate Modeling Section

Uli Schneider; University of Colorado at Boulder; October 1, 2003 – June 30, 2005; Geophysical Statistics Project

Ryan Sriver; Purdue University; July 23, 2004 – August 31, 2004; Climate Change Research

Chris Storlie; CSU; October 1, 2003 – June 30, 2005; Geophysical Statistics Project

John Snyder; NEC-HNSX Supercomputers; November 10-14, 2003; Oceanography Section

Nils Christian Stenseth; University of Oslo; November 30 2003 – December 2, 2003; Terrestrial Sciences Section

Jonathan Stroud; University of Pennsylvania; May 1-31, 2004; Geophysical Statistics Project

Hiroshi Takahara; NEC Corporation, Tokyo, Japan; October 14-17, 2003; Oceanography Section

Roger Temam; Indiana University; July 13-16,2004 and August 4-13, 2004; Climate Dynamics and Predictability Section

DaisukeTsumune; CRIEPI; October 1, 2003 – March 26, 2004; Oceanography Section

Hans von Storch; Institute of Coastal Research; December 8-11, 2003; Geophysical Statistics Project

Ilana Wainer; University of Sao Paulo, Brazil; January 6, 2004 – February 14, 2004; August 1-31, 2004; Climate Change Research Section

Wilbert Weijer; Scripps Institution of Oceanography; March 11-12, 2004; Oceanography Section

Leah Welty; Johns Hopkins University; May 16-18, 2004; Geophysical Statistics Project

Yoshikatsu Yoshida; CRIEPI; October 14-17, 2003; Oceanography Section

Masaru Yoshioka; University of California, Santa Barbara; October 1, 2003 – June 30, 2004; Terrestrial Sciences Section

Bin Yu; University of California at Berkeley; April 26-27, 2004; Geophysical Statistics Project

Charlie Zender; University of California at Irvine; December 13, 2003 – January 17, 2004; Terrestrial Sciences Section

Rong Zhang; Princeton University; March 16-17, 2004; Oceanography Section

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Collaborators

Rodrigo Abarca del Rio; Universidad de Concepcion, Chile; climate-solar variability

Michael Alexander; NOAA, Climate Diagnostics Center; climate variability; diagnosis of CCSM experiments

Julie Arblaster; BMRC; Climate Change Prediction Program

Phil Arkin; University of Maryland; reanalysis

Gregg Asner; University of Colorado; ecosystem dynamics

Julio Bachmeister; NASA Global Modeling and Assimilation Office; Gravity wave parameterizations

David Bader; Lawrence Livermoe National Laboratory; Climate Change Prediction Program

Ferdinand Baer; University of Maryland; spectral element atmosphere model

Anjuli Bamzai; U.S. Department of Energy; Climate Change Prediction Program

Bernard Barnier; Laboratoire des Ecoulements Geophisiques et Industiels, France; oceanography

Jill Baron; Colorado State University; ecosystem dynamics, hydrology, and climate change

Mark Battle; Bowdoin College; atmospheric chemistry

David Beerling; University of Sheffield; paleoclimate and vegetation

Michael Bender; Princeton; geochemistry and oceanography

John Bergman; NOAA Climate Diagnostics Center; cloud radiation

L. Mark Berliner; Ohio State University; Bayesian models; ensemble data assimilation

Craig Bishop; Naval Research Laboratory; ensemble data assimilation

Cecilia Bitz; University of Washington; polar climate

Meinte Blaas; University of California, Los Angeles, oceanography

Mike Blackburn; University of Reading, Aqua Planet Experiment

George Boer; Canadian Centre for Climate Modelling and Analysis; model intercomparison

Tami Bond; University of Illinois; aerosols

Jim Boyle; Lawrence Livermore National Laboratory; climate change detection; CCPP-ARM parameterization testbed

Pascale Braconnot; LSCE; paleoclimate modeling

Ray Bradley; University of Massachusetts; paleoclimate

Rob Braswell; University of New Hampshire; data assimilation and remote sensing

Guy Brasseur; Max Plank Institute for Meteorology, Hamburg; Monsoon modeling

Amy Braverman; Jet Propulsion Laboratory; data compression

Chris Bretherton; University of Washington; boundary layer parameterization

Keith Briffa; Climatic Research Unit; paleoclimate Rob Bryant; Sheffield University; hydrology

Neil Buchart; The Met Office; WACCM data for ozone trends

Doug Capone; University of Southern California; oceanography

Antonietta Capotondi; NOAA, Climate Diagnostics Center; oceanography

Xavier Capet: University of California, Los Angeles; oceanography

Rick Cederwell; PCMDI, Lawrence Livermore National Laboratory, CCPP-ARM parameterization testbed

Ben Chandran; University of California, Los Angeles; coherent structures of turbulent flows in astrophysical regimes

Oliver Chadwick; University of California, Santa Barbara; soil

Ping Chang; Texas A&M University; tropical Atlantic variability and Institute of Arctic Biology, University of Alaska, Fairbanks; ecosystem dynamics

Tom Charlock; NASA Langley Research Center; calculation of aerosol effects on surface energy budget

Dudley Chelton; Oregon State University; air-sea interactions

Clifford Chen; Fujitsu America Inc.; CCSM development

T.-C. Chen; Iowa State University; climate variability

Galina Churkina; Max-Planck Institute; ecosystem modeling

Gabriel Clauzet; Universidade de Sao Paulo, Brazil ; paleoclimate modeling

Amy Clement; University of Miami; paleoclimate

Bruce D. Cornuelle; University of California, San Diego; oceanography

Curtis Covey; Program for Climate Model Diagnosis and Intercomparison (PCMDI); model intercomparison

Steven Cowley; University of California, Los Angeles; coherent structures in turbulent flows in astrophysical regimes

Thomas Crowley; Texas A&M University; paleoclimate modeling

Ulrich Cubasch; DKRZ; climate change research

Judith Curry; Georgia Institute of Technology; ice/ocean interactions

Laurent Debreu; University of California, Los Angeles; geophysical fluid dynamics

Andrew Dessler; University of Maryland; Isotope modeling in WACCM/CAM

Tommy Dickey; University of California, Santa Barbara; upper ocean physics

Chris Ding; Lawrence Berkeley National Laboratory; climate system model infrastructure

Scott Doney; Woods Hole Oceanographic Institute, oceanography; modeling ocean tracers

Leo Donner; Geophysical Fluid Dynamics Laboratory, cumulus parameterization

Charles Doutriaux; Lawrence Livermore National Laboratory; climate change detection

Bob Drach, Lawrence Livermore National Laboratory; climate change research

John Drake; Oak Ridge National Laboratory; Collaborative design and development of CCSM for terascale computers

Philip Duffy; Lawrence Livermore National Laboratory; high-resolution global modeling

Timothy Dunkerton; Northwest Research Associates; Monsoon modeling

Jean-Louis Dufresne; Centre National de la Recherche Scientifique (CNRS), France; atmospheric radiation

Steve Eckerman; NRL; Gravity wave parameterizations

James Edmonds; Joint Global Climate Research Institute; emissions modeling

Annemarie Eldering; NASA Jet Propulsion Lab; Satellite observations, validation and modeling UT/LS

Jerry Elwood; U.S. Department of Energy; Climate Change Prediction Program

Kerry Emanuel; Massachusetts Institute of Technology; convection

Jenni Evans; Pennsylvania State University; climate extremes

Johannes Feddema; University of Kansas; land surface changes

Eric Fetzer; NASA Jet Propulsion Lab; Satellite observations, validation and modeling UT/LS

Chris Field; Carnegie Institution of Washington; ecosystem dynamics

Luc Fillion; Atmospheric Environment Service, Canada; variational data assimilation

Michael Fiorino; Lawrence Livermore National Laboratory, climate change detection

Joel Finnis; University of Colorado at Boulder; polar climate

Gregory Flato; University of Victoria

Chris Folland; Hadley Centre for Climate Prediction and & Research; climate

Piers Forster; University of Reading; Radiation observations and modeling

Jorgen Frederiksen; Commonwealth Scientific and Industrial Research Organization, Australia; interannual variability

Mark Friedl; Boston University; remote sensing and land surface modeling

Lee Fu; Jet Propulsion Laboratory; general ocean circulation and climate dynamics

Qiang Fu; University of Washington; Radiation observations and modeling

Monserrat Fuentes; North Carolina State University; statistics in the atmosphere

Masatomo Fujiwara; Hokkido University; Radiation observations and modeling

Inez Fung; University of California, Berkeley; global carbon cycle

Robert Gallimore; University of Wisconsin; paleoclimate modeling and vegetation dynamics

Blanca Gallego; University of California, Los Angeles; oceanography

Kevin Gallo; National Climatic Data Center; climate analysis

Catherine Gautier; University of California, Santa Barbara; atmospheric radiation

Peter Gleckler; Lawrence Livermore National Laboratory; model intercomparisons and climate change research

Stephen M. Griffies; Geophysical Fluid Dynamics Laboratory; ocean model intercomparison and development

Andrei Gritsoun; Russian Academy of Science; fluctuation dissipation applied to climate

Richard Grotjahn; University of California, Davis; polar meteorology/climat

Dale B. Haidvogel; Rutgers University; ocean modeling and data assimilation, and coastal ocean modeling

Gregory Hakim; University of Washington; ensemble data assimilation

Tom Hamill; Cooperative Institute for Research in Environmental Sciences; ensemble data assimilation

Bill Hamner; University of California, Los Angeles; U.S. West Coast ocean modeling

Weiqing Han; University of Colorado, Boulder; ocean circulation

Jenny Hand; Colorado State University; atmospheric aerosol

Jim Hansen; Massachusetts Institute of Technology; ensemble data assimilation

Fumio Hasebe; Ibaraki University; Balloon based observations of tropical UT/LS

Sandy Harrison; University of Bristol; paleoclimate

Matthew Hecht; Los Alamos National Laboratory; modeling of the ocean general circulation

Isaac Held; Geophysical Fluid Dynamics Laboratory; Intergovernmental Panel on Climate Change

Robert Herman; NASA Jet Propulsion Lab; H2O observations and satellite validation in UT/LS

Kathy Hibbard; Oregon State University; ecosystem modeling

Jay Hnilo; PCMDI, Lawrence Livermore National Laboratory; CCPP-ARM parameterization testbed

Martin Hoerling; Cooperative Institute for Research in the Environmental Sciences; climate

Forrest Hoffman; Oak Ridge National Laboratory; land surface modeling

Brian Hoskins; University of Reading, Aqua Planet Experiment

Paul Houser; Goddard Space Flight Center; land surface modeling

Matthew Huber; University of California, Santa Cruz; paleoclimate

Malcolm Hughes; University of Arizona; paleoclimate

Elizabeth Hunke; Los Alamos National Laboratory; sea-ice modeling and dynamics

Shin-ichi Ichikawa; Fujitsu Ltd.; CCSM development

Shiro Imawaki; Research Institute for Applied Mechanics; oceanography

Mark Iredell; National Centers for Environmental Prediction; ensemble data assimilation

William Irion; NASA Jet Propulsion Lab; Satellite observations, validation and modeling UT/LS

Robert L. Jacob; Argonne National Laboratory; CCSM development

Anthony Janetos; NASA; Vegetation/Ecosystem Modeling and Analysis Project (VEMAP) and ecosystem dynamic

Steve Jayne; Woods Hole Oceanographic Institution; oceanography

Charles Jones; University of California, Santa Barbara; atmospheric dynamics

Phil D. Jones; Climate Research Unit, paleoclimate/span>; IPCC

Phil Jones; Los Alamos National Laboratory; parallel climate modeling

Fortunat Joos; University of Bern; paleoclimate and carbon cycle

Per Kallberg; European Centre for Medium-Range Weather Forecasting; reanalysis

Tom Karl; National Climatic Data Center; climate change

David Karoly; University of Oklahoma; climate change indices

David Keith; Carnegie Mellon University, climate impacts

Shree Khare; Princeton University; ensemble data assimilation

George Kiladis; NOAA; scale interaction

Dong-Hoon Kim; CRIEPI Abiko Laboratory, Japan; global climatemodeling

Rodney Kinney; University of California, Los Angeles; coherent structures of turbulent flows in astrophysical regimes

Hideyuki Kitabata; CRIEPI, Japan; CCSM development

Steve Klein; Geophysical Fluid Dynamics Laboratory, climate modeling

Patrice Klein; French Research Institute for Exploitation of the Sea (IFREMER); role of ocean meso-scale eddies in extracting wind energy

Tom Knutson; Geophysical Fluid Dynamics Laboratory; climate extremes

Hidemi Komatsu; Fujitsu Ltd.: CCSM development

Zav Kothavala; McMasters U niversity; paleoclimate modeling

Arun Kumar; National Centers for Environmental Prediction; climate modeling

John Kutzbach; University of Wisconsin; vegetation dynamics and paleoclimate modeling

Ulrike Langematz; Free University of Berlin; WACCM data for ozone trends

J. Walter Larson; Argonne National Laboratory; CCSM development Mojib Latif; Max-Planck-Institute; model intercomparison

Kara Lavender; Woods Hole Oceanographic Institution; velocity estimation

Beverly Law; Oregon State University; flux measurements

Mark Lawrence; Max Planck Institute; Indian Ocean Experiement (INDOEX)

Sonya Legg; Woods Hole Oceanographic Institution; oceanic deep convection

Warren Lee; Canadian Centre for Climate Modelling and Analysis; coupled modeling

Xin-Zhong Liang; Illinois State Water Survey; water cycle diurnal cycle

S.-J. Lin; NASA Data Assimilation Office; numerical atmospheric modeling

Ernst Linder; University of New Hampshire; geophysical statistics

Bill Lipscomb; Los Alamos National Laboratory; polar climate

Ping Liu; IPRC, University of Hawaii; parallel climate modelZhengyu Liu; University of Wisconsin; paleoclimate modeling

Johannes Loschnigg; International Pacific Research Center (IPRC), University of Hawaii; Asian-Australian monsoon

Chao Luo; University of California, Santa Barbara; aerosols

Roger Lukas; University of Hawaii; scale interaction

Gudrun Magnusdottir; University of California, Irvine; sea ice; atmospheric dynamics

Jean-Francois Mahfouf; European Centre for Medium-Range Weather Forecasts; assimilation of precipitation data

Andrew Majda; Courant Institute; reduced stochastic modeling

Robert Malone; Los Alamos National Laboratory; Climate Change Prediction Program

Mathew Maltrud; Los Alamos National Laboratory; ocean modeling for climate, ocean model development, and modeling the circulation of the North Atlantic

Michael Mann; University of Virginia; paleoclimate

Mike Manton; Bureau of Meteorology Research Centre; global climate observing system

Patrick Marchesiello; LMC-IMAG, Grenoble, France; U.S. West Coast ocean modeling

Shawn Marshall; University of Calgary; paleoclimate modeling

Koki Maruyama,CRIEPI; CCSM on the Earth Simulator; global climate modeling

Jason Maron; University of California,Los Angeles; astrophysics

Paul Mason; University of Reading; global climate observing system

Adrian Matthews; University of East Anglia; planetary scale waves

Nikolai Maximenko; University of Hawaii; oceanography

Julie L. McClean; Naval Postgraduate School; modeling of the ocean general circulation

Trevor McDougall; CSIRO Oceanography Centre, Hobart; ocean modeling

David McGuire; University of Alaska, Fairbanks; Vegetation/Ecosystem Modeling and Analysis Project (VEMAP) and ecosystem dynamics and Arctic vegetation

Carl Mears; Remote Sensing Systems; climate change detection

Wendy Meiring; University of California, Santa Barbara; statistics in the atmosphere

Jerry Melillo; Marine Biological Laboratory; Vegetation/Ecosystem Modeling and Analysis Project (VEMAP) and

ecosystem dynamics

Bill Merryfield; Canadian Centre for Climate Modelling and Analysis; coupled modeling

Tony Michaels; University of Southern California; oceanography

Gifford Miller; University of Colorado; paleoclimate modeling

Martin Miller; European Center for Medium-Range Weather Forecasts; transpose AMIP (Atmospheric Model Intercomparison Project)Ralph Milliff; Colorado Research Associates; oceanography

David Mitchell; Desert Research Institute; ice microphysics

Martin Mlynczak; NASA Langley Research Center; far-infrared spectrometer John Moisan; University of Long Island; coastal ocean modeling

Adam Monahan; University of Victoria, Canada;El Nino variability Russ Monson; University of Colorado; carbon fluxes

Jefferson Keith Moore; University of California, Irvine; oceanography

Richard Moritz; University of Washington; sea-ice modeling and albedos

Steve Mullen; University of Arizona; analysis error estimation

Peter Muller; University of Hawaii; oceanography

Norikazu Nakashiki ; Central Research Institute of Electric Power Industry (CRIEPI), Japan; global climate modeling

ility Philippe Naveau; University of Colorado; paleoclimate and statistics

Richard Neal; NOAA Climate Diagnostics Center, Aqua Planet Experiment

Nikolay P. Nezlin; University of California, Los Angeles and P.P. Shirshov Institute of Oceanology RAS, Moscow, Russia; oceanography

Pearn P. Niiler; Scripps Institution of Oceanography; air-sea interaction

David Noone; University of Colorado, Boulder; Isotope modeling in WACCM/CAM

Robert Oglesby; Purdue University; paleoclimate modeling and sensitivity experiments with Community Climate Model

Hee-Seok Oh; University of Alberta; paleoclimate and statistics

Dennis Ojima; Colorado State University; ecosystem dynamics

Greg Okin; University of Virginia; terrestrial ecosystems

Everst T. Ong; Argonne National Laboratory; CCSM development

Andreas Oschlies; University of Kiel; ocean modeling

Jonathan Overpeck; University of Arizona; paleoclimat

Breck Owens; Woods Hole Oceanographic Institution; oceanography

David Parrish; National Center for Environmental Prediction; ensemble data assimilation

Ari Patrinos; U.S. Department of Energy; Climate Change Prediction Program

Steven Pawson; NASA Data Assimilation Office; gravity-wave paramaterization

Bill Pennell; Pacific Northwest National Laboratory; Accelerated Climate Prediction Initiative (ACPI)

Pierrick Penven; Institut de Recherche pour le Developpement and Laboratore de Physique des Oceans; coastal ocean modeling

Jon Petch; The Met Office; GCSS WG4 Case 5Tom Phillips; PCMDI, Lawrence Livermore National Laboratory, CCPP-ARM parameterization testbed

Hugh Pitcher; Joint Global Climate Research Institute; emissions modeling

Alan Plumb; Massachusetts Institute of Technology; atmospheric dynamics Lorenzo Polvani; Columbia University; stratosphere-troposphere interaction

Jerry Potter; PCMDI, Lawrence Livermore National Laboratory; atmospheric dynamics Colin Prentice; Max-Planck-Institute for Biogeochemistry, Germany; ecosystem dynamics

Ronald Prinn; Massachusetts Institute of Technology; atmospheric chemistry V. Ramanathan; Scripps Institution of Oceanography; clouds and radiation

Marilyn Raphael; University of California, Los Angeles; quasi-stationary waves of the Southern Hemisphere; polar climate

Juan Restrepo; University of Arizona; wind-driven ocean circulation

Richard Richels; Electric Power Research Institute; emissions modeling

Lucrezia Ricciardulli; Remote Sensing Systems; Convective Parameterizations

Eric Richard; Aeronomy Lab NOAA; O3 observations and satellite validation in UT/LS

James Risby; Carnegie-Mellon University; climate change detection, and (ACACIA) A Consortium for the Application of Climate Impact Assessments

Dar Roberts; University of California, Santa Barbara, land surface

David Robinson; Rutgers University; climate analysis

Alan Robock; Rutgers University; volcanic aerosols

Mark Rodwell; European Centre for Medium-range Weather Forecasting; climate modeling

Anthony Rosati; NOAA/GFDL; ocean model intercomparison and development

Karen Rosenlof; Aeronomy Lab NOAA; H2O, temp observations and satellite validation in UT/LS

William B. Rossow; NASA/GISS; ocean forcing data sets

Doug Rotman; Lawrence Livermore National Laboratory; climate system model infrastructure

Steven Running; University of Montana; ecosystem dynamics and land surface modeling

Scott Rutherford; Roger Williams University; paleoclimate

Suranjana Saha; National Center for Environmental Prediction; ensemble
data assimilation

Eileen Saiki; Ball Aerospace & Technologies Corp.; direct numerical simulations of three-dimensional thermohaline fingering in the ocean

Murry Salby; University of Colorado; satellite data analysis

Bruno Sanso; University of California, Santa Cruz; Bayesian statistics

Benjamin D. Santer; Lawrence Livermore National Laboratory; climate change

Prashant Sardeshmukh; NOAA, Climate Diagnostics Center; climate

Yuji Sasaki; NEC Informatec Systems; CCSM development

Takayuki Sasakura; NEC solutions (America), Inc.; CCSM development

Robert Sausen; Institute fur Physik der Atmosphare; climate change detection

Crystal Schaaf; Boston University; remote sensing and land surface modeling

Matthias Schabel; Remote Sensing Systems; climate change detection

Frank Selten; Royal Netherlands Meteorological Institute, The Netherlands; diagnosis of CCSM climate change experiments

Mark Serreze; CIRES, University of Colorado; polar climate

Alexander Shchepetkin; University of California, Los Angeles; geophysical fluid dynamics, and coastal ocean modeling

Sang-Ik Shin; NOAA Climate Diagnostics Center; paleoclimate

Masato Shiotani; Kyoto University; Balloon based observations of tropical UT/LSRon Siefert; University of Maryland; atmospheric chemistry

David Siegel; University of California, Santa Barbara; oceanography

Adrian Simmons; European Centre for Medium-Range Weather Forcasting; reanalysis Harper Simmons; University of Alaska, Fairbanks; ocean model comparison and development

Stephen Sitch; Potsdam Institute for Climate Impact Research, Germany; Vegetation/Ecosystem Modeling and Analysis Project (VEMAP) and ecosystem dynamics

Lisa Sloan; University of California, Santa Cruz; paleoclimate modeling

Richard Smith; Los Alamos National Laboratory;modeling of the ocean general circulation

Steve Smith; Joint Global Climate Research Institute; emissions modeling

John Snyder; NEC Solutions (America), Inc.; CCSM development

Brian Soden; Geophysical Fluid Dynamics Laboratory; Iupper troposphere water vapor

Susan Soloman; NOAA; Intergovernmental Panel on Climate Change; precipitation variability

Ken Sperber, Lawrence Livermore National Laboratory; intraseasonal variability

Will Steffen; International Geosphere-Biosphere Programme Secretariat, Sweden; ecosystem dynamics

Jacek Stegman; University of Stockholm; upper atmosphere data Nils Chr. Stenseth; University of Oslo; climate, biology

Leo Sternberg; University of Miami, isotope measurements

Robert Stockwell; Colorado Research Associates(CORA);>meteorology; transfer of wind energy to the ocean

Keith Stolzenbach; University of California, Los Angeles; U.S. West coast ocean modeling

Ron Stouffer; Geophysical Fluid Dynamics Laboratory; model intercomparison

Ajit Subramanian; University of Maryland; oceanography

Yin Sun; NOAA; IPCC

Hiroshi Takahara; NEC Corporation; CCSM development

Karl Taylor; Lawrence Livermore National Laboratory; netCDF standards, and database management

Roger Teman, University of Indiana; numerical mathematics

Alan Townsend; University of Colorado; ecosystem dynamics

Daisuke Tsumune; CRIEPI; global climate modeling

Jun-ichi Tsutsui; CRIEPI; global climate modeling

Junichiro Ueno; Fujitsu Ltd.;CCSM development

Sakari Uppala; European Centre for Medium-range Weather Forcasting; reanalysis

Francisco Valero; Scripps Institution of Oceanography; clouds and climate

Harry van Loon; Colorado Research Associates; southern oscillation

Andreas Villwock; World Climate Research Programme; CLIVAR

Martin Visbeck; Lamont-Doherty Earth Observatory; CLIVAR

Andrew Vogelmann; Scripps Institution of Oceanography; satellite analysis of cloud water

Holger Vomel; CMDL, NOAA; Radiation observations, balloon observations of UT/LS

Tomislava Vukicevic; Cooperative Institute for Research in the Atmosphere, Colorado State University; adjoint methods

Ilana Wainer; University of Sao Paulo, Brazil; South Atlantic in the CCSM and paleoclimate

Guiling Wang; Goddard Space Flight Center; land surface modeling

Christopher Webster; NASA Jet Propulsion Lab; Isotope and H2O observations and modeling in UT/LS

Michael Wehner; Lawrence Berkeley National Laboratory; climate change detection

Klaus Weickmann; NOAA; scale interaction

Elliot Weinstock; Harvard University; H2O observations and satellite validation in UT/LS

Jeffrey Weiss; University of Colorado; vortex dynamics; data assimilation

Frank Wentz; Remote Sensing Systems; climate change detection

Penny Whetton; Commonwealth Scientific and Industrial Research Organization, Australia; climate extremes

Bruce Wielicki; NASA Langley; Clouds and the Earth's Radiative Energy System (CERES)

Christopher K. Wikle; University of Missouri; Bayesian hierarchical modeling; El Niño forecasting, statistics in the atmosphere, and data; ensemble data assimilation

David Winker; NASA Langley Research Center; assimilation of LITE and PICASSO lidar aerosol profiles

Michael Winton; GFDL; ocean model intercomparison and development

Annie Wong; Joint Institute for the Study of the Atmosphere and the Oceans; climate

Sun Wong; University of Maryland; Isotope modeling in WACCM/CAM

Patrick Worley; Oak Ridge National Laboratory; CCSM development

Yoshikatsu Yoshida; CRIEPI; global climate modeling

Jin-Yi Yu; University of California, Irvine; oceanography

Minghua Zhang; State University of New York; parameterizations of cumulus convection

Guang J. Zhang; Scripps Institution of Oceanography

Francis Zwiers; Canadian Centre for Climate Modelling and Analysis; climate extremes

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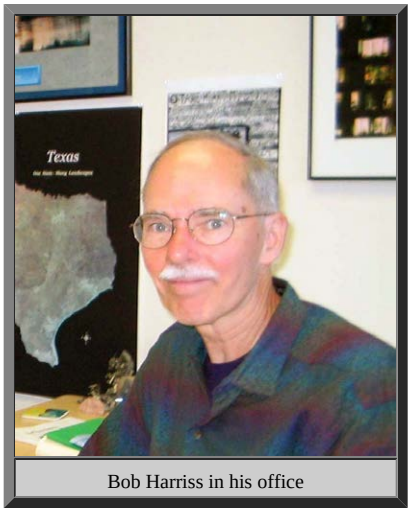
ESIG Director's Message



Bob Harriss in his office

In June 2004, the Environmental and Societal Impacts Group (ESIG) catalyzed the **Workshop on Communicating Urgency, Facilitating Social Change: New Strategies for Climate Change**, which engaged a diverse group of academics, environmental advocates, and media experts in a dialogue that aims to integrate considerations of risk, ethics, policy, organizational and individual behaviors in the context of improving climate change communication. One product of the workshop will be a unique edited volume on strategies for improving the public discourse on human actions and climate change. This book will also provide an exciting research agenda for advancing the science of ecoliteracy in America.

A **Summer Colloquium on Climate and Health**, sponsored by ESIG, NCAR's Strategic Initiative on the Science Weather and Climate Impact Assessment, and NCAR's Advanced Studies Program, brought together 31 senior experts and 30 international graduate and postgraduate students to shape a program for research and professional training in climate and health. This emerging field of interdisciplinary exploration must nurture a community of practitioners and scholars who will build a scientific foundation of shared theory and methods for understanding the role of climate in health. The NCAR **Strategic Initiative on the Science of Weather and Climate Impact Assessment** will take the leadership role in building momentum for progress in the area that will surely grow in importance in the warmer world of the twenty-first century.

This Annual Scientific Review reports many other important accomplishments in ESIG's ongoing programs in the use and value of weather and climate information, weather and climate impact assessment, and education and outreach. These research activities reach across the nation and the world, with an emphasis on connecting science to help create better futures for humankind.

The end of this fiscal year gave birth to the Institute for the Study of Society and Environment (ISSE). The ESIG program forms the core of this new NCAR Institute. ESIG staff dedicated an enormous amount of effort throughout this year to shape an expanded vision and research agenda for the future growth in societal impacts research at NCAR. New programmatic emphases will include research on process studies related to vulnerability, adaptation, thresholds, and resilience of coupled social and natural systems, and an increased focus on the role of uncertainty in the use of scientific information for decision making. The existing highly productive ESIG research, education, and outreach programs will continue in the new ISSE organization. The commitment of NCAR to a more vigorous leadership role in future national and international environment-society programs reflects the more than three decades of outstanding contributions by the scientists and staff of the Environmental

Deputy Director Linda Mearns

and Societal Impacts Group.

--Robert Harriss

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ESIG Executive Summary

ESIG (Environmental and Societal Impacts Group) has been a program at the National Center for Atmospheric Research for more than three decades, and at the beginning of FY2005 (1 October 2004) expanded into the Institute for the Study of Society and Environment (ISSE). This final ESIG Annual Scientific Report thus serves both as an affirmation of the tremendous accomplishments of the ESIG staff over the last fiscal year and as a springboard into ISSE's future. “ESIG” will remain a subgroup within the institute.

The main focus of ESIG's FY2004 research falls within four categories:

(1) fundamental research;
(2) enhancing productivity and resilience of natural resources;
(3) protection of life and property; and
(4) education and outreach activities.

Highlights of ESIG's FY04 activities are summarized below and the full description of ESIG activities is available in this report under ESIG Achievements.

Fundamental Research

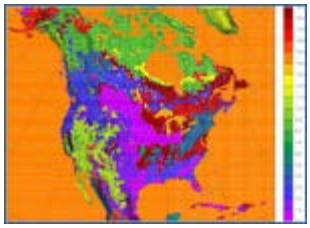
Climate and weather phenomena and their impacts create a variety of hazards as well as opportunities for societies across various spatial scales, from local to global. ESIG advances the science of impacts assessments, conducts climate variability studies, characterizes and communicates uncertainties in decision-making, develops climate scenarios, and performs interdisciplinary research in climate and human health. Also, ESIG (ISSE) is increasing its role in serving decision support needs in regards to the global carbon cycle. ESIG leads, as well as is involved with, several of the NCAR-wide Strategic Initiatives.

Major Highlights during FY2004:

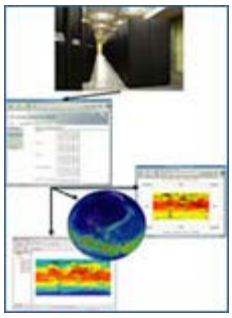
The Weather and Climate Impact Assessment Science Initiative (herein referred to as the Assessment Initiative), with Director Linda Mearns, Doug Nychka (CGD), Acting Director for much of FY04, and Lisa Dilling as Project Manager, is based in ESIG. The Assessment Initiative brings together scientists from ESIG, CGD, RAP, UCAR's E&O, and several UCAR member universities to address the themes of climate uncertainty, extremes, and climate and health.

The Assessment Initiative's interactions with the university community include projects involving the Johns Hopkins University (JHU), University of Kansas, University of Colorado in Boulder, and the University of North Carolina. University involvement extends across several of the Initiative's projects, including the role of climate in human

health, land cover forcing from the SRES scenarios in climate models, climate variability in past centuries, and the effects of extreme meteorological events in climate models. A comprehensive high-quality website (www.assessment.ucar.edu) was created during FY04 for the Initiative to provide extensive information on each of the subprojects and reinforces the Assessment Initiative as a bridge between regional assessments and global/regional modeling observations. The Initiative held a Summer Colloquium on Climate and Health (co-Chaired by Jonathan Patz (JHU), in collaboration with ASP. It is hoped that a Colloquium series based on this initial prototype will become an annual world-class training and capacity-building program in interdisciplinary climate and health studies.



The North American Regional Climate Change Assessment Program (NARCCAP) was also initiated by Linda Mearns during FY04. The main goals of this program are to explore multiple uncertainties in regional model and global climate model regional projections, as well as to develop multiple high-resolution climate scenarios for use in impacts models. Click on the thumbnail image at right for a larger view of US topography and GLCC (global land cover characteristics) vegetation.



The Geographic Information Systems (GIS) Strategic Initiative is co-hosted in ESIG and RAP, with Olga Wilhelmi as Director and Jennifer Boehnert (ESIG/RAP) as NCAR's GIS Coordinator. Terri Betancourt (RAP) was a co-Director in FY04. This initiative focuses on bridging GIS and the atmospheric sciences by developing infrastructure and methods to manage and distribute geospatial data on research in GIS technology, as well as supporting scientific research projects at NCAR/UCAR that use GIS technologies. In FY04, the GIS Initiative started a "GIS Climate Change Scenarios" project to serve a wide external community of GIS users interested in interdisciplinary issues of global climate change. A GIS data portal will allow for a web-based distribution of climate change model output data in a GIS format, which will be used in the upcoming Fourth Assessment Report (AR4) of the IPCC by the Community Climate Systems Model (CCSM). Click on the thumbnail image at left for a larger view of the CCSM IPCC data integration and distribution.

Other ESIG scientific staff contributed in FY04 to NCAR's Wildland Fire Strategic Initiative (Kathleen Miller, Robert Harriss, Seth McGinnis, and Olga Wilhelmi). Harriss and McGinnis collaborated with Brian Muller and Ernesto Arias (both of the University of Colorado at Boulder) on the development of computer-aided tools and methods for mitigation of wildfire hazards at the urban-wildland interface.

All these Initiatives received positive external reviews during FY04. The Review Committees assessed their relevance to national and international needs as well as their ability to cut across disciplinary and institutional boundaries.

In June 2004, Susanne Moser and Lisa Dilling co-hosted a groundbreaking three-day workshop entitled Communicating Urgency – Facilitating Social Change: New Strategies for Climate Change. The workshop brought together more than 45 experts from a wide range of academic disciplines as well as practitioners from local and state government, the business world, and the nonprofit civic sector to explore the effectiveness of communication strategies and ways to mobilize the public for stimulating behavioral, organizational and social change. This MacArthur-, NCAR- and NSF-funded project will produce several publications and new collaborations. An edited volume will be produced in FY05, and a paper was accepted for publication in *Environment*.

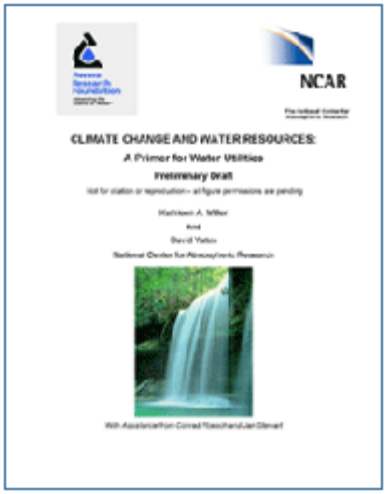
Linda Mearns, Claudia Tebaldi, Doug Nychka (CGD), and Richard Smith of the University of North Carolina developed a formal probabilistic treatment of super-ensemble experiments during FY04, by which different

ocean-atmosphere models are run under the same scenario of future anthropogenic emissions. Probability density functions (PDFs) of climate change signals are produced at regional levels and are used as input for climate change impact studies. This newly developed method will be applied to the runs that will be produced by the IPCC's Fourth Assessment.

Enhancing Productivity and Resilience of Natural Resources

ESIG conducts research to enhance the conservation, promotion, and sustainable development of natural resources and to examine the effect of resource scarcity on limiting a region's or country's possibilities for economic and sustainable growth. For the past several years, ESIG scientists have undertaken studies on, among others, climate variability in the Alaskan North Slope coastal region, coral reefs and climate change, fisheries and climate variability, and the effect of climate change on water resources.

Major Highlights during FY2004:



For water utilities to plan effectively for the possible effects of global warming on water resources, they need timely, credible, and useful information about the scientific basis for climate change and its implications for hydrology. NCAR and the American Water Works Association (AWWA) Research Foundation convened a two-day workshop in FY04 that brought together members of the atmospheric and hydrological scientific communities with representatives of the water utilities industry to discuss the potential impacts of climate change on water resources. As a result, they jointly prepared an informative document on climate change to help water utility managers prepare for the potential impacts of future climate change on water resources and the implications for utility operations and planning. During FY04, Kathleen Miller and David Yates (RAP) completed the initial draft manuscript for the AWWA. The document will be published by AWWA for water resource and water utility managers in FY05.

Collaboration by Kathleen Miller with researchers at the University of Montana and Moscow State Lomonosov University focused on the impacts of climate variability on international marine fisheries and the implications for the design of cooperative fishery management agreements. Research during FY04 included development of game theoretic models applied to a comparative assessment of the role of climate variability in international fisheries, especially highly migratory tuna resources. Miller assumed leadership of Working Group 5 (Socioeconomic Impacts and Management Implications) of the GLOBEC Climate Impacts on Oceanic Top Predators (CLIOTOP). She also prepared two papers (accepted for publication) with researchers from the University of British Columbia and the University of Portsmouth (UK) on an assessment of the pressures created by climate-related uncertainty for international fishery management agreements. Miller also created a new website during FY04 to provide readers with access to recent research in the field of water resources and climate change at www.isse.ucar.edu/water_climate/

Coral reefs are complex and important features of the marine environment and have the highest biodiversity of any marine ecosystem. The Pew Center on Global Climate Change commissioned Coral Reefs and Global Climate Change: Potential Contributions of Climate

Change to Stresses on Coral Reef Ecosystems as the tenth in a series of Pew Center reports examining the potential impacts of climate change on the environment. Report authors are R.W. Buddemeier (University of Kansas), Joan Kleypas (ESIG), and R.A. Aronson (Dauphin Island Sea Lab). They found that (1) increases in ocean temperatures associated with global climate change will increase the number of coral bleaching episodes; (2) increases in atmospheric concentration of CO_2 will drive changes in surface ocean chemistry; (3) the effects of global climate change will further degrade coral reef ecosystems; and (4) multiple strategies will be necessary to ensure their sustainability. The report is available in hard copy and on line at the Pew Center on Global Climate Change.

Protection of Life and Property

Natural systems vary naturally and – along with social environments – change over long time scales. Together with technological dependencies and interdependencies, these changing interactions pose lasting, and in some instances growing, challenges to the management of complex environmental disasters. Experience suggests that adverse effects of climate change and variability can be diminished through proactive and sustained risk reduction measures. ESIG scientists have studied ways to improve early warning systems of hydrological and meteorological hazards in order to alert at-risk people, communities, and governments about the possible onset of those hazards and impacts of extreme weather and climate events.

Major Highlights during FY2004:

Michael Glantz convened an international workshop on El Niño Early Warning for Sustainable Development in Pacific Rim Countries and Islands during FY04 in the Galapagos Islands to examine scientific and societal aspects of ENSO forecasts. The workshop also addressed the notion of “El Niño knowledge.” El Niño can spawn climate anomalies and climate-related hazards around the globe. The workshop brought together participants from marine biology, fisheries, oceanography, agriculture, communications, political science, economics, meteorology, anthropology, forestry, and history. They came from 11 countries and represented universities, funding organizations, and fisheries institutions. The workshop deliberations were placed on a website in audio format, with daily dispatches from an invited participant from the Exploratorium in San Francisco. A workshop report will be available in FY05 in both hard copy and on the websites. For more information, see www.isse.ucar.edu/galapagos or www.exploratorium.edu/el_nino

Several ESIG scientists contributed in FY04 to a better understanding of the impacts of extreme heat on communities and human health. Olga Wilhelmi, together with ESIG Director Robert Harriss, developed a GIS-based urban heat warning system, while Claudia Tebaldi, together with CGD senior scientist Gerald Meehl, developed statistical methods to extract heat extremes information from global climate models. Susanne Moser worked with researchers from the University of Delaware, Kent State University, and the Lawrence Berkeley Laboratory on new projections of heat-related mortality in five California metropolitan areas under various climate change scenarios. Wilhelmi and colleagues also published a paper in *Natural Hazards Review* during FY04 on "Designing a geospatial information infrastructure for the mitigation of heat wave hazards in urban areas." A website was

created in FY03 about the heat wave project with more information at www.isse.ucar.edu/heat/

Education and Outreach Activities

Outreach, defined as a proactive method of making connections and getting information to people, is a high-priority theme for ESIG researchers and visitors, who are committed to developing tools for research, applying their research to climate-related societal problems, and educating policymakers and the general public. Nearly all ESIG research produces far-reaching information materials that are communicated in user-friendly terms.

Major Highlights during FY2004:

ESIG convened six highly visible international and national conferences during FY04. These workshops brought together researchers from all over the world and from many different disciplines. Details of these workshops and their rationales are available in the longer section of this report.

- *Early Warning Systems: Do's and Don'ts* (Shanghai, China, 20–23 October 2003);
- *Climate Change and Water Resources* (Boulder, Colorado, 15–16 March 2004);
- *Communicating Urgency, Facilitating Social Change: New Strategies for Climate Change* (Boulder, 8–11 June 2004);
- *Workshop on Native American Decision-Making* (Boulder, 12–13 July 2004);
- *Summer Colloquium on Climate and Health* (Boulder, 21–28 July 2004); and
- *El Niño Early Warning for Sustainable Development in the Pacific Rim and Islands* (Galapagos Islands, Ecuador, 13–16 September 2004).

Michael Glantz successfully launched his “Flip Side of Science” educational series during FY04 with two different versions of his book, *Forecasting El Niño: Science's Gift to the Twenty-First Century*, one for Africa (in English and French) and one for Latin America (in English and Spanish). The World Climate Programme of the World Meteorological Organization (WMO) published the four books. Glantz geared the text in each book toward the regions in order to emphasize the impacts of El Niño on the different continents. Glantz is finalizing another version of his “flip book” on the Aral Sea that will be published by the WMO in FY05.

During FY04, Eric Scharff and Jeff Lazo (ESIG/RAP) began initial steps to create a Digital Library on Societal Impacts (DLSI), designed to be a Web-based resource for collecting and disseminating research findings related to the use and value of weather forecasts. The goal of this library is to make research results, including case studies, websites, decision support tools, and other resources accessible to the various user communities. Results will be synthesized so that they are useful to policymakers and researchers interested in the use of weather forecasts. Postdoctoral researcher Asim Zia began to assist in the development of the synthesis and library during FY04. This is a project under the auspices of the Societal Impacts Program (SIP), which was created in FY04, with Jeff Lazo as the leader of this NCAR US Weather Research Program's Collaborative Program, to study the societal impacts and economic benefits of weather information. More information about SIP is available in the Fundamental Research section of the longer report.

ESIG 2004 Achievements

Fundamental Research

Enhancing Productivity and Resilience of Natural Resources

Protection of Life and Property

Education and Outreach Activities

ESIG 2004 Achievements

Fundamental Research

Carbon Cycle Science

Life on earth depends on the cycling of carbon through myriad transformations and transfers among the atmosphere, the oceans, plants and animals, soils, and even rocks and sediments far below the surface. In the atmosphere, carbon exists primarily in the form of the gas carbon dioxide (CO_2). During FY04, ESIG participated in several activities centered around the use of carbon cycle scientific information. Lisa Dilling co-convened a special session at the AGU on the “Role of Human Dimensions in the Carbon Cycle in North America.” It highlighted aspects of energy use, technology, and the role of policy in affecting carbon budgets over the continent. Dilling is also a member of the Coordinating Team that has begun to develop a significant contribution to carbon cycle science through a “State of the Carbon Cycle Report” (SOCCR). SOCCR will summarize current knowledge about carbon cycle properties and change, as well as provide scientific information for decisionmaking support and policy formulation concerning the carbon cycle. Dilling is joined on the Coordinating Team by colleagues from the Oak Ridge Laboratory, the US Geological Survey, and the Consensus Building Institute. An essential aspect of the development of SOCCR during FY05 is the development of an interactive high-quality website, which will reside at NCAR under Dilling's supervision. This website is now available at www.isse.ucar.edu/soccr/.

During FY04, Shui Bin and Robert Harriss studied carbon emissions encompassed in the North American Free Trade Agreement in order to initiate a study on CO_2 embodiment in trade, as well as examine possible improvements to current CO_2 accounting and trade accounting schemes. As one of the results, Shui and Harriss suggest a proposed within-border-consumption (WBC) accounting framework to better estimate a country's carbon emissions, which would more accurately mirror a country's actual share of global carbon emissions. Based on the WBC, a concept entitled the "broad term of trade balance" (BTOTB) was developed to integrate both financial terms and CO_2 terms of trade in the unit of monetary value. BTOTB provides a new perspective to discuss conventional trade issues. A paper is currently in preparation. Shui and Harriss are also working on another paper that explores the issue of carbon dioxide emissions embodied in Sino-US trade flows and suggest that any trade issue should be discussed and evaluated in the context of both economic and environmental impacts. The concept of BTOTB is expanded in this manuscript. Both will be submitted for publication during FY05.

Circle of Knowledge: Climate, Weather and Environmental Change

Shannon McNeeley has been in collaboration with Alaska Natives along the Koyukuk River in Alaska and scientists who study Arctic and global climate change to document Native Elders' observations and stories of change. A paucity of data and observations in this region have increased interest in the integration of western science with indigenous knowledge and Native observations of climate change. Native elders and hunters

possess a legacy of traditional knowledge and observations of weather and environmental change, and they are concerned about the dramatic changes they are witnessing. In 2004, in partnership with the village Tribal Councils of Hughes, Huslia, and Koyukuk, McNeeley began the interview process and interviewed some 20 Elders in these villages. This research will continue in FY05.

Communication and Social Change

This project builds upon the foundation of an interdisciplinary workshop held at NCAR during FY04. The workshop was funded by the MacArthur Foundation, NSF, ESIG, and the Walter Orr Roberts Institute, entitled Communicating Urgency, Facilitating Social Change: New Strategies for Climate Change. Designed to maximize communication among participants from different fields, Susanne Moser and Lisa Dilling of ESIG invited more than 40 participants from different disciplines and from the practitioner community to exchange ideas about how to achieve successful communication between the climate science and climate policy, business, and NGO communities. Based on the workshop deliberations, Moser and Dilling are currently writing an edited volume on effective communication and social change strategies that support societal response to climate change. An interactive website has been designed for use in project development at www.isse.ucar.edu/communication/

Effects of Climate on Simulated Crops

While most studies of the impacts of climate change on ecosystems have examined the effect of mean change in climate, it is widely believed that climate variability, in addition to the mean, has substantial effects on ecosystems. This issue is becoming more important as we learn more about how climate may vary in coming decades. During FY04, Linda Mearns and colleagues continued examination of the possible additional effects of changes in variability on simulated crops. Mearns, with Cynthia Rosenzweig and Richard Goldberg (NASA Goddard, New York), continued research on the effect of changes in variability of climate on simulated crop yields at other locations in the Great Plains and Midwest. They applied time series of temperature and precipitation with changed variances to CERES-corn and CROPGRO-soybean models. Results so far indicate that increased variance of temperature and precipitation cause substantial decreases in yield, while decreases in variability cause only slight increases in yield. They have applied changes in variance from two major atmosphere-ocean general circulation models (AOGCMs), the NCAR Parallel Climate Model (PCM), and that of the NASA Goddard Institute for Space Studies, for the region of the Midwest and Great Plains to these crop models for the end of the twenty-first century. With Marta Vinocur (National University of Redo, Cordoba, Argentina), Mearns has investigated simulated peanut crop responses to climate variability in Cordoba, Argentina. Using PeanutGRO, they explored the effects of different combinations of mean and variance changes of temperature. They found that the crop model was sensitive to both mean and variance changes, but that increases in temperature variance substantially exacerbated decreases in yield and greatly increased the likelihood of crop failures. They are currently exploring the causes for these crop model responses.

Ethics of Generation and Use of Weather and Short-term Climate Forecasts

In FY04, Eugene Wahl and Rebecca Morss systematically analyzed weather and short-term climate forecast generation and use from an ethical perspective, using methods and criteria drawn from modern applied ethics. By applying the method of iterative, reflective specification (developed by John Rawls) to specific case situations, they examined how three analytic criteria from the Georgetown School of Medical and Business Ethics (beneficence, justice, and autonomy) can be interpreted in the arena of weather and climate forecasting. A manuscript based on the results is currently in preparation. Dale Jamieson (New York University) is acting as adviser on systematic and applied ethics.

Land Cover Forcing from SRES Scenarios in Climate Models

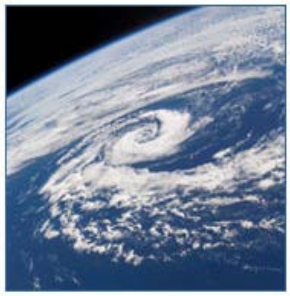
As part of the Assessment Initiative, this project was begun in FY03 in collaboration with CGD to extend future climate change scenarios to include human impacts on land cover and soils. Linda Mearns and colleagues in ESIG, Gordon Bonan in CGD, and Johannes Feddema (Project Lead, University of Kansas) have created two alternative present-day land cover representations and run them in the Parallel Climate Model (PCM). Initial results indicate that the model is very sensitive to land cover change. Additionally, they found that when

changing from potential vegetation to an equivalent present-day land cover, the PCM predicts significant cooling, particularly in the midlatitude of the Northern Hemisphere. During FY04, crop models for spring wheat, winter wheat, corn, and soybeans were developed and incorporated into the CLM (Community Land Model). They were designed specifically for use in global climate models. Information on the model runs is available at www.cgd.ucar.edu/tss/clm. This ongoing project will continue through FY05.

Little Ice Age: Climate Variability of Past Centuries

The Little Ice Age component of the Assessment Initiative focuses on the uncertainty characteristics of external forcing, its influence on climate, including variability on different spatial and temporal scales. This multiyear project was initiated in FY03 and continued development during FY04, in cooperation with CGD, to involve simulations of multiple centuries, including an initial period of the Little Ice Age. This project "fingerprints" volcanic and solar forcings. Secondly, this project will continue its investigation into the role of the North Atlantic Oscillation (NAO), with emphasis between empirical paleo-data and patterns of forced temperature variation. Additionally, regional expressions of forced and unforced climate variability as generated by a coupled climate model are being evaluated and compared to reconstructions with multi-proxy networks. New developments in climate mode response to external forcing are explored as well. Linda Mearns, Eugene Wahl, along with Caspar Ammann, Doug Nychka, and Bette Otto-Bleisner of CGD, have begun the processing phase of this research. Some studies are taking shape or are being evaluated against existing base data.

Observing Network Design for Weather and ENSO Prediction



Because resources for meteorological observations are limited, choices must be made among proposed enhancements to the weather prediction observing system. In FY04, Rebecca Morss analyzed meteorological observing system design from a public policy perspective. The results are presented in a manuscript (accepted for publication in BAMS) that explains the role of problem definition in policy research and decisionmaking to a meteorological audience, using 5 alternate definitions of the observing system design problem to demonstrate how different problem definitions can lead to different results. An important consideration in observing system design is the costs and benefits of different observations. Although the meteorological community has discussed the question of optimal investment in observations for more than three decades, it still lacks a practical, systematic framework for analyzing the issue. In FY04, Morss, Kathleen Miller, and Maxine Vasil (University of Colorado graduate student) developed an economic approach to analyzing the optimal observing system. They present the approach in a publication (in press, *Monthly Weather Review*) and then combine meteorological cost/benefit information to demonstrate the approach for a simplified version of the actual observing and prediction system.

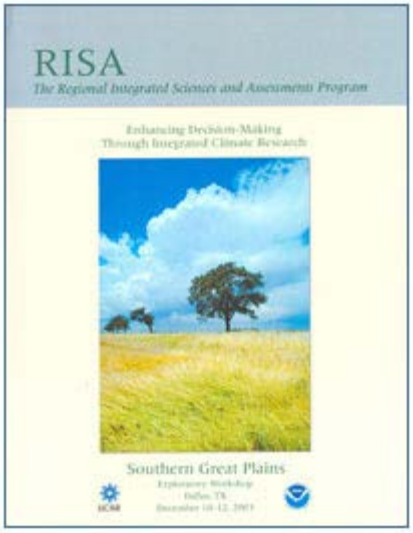
The Tropical Atmosphere-Ocean (TAO) array of moored buoys in the tropical Pacific Ocean is a major source of data to understand and predict ENSO (El Niño-Southern Oscillation). Despite the importance of the TAO array, limited work has been performed to date on the number and locations of observations required to predict ENSO effectively. To address this issue, Morss and David Battisti (University of Washington) performed a series of observing system simulation experiments (OSSEs) with an intermediate coupled model. The experiments suggest which observations are most important for ENSO prediction and were used to develop efficient observing networks for forecasting ENSO in this simulated system. Two publications based on the results appeared during FY04 in the *Journal of Climate* (available in PDF format in the Publications section of this report).

Outlook for US Meteorological Research in a Commercializing World: Lessons from Biotechnology

The future of meteorological research looks bright in many ways: knowledge and supporting technology are advancing rapidly, and the accuracy and timeliness of meteorological forecasts improve each year. As a result, new and growing markets eagerly await the products of weather research, and opportunities for commercialization abound. Other trends, however, give cause for concern. In particular, the growing value of

weather services is straining long-established public, private, and international partnerships, and the meteorological community is beginning to see signs of some of the same commercialization difficulties that now plague biotechnology. During FY04, Rebecca Morss and William Hooke (AMS) wrote a manuscript that synthesizes lessons from the biotechnology community's experience with commercialization of research. They point out that meteorological community must initiate a discussion within the community to raise awareness of these potential pitfalls in order to minimize the risks. The manuscript, "Outlook for US Meteorological Research in a Commercializing World: Lessons from Biotechnology," has been submitted to BAMS.

Regional Integrated Sciences and Assessment (RISA) Program



Susanne Moser facilitated an ongoing collaborative effort between NOAA's RISA Program for Climate-Sensitive Decision-Making and Policy Planning and NCAR scientists. The goal of the collaboration is to support each other in fulfilling common strategic and scientific goals. The RISA program currenty supports various teams around the country to develop climate variability and change information relevant to local and regional decisionmaking. Decisionmakers must be made aware of the multiple stresses that climate-sensitive sectors and environments are facing. The first part of the NCAR/RISA collaboration consists of supporting exploratory workshops for those regions of the country that currently do not have RISA centers. The first of these workshops was held in Dallas, Texas in December 2003, sponsored by NOAA's Office of Global Programs and the National Weather Service. A summary report was prepared by Moser and colleagues, "Enhancing Decision-Making through Integrated Climate Research: Southern Great Plains." A second workshop was held in Anchorage, Alaska in February 2004, and a workshop report entitled "Enhancing Decision-Making through Integrated Climate Research: Alaska" was prepared by Moser. This collaborative effort will continue with an exploration of more direct NCAR/RISA involvement during FY05.

Societal Impacts and Economic Benefits of Weather Information

During FY04, Jeff Lazo (ESIG/RAP) and researchers from NCAR's COMET program, RAP, and MMM formed a joint collaborative program (Societal Impacts Program, or SIP) on the societal impacts and economic benefits of weather information, with funding from the US Weather Research Program. Bill Mahoney (RAP), Robert Harriss, and Rebecca Morss were instrumental during FY04 in laying the groundwork and developing the research agenda for this program. Priority activities include the development of a Digital Library on Societal Impacts (DLSI) with Eric Scharff as Project Lead. DLSI will be a web-based resource for collecting and disseminating research findings related to the use and value of weather forecasts. SIP researchers have also begun a literature synthesis to identify gaps and needs in weather products from a user's perspective. Asim Zia was hired to work with Morss to undertake original research related to the SIP and assist in the development of DLSI. Working with COMET, the SIP is also developing a blueprint to examine the capacity of meteorological services worldwide with the goal of improving the application of new science and technology developed in THORPEX. (THORPEX is a ten-year international research and development program focused on improving high-impact weather forecasts on a one- to 14-day timescale to benefit society.) Another priority of SIP is the improvement of quantitative precipitation forecasts (QPFs). To help set priorities in QPF-related research and product development, Asim Zia, Morss, and Lazo will conduct a synthesis of research on the societal, economic, and environmental value of QPFs during FY05. This is a follow-up of work begun in FY04 by Morss for the USWRP. SIP researchers have begun planning for a workshop in FY05 to develop a social science research agenda on the hurricane forecasting and warning system.

Also during FY04, Morss collaborated with a number of researchers in the international societal impacts and weather prediction communities to develop the Societal and Economic Applications (SEA) components of the international and US science and implementation plans for THORPEX. Major elements of the SEA components of THORPEX include: identifying high-impact weather forecasts, assessing the impact of improved forecasts, developing advanced verification measures, estimating costs and benefits of improved forecast systems, developing new user-specific weather products, and facilitating the transfer of THORPEX advances to forecast

centers around the world. This effort will continue in FY05, as THORPEX planning continues at the international and national levels.

Richard Katz, in collaboration with Martin Ehrendorfer (University of Innsbruck, Austria), developed a Bayesian approach to decisionmaking using ensemble weather forecasts. During FY04, a counterintuitive result was obtained, indicating that the economic value of ensemble-based probability forecasts could *decrease* as the ensemble size increases; that is, if the uncertainty in deriving the estimated forecast probability is ignored, as is common practice.

Superstorm '93

On 12-15 March 1993, a major winter storm affected 26 US states, Cuba, and eastern Canada, causing high winds, severe weather, storm surges, heavy rain, record snowfalls, and record low temperatures. Several weather prediction models and forecasters at the National Meteorological Center recognized the threat of a significant storm and were able to predict the storm several days in advance. However, both models and forecasters failed to predict the extent of the rapid deepening of the storm. Headed by Michael Glantz, this two-year project involves NCAR scientists across three divisions: MMM (Morss and Liam Cavanaugh), ESIG, and CGD (Joe Tribbia), as well as researchers from the University of Colorado in Colorado Springs, Santiago de Compostela University in Spain, and Uktal University in Orissa, India. They have studied the event as being representative of a class of events and approached the project as a unique and exploratory effort to integrate meteorological and societal impacts knowledge, research, and research applications. During FY04, Glantz expanded the project to examine the "supercyclone" that occurred in Orissa, India, in October 1999. Preliminary results and more information about the project are available on the website at www.isse.ucar.edu/superstorm/

Uncertainty in Climate Model Simulations

This continuing project of the Assessment Initiative developed techniques for quantifying uncertainty in climate model projections during FY04 and began to apply these techniques to transient runs of AOGCMs (atmosphere-ocean general circulation models). Linda Mearns joined Doug Nychka (CGD), along with Claudia Tebaldi (ESIG/RAP) to analyze "super ensembles" of climate change runs in order to characterize the uncertainty in the AOGCMs. Using this method, probability density functions (PDFs) of climate change signals (temperature and precipitation changes as projected by the AOGCMs at the end of the 21st century) are produced at regional levels. In the statistical model, the team formalized two criteria of model reliability: the climate change responses observed in the AOGCMs with large biases in reproducing current climate, and AOGCMs that do not agree with the majority of the ensemble members. These retain relatively less weight in the final results. The PDFs derived are being used as input of climate change impact studies at regional levels; for example, in a water resource study focused on the Sacramento river basin in California, and the method will be applied to the model runs that are being produced for the IPCC's next assessment process (AR4). A paper was accepted for publication on this process in the *Journal of Climate*.

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Protection of Life and Property

Climate Variability and Uncertainty in Flood Hazard Planning

Flood risk estimates are particularly uncertain in mountainous areas of the western United States, because of sparse data and highly variable precipitation. Yet, the design of floodplain maps, flood-control structures, storm drainage systems, and bridges depends on these estimates. This project aims to facilitate improvement in estimates of local risks of extreme warm season rainfall in Colorado and other Rocky Mountain states. Goals of the project are (1) to learn how scientific information and uncertainty are incorporated into flood-related decisionmaking and regulation, and (2) to develop improved methods of estimating precipitation frequencies through meteorological analysis and the use of extreme value statistics. In FY04, the research team included Mary Downton, Rebecca Morss, Olga Wilhelmi, and Melissa Crandall (all of ESIG), Uli Schneider and Doug Nychka (GSP), and Eve Gruntfest (University of Colorado-Colorado Springs). Papers are being prepared on how decisionmakers deal with uncertainty in flood risk information, and case studies in which disagreement among scientists led to dilemmas for decisionmakers. The study has identified inadequancies in the precipitation frequency information available for flood management in Colorado, leading to an ongoing investigation using methods of extreme value statistics.

Development of a Climate/Human Health Program

As a major component of the Assessment Initiative, the development of the Climate and Human Health module continued during FY04. Linda Mearns and Jonathan Patz (Johns Hopkins University) invited health scientists and students to an intensive series of lectures and hands-on computer labs, which helped them learn more about the conceptual and methodological challenges for defining the possible effects of climate change on health. Top NCAR climatologists and statisticians, along with health scientists from the CDC (US Centers for Disease Control and Prevention), Johns Hopkins University , and other institutions around the globe presented case studies (e.g., heat mortality and vector-borne diseases). Statistical methods, such as time-series analysis and extreme value theory, demonstrated ways to analyze climate data. Modelers and risk assessment experts taught integrated modeling and strategies to communicate scientific findings and uncertainties. This event was the first step in a long-term program integrating climate and health recommended by the National Academy of Sciences/National Research Council. Such a program is necessary to successfully tackle research questions in climate-society-health interactions. The six-day-long joint ESIG/ASP Summer Colloquium brought together these experts in order to begin this component of the Assessment Initiative. More information about the Colloquium is available on the website at www.asp.ucar.edu/colloquium/2004/CH

Early Warning Systems

Michael Glantz received funds from NSF and NCAR to convene a workshop on *Usable Science VIII: Early Warning Systems Do's and Don'ts*. An early warning system is made up of several components: the formulation of the warning, the issuance of the warning, and the reception of and response to the warning -- each of which has to be considered in the evaluation of an early warning system. A weakness in any part of the process can render the early warning system ineffective, and a system that does not warn effectively will not be taken seriously. The workshop was co-sponsored by the Chinese Meteorological Administration and the Chinese Academy of Meteorological Sciences, and held in Shanghai, China, in mid-October 2003. Thirty-two participants from 12 different countries (Australia, Brazil, China, India, Italy, Japan, Malaysia, Russia, Spain, Switzerland, the UK, and the US) and from several different disciplines and funding agencies gathered to examine ways to improve early warning systems, including types of early warning systems in theory and practice, sustainable development, politics, capacity building for early warning, and much more. A comprehensive workshop report is available on the website in both hard copy and on line at www.isse.ucar.edu/warning

Glantz also held a workshop on *El Niño Early Warning for Sustainable Development in Pacific Rim Countries and Islands* in September 2004 in the Galapagos Islands, Ecuador. Michael Glantz (ESIG) and Jose Luis Santos of CIIFEN (Centro Internacional para la Investigación de El Niño) in Guayaquil, Ecuador, gathered 34 participants from 12 countries (Australia, Canada, Chile, China, Colombia, Costa Rica, Ecuador, Germany, Mexico, United Kingdom, United States, and Uruguay) in an attempt to regionalize the focus on a specific early warning activity for ENSO (El Niño-Southern Oscillation). Participants represented many disciplines, including marine biology, fisheries, oceanography, agriculture, communications, political science, economics, meteorology, anthropology, forestry, philosophy, and history. This activity was a follow-up to the workshop held in October 2003 in Shanghai, China. A workshop report is in preparation and will be available on the website in FY05 at www.isse.ucar.edu/galapagos

Economic Value of Seasonal Hurricane Forecasts to the Insurance Industry

In FY04, Richard Katz, in collaboration with Matt Coleman (SOARS protégé and graduate student at Pennsylvania State University), began a project on the optimal use and economic value of seasonal hurricane forecasts to the insurance and re-insurance industries. These forecasts of hurricane activity are based largely on the ENSO (El Niño-Southern Oscillation) state. Preliminary work included the development of a simulation model of hurricane damage.

Extreme Weather and Climate Events

Many NCAR divisions are involved in research aspects of extreme weather and climate events. ESIG plays a significant role in modeling and statistical analysis of climate extremes. The following three projects are part of the Assessment Initiative. This work is important in order to understand and reduce societal vulnerability and impacts, as well as to link the social sciences to new discoveries in physical meteorology and climate in order to enhance protection of life and property.

Extremes Toolkit

This project is another activity within the Assessment Initiative. The “extremes toolkit” is web-based, open source software that allows for the statistical analysis of weather and climate extremes and their impacts, available at www.isse.ucar.edu/extremevalues/evtk.html . It includes a tutorial and graphical user interface designed to be accessible to non-statisticians in fields such as climate and climate impacts. During FY04, Eric Gilleland (RAP/GSP) and Rick Katz made minor modifications to the software, and the tutorial was extensively revised.

Extreme Events in Climate Models

As another activity within the Assessment Initiative, Claudia Tebaldi, in collaboration with Doug Nychka and Jerry Meehl (both of CGD) continued an analysis of the frequency and intensity of

various extreme events that have particular relevance to climate impacts in regional and global climate models. Extreme value theory is being used in these analysis, along with undertaking a detailed examination of the spatial scaling characteristics of extremes in climate models.

Managing Wildland Fire Risks

The vulnerability of individual property, as well as whole communities, to wildland fire events is the product of a large number of autonomous (but mutually interdependent) decisions made over time by individuals whose interests and objectives may conflict. This project, headed by Kathleen Miller and Robert Harriss, modeled the interconnections between land use and management decisions made by adjacent property owners and local government entities. The significance of such interconnections was assessed by conducting a local case study of wildfire risk mitigation activities, focusing on analyzing the effects of uncertainty and information in such situations. This research contributes to the development of policy alternatives, decision support tools, and risk communication methods to improve societal management of wildland fire risks. This project entails major collaboration with the Wildland Fire Strategic Initiative, and also some with the Water Cycle Strategic Initiative.

Statistics of Extremes: Ecological Disturbances

In collaboration with Grace Brush (Johns Hopkins University) and Marc Parlange (Johns Hopkins University and the Swiss Federal Institute of Technology), Richard Katz completed a project on using the statistics of extremes to model ecological disturbances. Extreme value theory is applied to time series of sediment rates, attempting to identify both the influence of hydrological events (e.g., heavy rainfall) and human activities (e.g., land use). A review paper has been accepted and will appear in FY05 as a special feature on the statistics of rarity in the journal *Ecology*.

Urban Transportation and the Environment

China has the world's fastest-growing automobile market. A robust economy and soaring demand are fueling the phenomenon in this increasingly urbanized country. Chinese cities are facing acute envirnomental challenges, as well as experiencing changes in land use, economic, socio-demographic, and institutional development. Shui Bin, with Robert Harriss, Al Cooper (ASP), and Jiang Kejun (Energy Research Institute, Beijing, China) began a study in FY04 that focuses on Chinese medium- and small-sized cities to explore the current challenges and opportunities in urban transportation development. The study will introduce decisionmaking tools to regional decisionmakers, as well as stimulate a wide-ranging discussion about sustainable transportation at the regional level. This study will continue during FY05, and a paper will be submitted with the study's results upon its completion.

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ESIG 2004 Achievements

Enhancing Productivity and Resilience of Natural Resources

Agroecosystems in the Pampas

In FY04, Richard Katz started participating in a multidisciplinary, multi-institutional project on adaptive management in agroecosystems in the Pampas of Argentina. The focus of the project, “Understanding and Modeling the Scope for Adaptive Management in Agroecosystems in the Pampas,” is on the role of variations in climate on annual-to-decadal time scales. Funded by the NSF Program on Biocomplexity in the Environment, this project involves researchers at several institutions, including the University of Colorado, Columbia University, the University of Miami, Pennsylvania State University, and the University of Buenos Aires. A broad span of disciplines is also represented, such as agronomy, climate, and decisionmaking. The ESIG component focuses on uncertainty analysis, ensuring that uncertainty is rigorously treated in all aspects of the project. This project will continue for three years.

Climate Variability in the Alaskan North Slope Coastal Region

The environmental issues affecting the Alaskan North Slope coastal region are the decline in ice extent in the Beaufort and Chukchi Seas, the destruction of shelves and coast by sea ice, sea level rise, and storm hazards. The focus of this NSF-sponsored project is to understand, support, and enhance the local decisionmaking process on the North Slope of Alaska in the face of climate variability on seasonal-to-decadal time scales, both natural and as a result of anthropogenic changes. During FY04, Linda Mearns and Claudia Tebaldi (ESIG/RAP) continued their examination of statistical models for downscaling large-scale climate signals into fine-scale meteorological information, such as winds, temperature, and precipitation. A presentation on the progress of the project after its first two years was made in Barrow, Alaska, in August 2004 (with contributions from team members Mearns and Tebaldi) to discuss ways of reducing vulnerability to coastal erosion and flooding in the region arising from storm hazards. The team compiled information from residents and scientists about trends and processes affecting the Barrow environment during the past fifty years. The goal of the project is to expand the range of informed options open to the residents in order to address the problem of climate change and climate variability. The project website is available at nome.colorado.edu/HARC/ and will continue through FY05.

Coral Reefs and Climate Change

For some time, researchers have been making dire predictions for the world's

reefs if the impact of humans is not curtailed. During FY04, Joan Kleypas examined how two consequences of increased atmospheric CO_2 concentration, greenhouse warming and changes in seawater chemistry, are affecting both coral reef organisms and the reef structures that they build. A major threat to coral reefs is the significant increase in summertime maximum temperatures, which induces a “coral bleaching” stress response that can lead to large-scale mortality of reef organisms. Kleypas and colleagues are combining CCSM (Community Climate System Model) output to help predict the probability of coral bleaching in future greenhouse scenarios. A new website has been created to link all coral reef studies being carried out in ESIG at www.isse.ucar.edu/coral/

A second threat to reefs is the increase in ocean acidity, which hampers calcium carbonate production. Kleypas and colleagues at NOAA and Columbia University have designed a field program to document seawater chemistry changes on a reef at the Caribbean Marine Research Center (CMRC) in the Bahamas. Through funding from the NCAR Opportunity Fund, the group deployed an automated seawater sampling system onto an existing time-series station on a reef near the CMRC to enable documentation of the diurnal cycle in seawater carbonate chemistry on the reef. This information will be used along with other time-series data (e.g., temperature, salinity, light, wind) to model coral reef calcification and organic production in response to environmental variables.

Additionally, Kleypas co-authored a study published in FY04 by the Pew Center on Global Climate Change entitled Coral Reefs and Global Climate Change: Potential Contributions of Climate Change to Stresses on Coral Reef Ecosystems. The study is available in both hard copy and on line.

Millennium Ecosystem Assessment for Drylands and Desertification

The United Nations Millennium Ecosystem Assessment (MA) is a four-year-long international program designed to meet the needs of decisionmakers for scientific information on the links between ecosystem change and human well-being. The MA is a complex project with complex findings, difficult to communicate even to those working in the field of sustainable development. Michael Glantz made a presentation at a Drylands Ecosystems Workshop in Tashkent, Uzbekistan, in August 2003. After that presentation, he was invited to join the Writing Team responsible for preparation of the Millennium Ecosystem Assessment Synthesis Report for Drylands. Glantz worked closely with the Team during FY04 and prepared a chapter entitled "Environmental Problems in Drylands: Challenges and Tradeoffs for Society." The final report of the MA is scheduled to be released in mid-2005. The desertification component is part of the Drylands Ecosystem Assessment, one of more than twenty ecosystems under review. The World Bank, GEF (Global Environment Facility), and the WRI (World Resources Institute) support it, among several other major institutions and foundations. A website with more information about the MA is available at www.millenniumassessment.org

International Fisheries and Climate Variability

Kathleen Miller continued the collaborative international project focused on fisheries and climate variability during FY04. As an outgrowth of the Climate Variability and Pacific Salmon project, Miller collaborated on a paper with Gordon Munro (University of British Columbia) that describes the general problems posed by climatic regime shifts for international fisheries management. The paper surveys the evidence of the significance of climatic regime shifts. It has been accepted for publication by *Marine Resource Economics*. Collaboration by Miller with researchers at the University of Montana and Moscow State Lomonosov University focused on the impacts of climate variability on international marine fisheries and the implications for the design of cooperative fishery management agreements. Research during FY04 included development of game theoretic models applied to a comparative assessment of the role of climate variability in international fisheries, especially highly migratory tuna resources. Miller assumed leadership of Working Group 5 (Socioeconomic Impacts and Management Implications) of the GLOBEC Climate Impacts on Oceanic Top Predators (CLIOTOP). She also prepared two papers (accepted for publication) with researchers from the University of British Columbia and the University of Portsmouth (UK) on an assessment of the pressures created by climate-related uncertainty for international fishery management agreements.

Water and Climate

Kathleen Miller served as the co-Principal Investigator with David Yates (RAP) on a project begun in ESIG during FY04 on "Climate Information for Water Supply Planning." Because water utilities must plan updates to their facilities decades in advance, effective planning requires an adequate understanding of the possible range of climate variability and climate change that may be faced in the future. This project convened an international workshop in FY04 to bring together members of the atmospheric, hydrologic, and water-resource scientific communities with representatives of the water supply industry in order to examine the current knowledge of potential effects of global climate change on water supply. ESIG secured funds from the American Water Works Association Research Foundation (AWWARF) to develop an educational report and host the workshop. Miller is working together with Yates to create a document designed to aid water resource managers with their ability to plan for the future, as well as to understand the basic scientific questions behind global climate change and water supply. The publication will be published by AWWARF in FY05. More information is available on the project website at www.isse.ucar.edu/water_conference/

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Education and Outreach

AMS (American Meteorological Society) Committee on Probability and Statistics

During FY04, Richard Katz continued to maintain and update the website for the American Meteorological Society Committee on Probability and Statistics. The site's purpose is to promote the sound use of statistical methods in the atmospheric sciences. (www.isse.ucar.edu/ams/ams_ps.html).

Capacity Building by Proxy

Michael Glantz began a new outreach activity that aims to foster human capacity building through research and educational activities across international borders and in developing areas. The first such effort began in FY04 as a “Peace Bridge Initiative” between Afghanistan and Uzbekistan. This cooperative effort involves professors and students of Termez State University in the city of Termez in southern Uzbekistan and Balkh University in Mazar-i-Sharif in northern Afghanistan. Although these universities are only 70 kilometers apart, the gap between their levels of development is very great. Uzbekistan was part of the Soviet Union, and their research and educational policies reflect the demands of Soviet leaders who put a high value on science and technology. Afghanistan has been in turmoil for decades, beginning in the early 1970s and continuing with the repressive rule of the Taliban and the war to oust them. The focus on “capacity building by proxy” refers to enabling Uzbek researchers and educators to work closely with their counterparts across the Amudarya River that forms the international border between these two countries. With the support of NCAR and NOAA, the notion has expanded from measuring air pollution in urban areas to include education and training on issues related to weather, climate, and water. Glantz is exploring a second initiative along these lines in FY05.

Studies of Forecast Value Website

This comprehensive website categorizes recent case studies of the value of imperfect weather and climate forecasts. Its scope is focused on prospective studies that obtain quantitative estimates of forecast value. During FY04, Richard Katz continued to maintain and update the site (www.isse.ucar.edu/HP_rick/esig.html).

Climate Affairs Developments

Michael Glantz's notion of Climate Affairs continued development during FY04. Glantz worked with Columbia University's Earth Institute to establish a “Climate and Society” Master's program, which began in the fall of 2004. The Asian Institute of Technology (AIT) in Bangkok is in the process of developing a Climate Affairs education program. Glantz attended a workshop in Malaysia in April 2004 to assist in the development of Climate Affairs activities. At that workshop, the University of Malaya committed resources to the development

of a Center of Excellence for Climate Affairs.

Glantz and Qian Ye traveled to China several times during FY04 in order to arrange for a Social and Economic Impacts Study to be conducted for the Chinese National Climate Center. Ye and Glantz were invited to lead the study, which is designed to benefit the Beijing 2008 Olympic Games. The project will be conducted from 2005 through 2009. Ye and Glantz were also invited to lead a preliminary workshop for the Chinese National Climate Center in order to assist in the development of a national operational system on climate and ecosystem interactions.

Glantz began initial work during FY04 on a “Water Affairs” activity with the United Nations University (UNU) International Network on Water, Environment and Health at McMasters University in Hamilton, Ontario. “UN-WATER” was recently confirmed as a system-wide interagency coordination mechanism in the United Nations, as an activity related to the recently announced UN International Decade for Action, “Water for Life” 2005–2015. The goal of a Water Affairs activity would be to assist in capacity development and knowledge management. A key contributing factor to the water crisis in many developing countries is the lack of indigenous capacity (scientific, educational, institutional, and managerial) for effective water management.

Alaska has recently observed a more drastic temperature change than any other part of the world. While reasons for this change are still a major focus of international research, the effects of this warming are seen all over Alaska. Shannon McNeeley continued work during FY04 on a Climate Affairs education and outreach program with the Alaska Native Science Commission and the University of Alaska. It focuses on the impacts of climate and environmental changes in Alaska, with a particular focus on Alaska natives. This program combines knowledge and techniques from western science and from indigenous traditional knowledge and wisdom. Two other projects on Alaska Climate Affairs are under way in ESIG, and a website has been created to educate others on those activities at Alaskan Climate Affairs.

Clim-Econ Discussion List

The Economics of Climate Variability and Global Change list (Clim-Econ) is a moderated electronic discussion group, created and managed by Kathleen Miller, which serves to facilitate interdisciplinary discussion on the economic aspects of climate variability and change. The initial subscribers included the participants in the Institute on the Economics of the Climate Resource held at NCAR in June 1995. The list currently has more than 500 subscribers from around the world, including individuals with a variety of backgrounds and professional affiliations. csf.colorado.edu/clim-econ/

Disaster Dynamics

Eric Scharff, Robert Harriss, and Seth McGinnis continued to develop the Disaster Dynamics project. The team has created several computer-based simulation prototypes targeted at undergraduate emergency management education. In addition to creating new tools, the team researched and facilitated existing games to encourage systems-thinking skills. The primary prototype emphasizes the planning and consensus-building surrounding hurricane mitigation and the consequences of those decisions. The team has presented work at emergency management education workshops and is working with users to design the learning modules. During FY04, the team tested prototypes with users and refined the game content and structure. Prototypes and documentation can be found on the project website at http://swiki.ucar.edu/dd/

Digital Library on Societal Impacts

During FY04, Eric Scharff began initial development of the Digital Library on Societal Impacts (DLSI). This will be a Web-based resource for collecting and disseminating research findings related to the use and value of weather forecasts. The goal of the library is to make research results, including case studies, websites, decision support tools, and other resources accessible to the appropriate communities. In particular, results should be synthesized so that they are useful to policymakers and researchers interested in the use of weather forecasts. This work is being done through the NCAR-USWRP Collaborative Program on the Societal Impacts and Economic Benefits of Weather Information (SIP). Asim Zia was hired in August 2004 to assist in the development of DLSI.

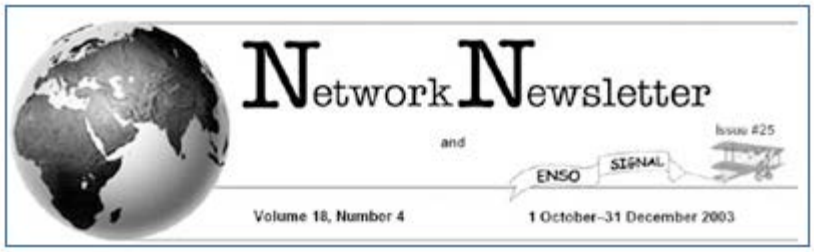
Fragilecologies Website

Michael Glantz continues to maintain a website of environmental editorials since the late 1990s. He wrote a column for the *Boulder Daily Camera* for six years and the *Boulder Planet* for two years thereafter. He then established this website focused primarily on climate-society-environment issues. It includes guest editorials, an Idea Bank, and other editorials on a wide range of climate-related topics. At present, this website receives approximately 8,000 "hits" per week and is growing. **www.fragilecologies.com**

Geophysical Statistics Project (GSP)

Richard Katz serves as co-Principal Investigator of NCAR's Geophysical Statistics Project (GSP, led by Doug Nychka (IMAGe). Other PIs include Jeff Anderson (IMAGe) and Joe Tribbia (CGD). During FY04, a renewal proposal was funded by the National Science Foundation's Division of Mathematical Sciences. The FY04 accomplishments of GSP are included under the FY04 ASR section of the Institute for Mathematics Applied to Geosciences (IMAGe) (www.cgd.ucar.edu/stats/IMAGe/).

Network Newsletter/ENSO Signal



The **Network Newsletter** has been published quarterly in ESIG for the past nineteen years. This international, multidisciplinary newsletter was combined in January 2003 with the ENSO Signal, which is intended for those interested in the ENSO cycle and its impacts on ecosystems and societies. The newsletter fosters a network of those interested in climate-related impact assessment. The **ENSO Signal** was originally published at NOAA's Office of Global Programs and has been published in ESIG since January 2000. Michael Glantz, Editor, and DJan Stewart, Managing Editor, continue to work on networking research centers, nongovernmental organizations, universities, institutes, and individuals in the production of these publications. The online version of the ENSO Signal receives thousands of “hits” every month and continues to grow its list of electronic subscribers. The printed version of the Newsletter is sent to more than 2,000 foreign subscribers and more than 2,000 domestic subscribers, who contribute articles, publications, and meeting news to the Managing Editor. NCAR continues to support the combined publication, which is distributed free of charge and are both available electronically and in hard copy.

Statistics of Weather and Climate Extremes

During FY04, Richard Katz continued to maintain and update a website on the statistics of weather and climate extremes. This site is intended to serve as a resource for the use of the statistical theory of extreme values in the analysis of weather and climate extremes and their impacts (www.isse.ucar.edu/extremevalues/extreme.html).

Telementoring

This refers to relatively long-term computer-based mentoring activities with colleagues in other countries as well as in the United States. Telementoring includes students as well as professionals wishing to know more about climate-society interactions, as well as those who ask for guidance on identifying topics, resources, and networks for research, which includes the physical, biological, and social sciences, and the humanities. ESIG scientists continued several telementoring activities during FY04.

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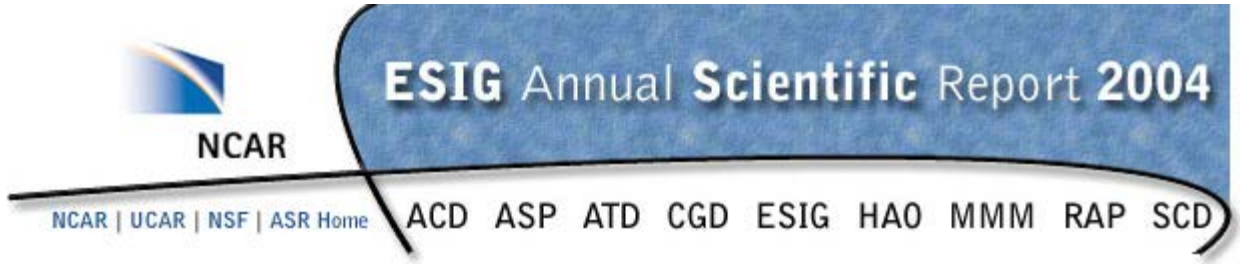

ESIG FY04 Education and Outreach

Formal Teaching Arrangements

Michael Glantz holds an appointment as Adjunct Professor, Division of Marine Affairs, Rosensteil School, University of Miami, Florida.

Michael Glantz holds an appointment as Professor Adjoint, Center for Environmental Journalism, School of Journalism and Mass Communication, University of Colorado, Boulder, Colorado.

Michael Glantz holds an appointment as Adjunct Professor, Department of Philosophy, University of Colorado, Boulder, Colorado.

Michael Glantz holds an appointment as an Affiliate Professor, Bard Center for Environmental Policy, Bard College, Annandale-on Hudson, New York.

Michael Glantz holds an appointment as Adjunct Professor, Columbia Earth Institute, Columbia University, New York.

Robert Harriss holds an appointment as Adjunct Professor of Planning, College of Architecture and Planning, University of Colorado, Boulder, Colorado.

Robert Harriss served as a lecturer in an undergraduate course on "Ecology and Design," School of Planning, University of Colorado, Boulder, Colorado during the Fall 2004 semester.

Richard Katz acted as Guest Professor in a graduate course on "Statistical Methods for Weather and Climate Forecasting and Decision Making," University of Innsbruck, Innsbruck, Austria, in October 2003.

Linda Mearns holds an appointment as Graduate Faculty Member, Department of Agricultural Meteorology, School of Natural Resources, University of Nebraska, Lincoln, Nebraska.

Linda Mearns acts as external reviewer of tenure applications, Department of Geography, University of Arizona, Tucson, Arizona.

Kathleen Miller holds an appointment as Faculty Affiliate, Colorado State University, Department of Earth Resources, Fort Collins, Colorado.

Olga Wilhelmi holds an appointment as Adjunct Assistant Professor, College of Engineering and Applied Sciences, University of Colorado at Denver, Colorado.

Dissertation Committees

Michael Glantz, Masters Committee for Brock Adam McCarty, Department of Geography, University of Colorado, Boulder. Thesis title: "Use of Famine Early Warning in African Development Strategies."

Robert Harriss, PhD Committee for Carrie Sonneborn, School of Engineering, Murdoch University, Perth, Australia. Thesis title: "Industrial Capacity Building with Respect to Market-Based Approaches to Greenhouse Gas Reduction: US and Australian Perspectives."

Richard Katz, PhD Committee for Dan Cooley, Department of Applied Mathematics, University of Colorado, Boulder. Thesis title: Modeling of Extreme Events in Climate Studies."

Joan Kleypas, PhD Committee for Derek Manzello, Marine Science and Biology, University of Miami, Coral Gables, Florida. Thesis title: "Effects of Seawater Chemistry on Coral Reef Development."

Workshops and Colloquia

Michael Glantz convened a workshop for 35 international participants to identify lessons from those who have worked with or helped to develop early warning systems for a wide range of societal concerns, *Early Warning Systems: Do's and Don'ts* in Shanghai, China, 20–23 October 2003.

Kathleen Miller and David Yates (RAP) hosted an international workshop for the water supply industry to examine the current knowledge of potential effects of global climate change on water supply, *Climate Change and Water Resources* (Boulder, Colorado, 15–16 March 2004).

Susanne Moser and Lisa Dilling co-hosted a three-day workshop that brought together more than 45 experts from a wide range of academic disciplines, *Communicating Urgency, Facilitating Social Change: New Strategies for Climate Change* (Boulder, 8–11 June 2004).

Keith James (Colorado State University) and Robert Harriss hosted a *Workshop on Native American Decision-Making* to develop an agenda for application and research on climate change and environmental decision-making in Native communities (Boulder, 12–13 July 2004).

A *Summer Colloquium on Climate and Health* was co-Chaired by Linda Mearns and Jonathan Patz (Johns Hopkins University) in collaboration with ASP in Boulder,Colorado, 21–28 July 2004.

Michael Glantz convened a workshop on *El Niño Early Warning for Sustainable Development in the Pacific Rim and Islands* for 35 international participants to examine scientific and societal aspects of ENSO forecasts in the Galapagos Islands, Ecuador, 13–16 September 2004.

Scientific or Technical Seminars

Linda Mearns was an invited speaker at the PRUDENCE Workshop and gave a talk 1 October 2003 on "The Issue of Spatial Scale in Integrated Assessments: An Example from US Agriculture" in Wengen, Switzerland.

Michael Glantz and Qian Ye made a presentation 2 October 2003 on "Problem Climates or Problem Societies? On the Creeping Environmental Problems in China" at the World Climate Change Conference in Moscow, Russia.

Richard Katz, invited speaker at the PRUDENCE Workshop on Regional Climate Change in Europe: Processes and Impacts, on "Misconceptions about the Use of Extreme Value Theory in Climate Change Assessments," on 3 October 2003, in Wengen, Switzerland.

Linda Mearns gave a talk 6 October 2003 at the Annual STARDEX Meeting on "Research in Extremes at the National Center for Atmospheric Research" in Interlaken, Switzerland.

Rebecca Morss gave a presentation 16 October 2003 on "Designing Observing Networks for Weather Prediction: Atmospheric Science and Public Policy Perspectives" at Texas A&M University, College Station, Texas.

Michael Glantz, 20 October 2003, Introduction to workshop and "Early Warning Systems in a Changing World," Shanghai, China.

Jerry Mahlman gave the opening talk on 4 November 2003 in celebration of the scientific career of Dr. James

K. Angell in Washington, DC.

Richard Katz, 30 October 2003, "Misconceptions about the Use of Extreme Value Theory in Climate Change Assessments," Swiss Federal Institute of Technology, Zurich, Switzerland.

Jerry Mahlman was the lead science speaker on 10 November 2003 at the Rhode Island Science Communication Mass Media Workshop at the University of Rhode Island, Kingston, Rhode Island.

Linda Mearns made a presentation on 16 November 2003 on "The NCAR Weather and Climate Impact Assessment Science Initiative" at the Tyndall Centre, UEA, Norwich, UK.

Linda Mearns, 18 November 2003, talk on "The NCAR Weather and Climate Impact Assessment Science Initiative" at the Environmental Change Institute in Oxford, UK.

Linda Mearns, 20 November 2003, talk on "The NCAR Weather and Climate Impact Assessment Science Initiative" at the Department of Meteorology, University of Reading, Reading, UK.

Linda Mearns, 15 December 2003, presentation on "The Issue of Spatial Scale in Integrated Assessments: An Example from US Agriculture" at Berlin Free University, Berlin, Germany.

Linda Mearns, 16 December 2003, presentation on "The NCAR Weather and Climate Impact Assessment Science Initiative" at the Potsdam Institute for Climate Impact Research (PIK) in Potsdam, Germany.

Richard Katz, at the American Meteorological Society (AMS) Short Course on Significance Testing, Model Evaluation, and Alternatives, gave a talk on "Introduction to Significance Testing" on 11 January 2004, in Seattle, Washington.

Michael Glantz, at the 14th Conference on Applied Climatology of the American Meteorological Society, 13 January 2004, gave a talk on "The Lifelong Contributions of Stan Changnon" in Seattle, Washington.

Richard Katz, at the AMS 17th Conference on Probability and Statistics in the Atmospheric Sciences, spoke about "Bayesian Approach to Decision Making Using Ensemble Weather Forecasts" on 14 January 2004 in Seattle, Washington.

Claudia Tebaldi, at the AMS meeting on 14 January 2004, made a presentation on "From Global Mean Responses to Regional Signals of Climate Change: Simple Pattern Scaling, Its Limitations (or Lack of) and the Uncertainty in its Results," as part of the 17th Conference on Probability and Statistics in the Atmospheric Sciences.

Linda Mearns, 15 January 2004, presentation on "The NCAR Weather and Climate Impact Assessment Science Initiative" at a MICE meeting in Poznan, Poland.

Michael Glantz made a presentation on 21 January 2004 on "Six Concepts for Understanding Environmental Change in Drylands" at the Workshop on Global Change, Sustainable Development and Environmental Management in Central Asia, Tashkent, Uzbekistan.

Linda Mearns made a presentation 12 February 2004 on "Uncertainty and Extremes in Climate Models: Applications to Stakeholder Concerns" at the DEFRA (Department for Environment, Food and Rural Affairs) Meeting at the University of Birmingham, Birmingham, UK.

Michael Glantz gave a talk 12 February 2004 on "A Review of the Context, Outputs and Promise of the Second International Conference on Early Warning" at the ISDR (International Strategy for Disaster Reduction) Early Warning Platform and Program, Bonn, Germany.

Joan Kleypas was an invited speaker at the AAAS Annual Meeting, 12-16 February 2004 and gave a talk entitled, "You Have Never Seen a Reef Like This Before," on 13 February 2004 in Seattle, Washington.

LInda Mearns gave a talk 14 February 2004 on "Quantification of Uncertainty of Regional Climate Change" to the Environmental Change Institute in Oxford, UK.

Joan Kleypas gave an invited talk to the Ocean Studies Board, "Coral Reefs in a Greenhouse Earth," to the Ocean Studies Board of the National Academies on 11 March 2004 in Monterey, California.

Linda Mearns gave a talk on 13 March 2004 on "The NCAR Weather and Climate Impact Assessment Science

Initiative" to the Physics of Climate and Weather Section of the International Center for Theoretical Physical (ICTP) in Trieste, Italy.

Richard Katz gave an invited talk on "Statistics of Extremes in Climate Change" on 22 March 2004 at the Cherry Bud Workshop on Analysis of Natural and Social Phenomena: Data Science and System Reduction, in Yokohama, Japan.

Michael Glantz was an invited keynote speaker on 22 March 2004, on "The Societal Aspects of High-Impact Weather and Climate: A Case Scenario of Superstorm '93" at the International Conference on High Impact Weather and Climate: Understanding, Prediction, and Socioeconomic Consequences, in Seoul, Korea.

Michael Glantz gave a talk 29 March 2004 on "Creeping Environmental Problems: The Concept" to the Shanghai Meteorological Bureau in Shanghai, China.

Michael Glantz gave the keynote address 15 April 2004, "Early Warning Systems and Sustainable Development" at a Workshop on Climate Affairs, held in Petaling Jaya, Malaysia.

Jeffrey Lazo gave a talk 23 April 2004 on "The Household Study of Forecast Use and Value" at the NOAA Weather and Water Mission Goal Social Science Workshop in Boulder, Colorado.

Joan Kleypas gave an invited presentation on "A Fair and Balanced View of Coral Reefs and Climate Change" on 14 May 2004 at the Hopkins Marine Station (Stanford University) in Monterey, California.

Michael Glantz gave an invited presentation 25 May 2004 on "Observational Needs for Adaptation to Climate Change" at the GCOS (Global Climate Observing System) Regional Workshop for Central Asia in Almaty, Kazakhstan.

Linda Mearns gave a talk on 10 June 2004 on "The NCAR Weather and Climate Impact Assessment Science Initiative" to the Ouranos Consortium in Montreal, Quebec, Canada.

Linda Mearns, 11 June 2004, gave an invited presentation on "The North American Regional Climate Change Assessment Program" at the California Energy Commission Meeting in Sacramento, California.

Michael Glantz was a keynote speaker 19 June 2004, "Global Warming: Fact or Fiction?" at the "This Tiny Planet" workshop in Seattle, Washington.

Michael Glantz gave an invited presentation 7 July 2004 at the Next Steps in the Gulf of Mexico conference on "Policy, Economics and Social Science: A Climate Affairs Approach" at the Texas A&M University, College Station, Texas.

Claudia Tebaldi gave a talk on 15 July 2004 on "Probabilistic Assessment of Regional Climate Change: A Bayesian Approach to Combining Predictions from Multi-Model Ensembles" at the Department of Atmospheric Physics in Oxford, UK.

Richard Katz gave an invited presentation at the NCAR Summer Colloquium on Climate and Health on 21 July 2004 on "Introduction to Statistical Theory of Extreme Values," Boulder, Colorado.

Linda Mearns, introduction to the NCAR Summer Colloquium on Climate and Health, 21 July 2004 on "A Challenge to Interdisciplinarity," Boulder, Colorado.

Linda Mearns, presentation at the NCAR Summer Colloquium on Climate and Health on 22 July 2004 on "The Use of Regional Models in Impacts Assessment" in Boulder, Colorado.

Jeffrey Lazo gave a talk 22 July 2004 to the NOAA Staff and Budget Offices on "The Societal Impacts of Weather Information" in Washington, DC.

Claudia Tebaldi gave an invited presentation at the NCAR Summer Colloquium on Climate and Health on 27 July 2004 on "Heat Wave (Mortality) Studies Based on Global Climate Models," Boulder, Colorado.

Linda Mearns gave the introduction and conclusion to the Review of the Weather and Climate Impact Assessment Science Initiative in Boulder, Colorado, on 3 August 2004.

Rebecca Morss, 3 August 2004, "Climate Variability and Uncertainty in Flood Risk Management in Colorado: An Interdisciplinary Project on Extremes, at the Review of the Weather and Climate Impact Assessment

Science Initiative in Boulder, Colorado.

Linda Mearns, presentation on 6 August on "The NCAR Weather and Climate Impact Assessment Science Initiative," at the Stanford Energy Modeling Forum in Snowmass, Colorado.

Claudia Tebaldi gave a talk on 13 August 2004 on "Discussing the Calibrated Probabilistics Mesoscale Weather Field Forecasting: The Geostatistical Output Perturbation Method" at the Joint Statistical Meetings in Toronto, Ontario, Canada.

Rebecca Morss gave a talk on 20 August 2004 on "THORPEX Societal and Economic Applications: International Plans and Ideas for U.S. Implementation" at the USWRP Open Workshop on the Implementation of THORPEX, Boulder, Colorado.

Jeffrey Lazo gave a presentation on 17 September 2004 on "The Economic Value of Weather Forecasts" at the Verification Workshop in Montreal, Quebec, Canada.

Jeffrey Lazo gave a talk 30 September 2004 on "The Household Study of Forecast Use and Value" at the NOAA Boulder Labs Social Science Workshop, Boulder, Colorado.

Non-Technical, Popular Presentations

Jerry Mahlman was one of two featured speakers on 25 October 2003 at a church in Longmont, Colorado, where he spoke on "The Ethics of Global Warming."

Michael Glantz gave a talk 19 February 2004 to a class at CU for the Environmental Policy Master's Program at the Earth Sciences Center at the University of Colorado.

Michael Glantz was a guest lecturer 26 February 2004 at the School of Anthropology, Colorado State University, Fort Collins, Colorado.

Jerry Mahlman gave expert testimony 3 March 2004 at the Senate Commerce Committee's Hearing on the Impacts of Global Warming in Washington, DC.

Jerry Mahlman presented an ACD-hosted talk on 8 March 2004 on "The Science and Ethics of Global Warming" at NCAR in Boulder, Colorado.

Jerry Malhman spoke to a senior seminar class at the Colorado School of Mines on 10 March 2004 in Golden, Colorado.

Michael Glantz spoke to a Political Science class at the University of Denver on 7 April 2004 on "Climate and Politics: A Climate Affairs Approach" in Denver, Colorado.

Richard Katz was a guest lecturer for a course on Introduction to Time Series on 13 April 2004 on "Sir Gilbert Walker and Time Series Analysis," University of Colorado, Boulder, Colorado.

Michael Glantz spoke to a class in Geography and Regional Development on 3 May 2004 on "Climate Affairs: Is the 21st Century the Climate Century?" in Tucson, Arizona.

Joan Kleypas made a presentation for UCAR's Education and Outreach program on 3 August 2004 to teachers on "Coral Reefs and Climate Change."

Claudia Tebaldi gave an interview on 13 August 2004 about the paper, "More intense, more frequent, and longer lasting heat waves in the 21st century" to an Italian radio program, "Il volo delle oche."

Jeffrey Lazo gave a briefing 9 September 2004 to D.L. Johnson of the National Weather Service on an "Overview of NCAR-USWRP Societal Impacts Program" in Boulder, Colorado.

Claudia Tebaldi testified on 15 September 2004 at a full committee hearing on the Impacts of Climate Change, to the Science, Transportation and Commerce Committee of the US Senate, on the paper, "More intense, more frequent, and longer lasting heat waves in the 21st century," in Washington, DC.

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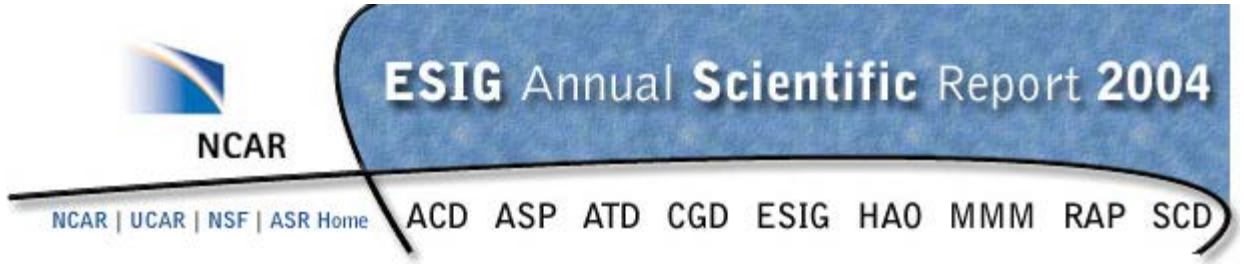

ESIG FY04 Community Service

Editorships of Peer-Reviewed Journals

Michael Glantz, Editorial Board, *Advances in Atmospheric Sciences* (2000-present).

Michael Glantz, Editorial Board, *Sustainability: Science, Practice & Policy* (2004-present).

Michael Glantz, Editorial Board, *Global Environmental Change* (1990-present).

Michael Glantz, Editorial Board, *Problems of Desert Development*, Journal of the Desert Institute, Turkmen Academy of Sciences (1994-present).

Robert Harriss, Associate Editor, *Chemosphere-Global Change Science* (1993-present).

Robert Harriss, Editorial Board, *Journal of Earth System Science Education* (2000-present).

Richard Katz, Editorial Board, *Extremes: Statistical Theory and Applications in Science, Engineering and Economics* (1997-present).

Richard Katz, Editorial Board, *Climatic Change* (1985-present).

Linda Mearns, Editorial Board, *Climatic Change* (1990-present).

Scientific, Policy, or Educational Committees, Advisory Panels, Boards

John Firor, Scientific Advisory Committee, Winslow Foundation (1991-present).

John Firor, Advisory Board, Natural Resources Law Center, University of Colorado (1998-present).

John Firor, Trustee, Environmental Defense (1974-present).

Michael Glantz, Advisory Board, *Colorado Journal of International Environmental Law* (1989-present).

Michael Glantz, Nominated Expert in support of the UN Framework Convention on Climate Change (UNFCCC) (January 1997-present).

Michael Glantz, US Representative, Trade Convergence Climate Complex International Network (TC3Net). Also on Regional Coordinating Committee of TC3Net (January 1997-present).

Michael Glantz, Member of Environmental Literacy Council, a program focusing on environmental education K-12 (1998-present).

Michael Glantz, Member of the Scientific Advisory Panel, Southeast Asian Regional Committee for START

(Global Change System for Analysis, Research and Training) (1996-present).

Michael Glantz, Member of the Scientific Advisory Committee (SAC) for the World Climate Impact Assessment and Response Strategies Programme (WCIRP) of the UN Environment Programme (1980-present).

Michael Glantz, Steering Committee, Center for Environmental Journalism, University of Colorado (1992-present).

Robert Harriss, Member, Scientific Advisory Board, National Institute of Aerospace (2003-present).

Robert Harriss, Member, NSF Advisory Committee for Geosciences (2003-2005).

Robert Harriss, Member, Board of Trustees, New Earth Organization (2003-present).

Robert Harriss, Chair, USWRP Science Implementation Planning Committee on Societal Impacts (2000-present).

Robert Harriss, NASA Stennis Space Center, Commercial Remote Sensing Program, Academic Advisory Board (1999-present).

Robert Harriss, National Research Council, Committee on Global Change Research (1999-2003).

Robert Harriss, Earth Data Analysis Center Advisory Board, U New Mexico (1998-present).

Robert Harriss, Houston Advanced Research Center, Policy Advisory Committee (1998-present).

Robert Harriss, Rio Grande Institute, Senior Fellow (1999-present).

Robert Harriss, Chair, Project on Sustainable Management, Water Environment Research Foundation (1999-present).

Richard Katz, Secretary, International Environmetrics Society (2002-present).

Richard Katz, Program Co-Chair, American Meteorological Society 17th Conference on Probability and Statistics in the Atmospheric Sciences (2004).

Richard Katz, Member, Scientific Committee, 13th International Conference on Quantitative Methods for the Environmental Sciences (2002-2003).

Richard Katz, Member, American Meteorological Society Committee on Probability and Statistics (2001-present).

Joan Kleypas, Secretary, Colorado Fulbright Association Board (2000-present).

Joan Kleypas, Member, NCAR Realignment Committee (2003-2004).

Joan Kleypas, Co-Chair, ESIG-CGD Seminar Series (2003-2004).

Jerry Mahlman, juror to select the winner of the 2003 Heinz Environment Award (2003-2004).

Jerry Mahlman, Member, International Panel to Re-Evaluate the Science Program of the Meteorological Service of Canada (2003-2004.

Jerry Mahlman, Member, Committee to Review the Department of Energy Climate Program (2004).

Jerry Mahlman, Science Advisor, National Geographic Magazine special issue (September 2004) featuring global warming (2004).

Linda Mearns, Internal Oversight Committee of the Review of NCAR by the American Physics Society for Climate for Women Scientists at NCAR (2000-present).

Linda Mearns, Proposal Review Panel, Canadian Climate Change Action Fund, Sectoral Climate Change Scenarios for Canada (2000-present).

Linda Mearns, Member, NIGEC National Office Committee on Integrated Assessment (1999-present).

Linda Mearns, Member, AMS Committee on the Status of the Bulletin of the AMS (1999-present).

Linda Mearns, Member, National Agricultural Sector Team, US National Assessment (1998-present).

Linda Mearns, Member, Climate Change Scenarios Writing Team, US National Assessment (1998-present).

Linda Mearns, Member, Regional Assessment Teams for the Southwest, and Rocky Mountain Basin and Range Regions (1998-present).

Linda Mearns, Member, Land Surface Working Group, Climate System Modeling Project, NCAR (1996-present).

Linda Mearns, Member, IPCC Task Force on Climate Change Scenarios (1996-present).

Rebecca Morss, Co-chair, Societal and Economic Assessment sub-program, and Member, International Scientific Steering Committee, THORPEX: A Global Atmospheric Research Program (2002-present).

Rebecca Morss, Representative on Societal Impacts, US and North American THORPEX Science Planning Committees (2003-present).

Susanne Moser, Member, Union of Concerned Scientists and member of Union of Concerned Scientists Sound Science Initiative (1998-present) .

Susanne Moser, Member, Association of American Geographers (AAG) (1992-present) and Chair, AAG Human Dimensions of Global Change Specialty Group (2002-present).

Susanne Moser, Member, National Council for Geographic Education (1998-2003).

Susanne Moser, Co-Chair of the ESIG-CGD Seminar Series (2003-2004).

Susanne Moser, Member, Scientific Steering Committee, Rocky Mountain Climate Organization (2003-present).

Robert Serafin Member of the American Meteorological Society (AMS) Executive Committee and AMS Planning Commission (2002-present).

Robert Serafin, NRC Space Studies Board and its Executive Committee (1999-present).

Olga Wilhelmi, leading the Geographic Information Systems (GIS) Initiative at NCAR (2000-present).

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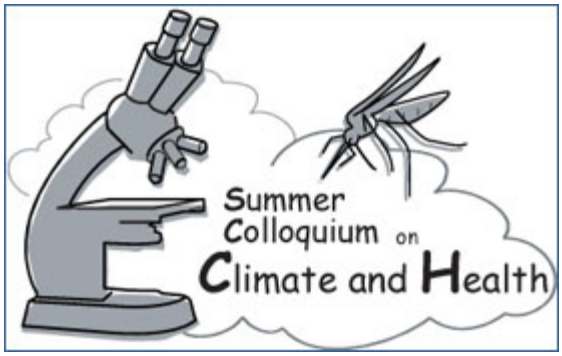
ESIG FY04 Involvement

in NCAR's Strategic Initiatives

The Weather and Climate Impact Assessment Science Initiative (herein referred to as the Assessment Initiative), with Director Linda Mearns, Doug Nychka (CGD), Acting Director for much of FY04, and Lisa Dilling as Project Manager, is based in ESIG. The Assessment Initiative brings together scientists from ESIG, CGD, RAP, UCAR's E&O, and several UCAR member universities to address the themes of climate uncertainty, extremes, and climate and health.



The Assessment Initiative's interactions with the university community include projects involving the Johns Hopkins University (JHU), University of Kansas, University of Colorado in Boulder, and the University of North Carolina. University involvement extends across several of the Initiative's projects, including the role of climate in human health, land cover forcing from the SRES scenarios in climate models, climate variability in past centuries, and the effects of extreme meteorological events in climate models. A comprehensive high-quality website (www.assessment.ucar.edu) was created during FY04 for the Initiative to provide extensive information on each of the subprojects and reinforces the Assessment Initiative as a bridge between regional assessments and global/regional modeling observations. The Initiative held a Summer Colloquium on Climate and Health (co-Chaired by Jonathan Patz (JHU), in collaboration with ASP. It is hoped that a Colloquium series based on this initial prototype will become an annual world-class training and capacity-building program in interdisciplinary climate and health studies.

The main objective of the Geographic Information Systems (GIS) Strategic Initiative is to promote and support the use of GIS as both an analysis and an infrastructure tool in atmospheric research, and to address the broader issues of spatial data management, interoperability, and geoinformatics research in the atmospheric sciences. As an integrating technology, GIS directly addresses NCAR's strategic goal of serving as an Integrator. The GIS Initiative is co-hosted in ESIG and RAP, with Olga Wilhelmi as Director and Jennifer Boehnert (ESIG/RAP) as NCAR's GIS Coordinator. Terri Betancourt (RAP) was a co-Director in FY04. The Iniative continued its work in each of its four major program elements: (1) education, training, and user support; (2) research enabled by GIS; (3) data integration and distribution, and (4) research in GIS technology. In FY04, the Iniative added an fifth important element to its program: community building. (Click on the image to the left to see a larger image of an ArcMap illustration.)

This year, the Initiative has opened a GIS Lab at NCAR with hardware, software, and personnel support available to all NCAR/UCAR staff and continued to provide GIS education and technical assistance with scientific projects and proposals. In FY04, the GIS Initiative started a "GIS Climate Change Scenarios" project to serve a wide external community of GIS users interested in interdisciplinary issues of global climate change. A GIS data portal will allow for a web-based distribution of climate change model output data in a GIS format, which will be used in the upcoming Fourth Assessment Report (AR4) of the IPCC by the Community Climate Systems Model. The Initiative has also been collaborating with representatives of the atmospheric science community and ESRI to develop an atmospheric data model that aims to provide a structure for seamless integration of atmospheric data in GIS. The Initiative website is available at www.gis.ucar.edu.

Other ESIG scientific staff contributed in FY04 to NCAR's Wildland Fire Strategic Initiative (Kathleen Miller, Robert Harriss, Seth McGinnis, and Olga Wilhelmi). Harriss and McGinnis collaborated with Brian Muller and Ernesto Arias (both of the University of Colorado at Boulder) on the development of computer-aided tools and methods for mitigation of wildfire hazards at the urban-wildland interface.

All these Strategic Initiatives received positive external reviews during FY04. The Review Committees assessed their relevance to national and international needs as well as their ability to cut across disciplinary and institutional boundaries.

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FY04 ESIG Publications

Note: **bold** denotes university affiliation; * denotes non-university, non-NCAR affiliation

Refereed

Buddemeier, R.W., J.A. Kleypas, and **R.B. Aronson**, 2004: *Coral Reefs & Global Climate Change: Potential Contributions of Climate Change to Stresses on Coral Reef Ecosystems*. Arlington, VA: Pew Center on Global Climate Change.

Committee on Setting Priorities for NSF-Sponsored Large Research Facility Projects (including R.J. Serafin), 2004: *Setting Priorities for Large Research Facility Projects Supported by the National Science Foundation*. National Research Council. Washington, DC: National Academies Press.

Downton, M.W., J.Z. Barnard Miller, and R.A. Pielke Jr., 2004: A reanalysis of the US National Weather Service flood loss database. *Natural Hazards Review* (accepted for publication).

Downton, M.W., and **R.A. Pielke Jr.**, 2004: How accurate are disaster loss data? The case of U.S. flood damage. *Natural Hazards* (accepted for publication).

Glantz, M.H., 2004: The Aral Sea. In: *Encyclopedia of World Environmental History* (S. Krech III, J.R. McNeill, and C. Merchant, eds.). Great Barrington, MA: Berkshire Publishing, 61-63.

Glantz, M.H., 2004: El Niño and La Niña. In: *Encyclopedia of World Environmental History* (S. Krech III, J.R. McNeill, and C. Merchant, eds.).Great Barrington, MA: Berkshire Publishing, 426-429.

Glantz, M.H., 2004: Problem climates or problem societies? Essay in *The Global Climate System: Patterns, Processes and Teleconnections* (J.E. Oliver and H.A. Bridgman, eds.). Cambridge, UK: Cambridge University Press (in press).

Glantz, M.H., 2004: Climate Affairs, Desertification, and El Niño. Three entries in *Encyclopedia of World Climatology* (J.E. Oliver and H.A. Bridgman, eds.), in the *Encyclopedia of Earth Sciences Series*. Lancaster, UK: Springer (in press).

Glantz, M.H., 2004: *Forecasting El Niño: Science's Gift to the Twenty-First Century* (in four versions: *Africa* in English and French; *Latin America* in English and Spanish). Geneva: World Climate Programme, World Meteorological Organization.

Gommes, R., J. du Guerny, M.H. Glantz, and L-N Hsu, 2004: *Climate and HIV/AIDS: A Hotspots Analysis for Early Warning Rapid Response Systems.* Bangkok: UN Development Programme, Southeast Asia HIV and Development Programme.

Hayes, M.J., O.V. Wilhelmi, and **C.L. Knutson**, 2004: Reducing drought risk: Bridging theory and practice.

Natural Hazards Review, **5**(2), 106-113.

Hayhoe, K., L. Kalkstein, S. Moser, and **N. Miller**, 2004: *Rising Heat and Risks to Human Health: Technical Appendix*. Cambridge, MA: Union of Concerned Scientists.

Imhoff, M.L., **L. Bounoua, T. Ricketts, C. Loucks**, R. Harriss, and **W.T. Lawrence**, 2004: Global patterns in human consumption of net primary production. *Nature*, doi:10.1038/nature02685.

Katz, R.W., 2004: Review of *Forecast Verification: A Practitioner's Guide to Atmospheric Science* (I.T. Jolliffe and D.B. Stephenson, eds.). *Biometrics*, **60**, 566-567.

Katz, R.W., **G.S. Brush**, and **M.B. Parlange**, 2004: Statistics of extremes: Modeling ecological disturbances. (PDF) *Ecology* (in press).

Kleypas, J.A., 2004: Constraints on predicting coral reef response to climate change. Chapter in: R. Aronson (eds.), *Geological Approaches to Coral Reef Ecology.* New York: Springer Verlag (in press).

Kleypas, J.A., 2004: Coral reefs and climate. Entry in *Encyclopedia of World Climatology* (J.E. Oliver and H.A. Bridgman, eds.), in the *Encyclopedia of Earth Sciences Series*. Lancaster, UK: Springer (in press).

Mearns, L.O., **G. Carbone**, R.M. Doherty, **E. Tsvetsinskaya**, **B.A. McCarl**, **R.M. Adams**, and L. McDaniel, 2003: The uncertainty due to spatial scale of climate scenarios in integrated assessments: An example from U.S. agriculture. *Integrated Assessment*, **4**(4), 225-235.

Meehl, G.A. and C. Tebaldi, 2004: More intense, more frequent, and longer lasting heat waves in the 21st century. *Science*, **305**(5686), 994-997.

Meehl, G.A., C. Tebaldi and D. Nychka, 2004: Changes in frost days in simulations of twenty-first century climate. *Climate Dynamics,* **23**(5), 495-511.

Meehl, G.A., W.M. Washington, C.M. Ammann, J.M. Arblaster, T.M.L. Wigley, and C. Tebaldi, 2004: Combinations of natural and anthropogenic forcings in twentieth-century climate. *J. Climate*, **17**(19), 3721-3727.

Miller, K.A., and **G.R. Munro**, 2004: Climate and cooperation: A new perspective on the management of shared fish stocks. *Marine Resource Economics*, **19**(3) (in press).

Miller, K.A., and D. Yates, 2004: *Climate Change and Water Resources: A Primer for Water Utilities*. Denver, CO: Awwa Research Foundation (accepted for publication).

Morss, R.E., 2004: Problem definition in atmospheric public policy: The example of observing system design for weather prediction. *Bull. Am. Meteor. Soc.* (accepted for publication).

Morss, R.E., and **D.S. Battisti**, 2004: Evaluating observing requirements for ENSO prediction: Experiments with an intermediate coupled model. *J. Climate*, **17**, 3057-3073. (PDF)

Morss, R.E. and **D.S. Battisti,** 2004: Designing efficient observing networks for ENSO prediction. *J. Climate*, **17**, 3074-3089. (PDF)

Morss, R.E., K.A. Miller, and **M.S. Vasil**, 2004: A systematic economic approach to evaluating public investment in observations for weather forecasting. *Monthly Weather Review* (in press).

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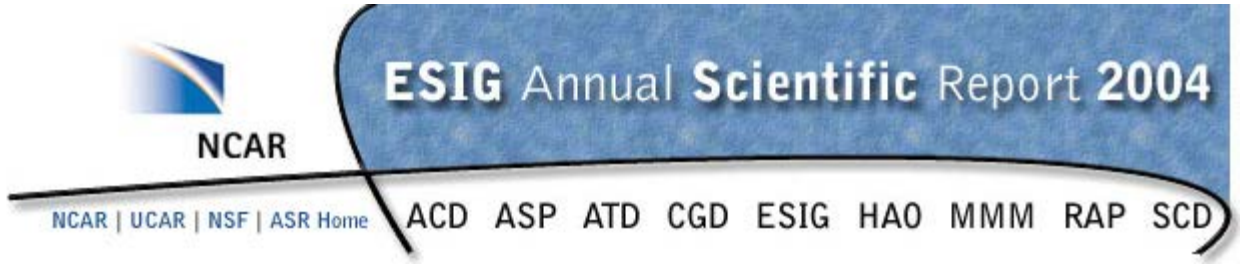

ESIG People

Staff

Robert Harriss, Director
Linda Mearns, Deputy Director

Jennifer Boehnert (50% ESIG, 50% RAP)
Julia Cantzler (casual, from 6/1/04)
Megan Connors (casual)
Melissa Crandell (to 5/4/04)
Heidi Cullen (on leave)
Lisa Dilling
Mary Downton (80%)
John Firor, NCAR Director Emeritus
Michael Glantz
Rebecca Haacker-Santos (from 5/3/04)
Scott Holladay (casual, from 4/19/04)
Victoria Holzhauer
Janet Hopper
Richard Katz
Joanie Kleypas
Emily Laidlaw (casual, from 8/23/04)
Jeffrey Lazo (50% ESIG, 50% RAP, from 4/1/04)
Cheryl Markel (from 10/04/04)
Erin McDaniel (from 2/2/04)
Larry McDaniel
Seth McGinnis
Shannon McNeeley (to 9/4/04)
Kathleen Miller
Rebecca Morss (50% ESIG, 50% MMM)
Susanne Moser
Anne Oman (to 4/16/04)
Jennifer Oxelson (80% ESIG, 20% HIAPER, to 9/3/04)
Jean Renz (80%)
Conrad Roesch (casual, from 12/4/03)
Eric Scharff
Robert Serafin, NCAR Director Emeritus
Sharon Shearer (casual, 1/19-7/21/04)
Joshua Sidon (casual, to 2/27/04)
D. Jan Stewart
Claudia Tebaldi (80% ESIG, 20% RAP)
Olga Wilhelmi

Qian Ye (casual)
Asim Zia (from 8/2/04)

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Long-Term Visitors

Adrienne Gret-Regamey, Swiss National Science Foundation, Bern, Switzerland, 12 August 2002 to 12 February 2004.

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Affiliate Scientists

Michele Betsill, Department of Political Science, Colorado State University (to 1/4/07).
Jonathan Patz, Johns Hopkins University (to 2/28/07).
Roger Pielke, Jr., University of Colorado/CIRES (to 2/28/07).
Susan Subak, University of East Anglia (to 1/4/07).

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ASP Postdoctoral Fellows

Shui Bin
Eugene Wahl (to 2/18/04)

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HAO Director's Message

Michael Knölker

The High Altitude Observatory of the National Center for Atmospheric Research explores the Sun and its effects on the Earth's atmosphere and physical environment. The achievements for this year stand out with breakthrough measurements of coronal magnetic fields through polarimetry in the near infrared, and the first physics-based prediction of aspects of the solar dynamo. The NCAR-wide effort to develop a Whole Atmosphere Community Climate Model (WACCM) continued. The expansion of the HAO upper atmosphere modeling effort to the near-Earth environment through coupling of modeling the ionosphere and the magnetosphere has gained momentum this year, making a significant contribution to the Boston University led Center for Integrated Space Weather Modeling (CISM).

After aggressive recruitment of young scientists in previous years, HAO focused on the consolidation of the program with the new staff and the expansion of the program, given the long-term priorities of the so-called four cornerstones of our research: The Dynamo, The Flux Eruption Process, The Structure and Dynamics of the Corona, and The Impacts of Solar Variability on the Earth's Atmosphere and Magnetosphere. Significant progress was achieved in all four cornerstones, as is described in this report. Beyond that, HAO has maintained its strong standing in the >identification of extra-solar planets.

HAO remains committed to a strong Education and Outreach program that, among other things, consists of program elements for short-term visitors, long-term visitors and post docs, graduate students, and affiliate scientists. The HAO Visitor Program remained a major commitment for the Observatory. Indeed we were able this year to moderately increase the allocation.

The HAO Instrumental and Observational program is running solar instrumentation at the >Mauna Loa Observatory in Hawaii and at the observatory in Izaña, Tenerife. Furthermore, HAO has had deployed for many years, the Advanced Stokes Polarimeter as a community post focus instrument at the Dunn Telescope at National Solar Observatory at Sacremento Peak. In combination with the other astrophysics and solar physics observatories, HAO is well suited to help the community to do specific measurements on solar variability at the source. HAO also continues the instrumental/observational program at Resolute Bay, Canada, a Fabry Perot instrument deployed there delivers data of high quality. The instrument is meeting all of our expectations and is making contributions to understanding physical processes above the Earth's magnetic north pole.

HAO's contributions to the NASA programs continued with the Solar-B instrument. Nearing completion and with the launch of that satellite not too far away, HAO has shifted activities towards comprehensive data analysis of

spectropolarimetric data. HAO/NCAR has started a strategic initiative to ultimately provide the community with standardized sets of tools for this kind of work.

As in the years before, I invite you to peruse the web pages of this Annual Scientific Report to share the excitement that we feel in pursuing our research, in working with people in the community, and in getting ready for new research frontiers in the solar planetary research scenario.

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Executive Summary

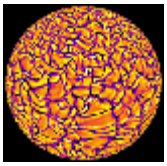
The various research activities of the High Altitude Observatory (HAO) are collectively directed toward the broad scientific goal of developing a comprehensive, quantitative understanding of the coupled Sun-Earth system. HAO scientists make progress in pursuit of this objective by investigating and elucidating the basic physics underlying the production of the Sun's magnetism and activity, the structure and dynamics of the terrestrial magnetosphere, ionosphere, and upper atmosphere, and the mechanisms by means of which the Earth's atmosphere and near-space environment are influenced by the radiative, particulate, and magnetic outputs of the Sun. HAO researchers utilize a variety of approaches in studying the processes and phenomena that affect the state of the Sun-Earth system, employing instrumental, observational, interpretive, computational, and theoretical expertise to address some of the fundamental problems of solar-terrestrial physics. Reflecting its position as a part of a national center, HAO is an active participant in joint projects with other NCAR science divisions, while assiduously fulfilling its committment of service to the community by providing access to instruments and observing facilities and the data acquired thereform, maintaining a suite of models that are available to outside users, and facilitating interaction and collaboration by hosting short- and long-term scientific visitors. The nature and scope of HAO's research program affords it a unique scientific situation, enabling it to bridge the disciplinary gap between the geosciences and astrophysics, contributing to an improved understanding of both the Sun's role in weather and climate, and of the Earth and Sun within the wider astronomical context, through efforts in planetary atmospheres, the detection of extrasolar planets, and stellar physics.

The foundation upon which the overall HAO program rests comprises four cornerstone research areas:

> the solar dynamo, with focus on the internal physical processes that contribute to the generation and evolution of the Sun's time-dependent magnetic field;
>
> the transport of the generated field through the convection zone, its emergence at the solar surface, and the inference of its properties in the photosphere and overlying atmospheric layers through spectro-polarimetric techniques;
>
> the energetics and dynamics of the solar corona and wind, including the eruptive events which are the major drivers of space weather and geomagnetic activity;
>
> the observation and modeling of the Earth's upper atmosphere, including its extensions and couplings to both the magnetosphere and interplanetary medium, and to lower atmospheric regions.

Research in these areas of emphasis is carried out within the three scientific sections that are the basic units of HAO's organizational structure. At the present time, staff members in the Solar Interior and Variability (SIV) section study the solar dynamo, the transport of magnetic flux, and related physical processes, while those in the Solar Atmosphere and Heliosphere (SAH) section are engaged in activities pertaining to the remote sensing of the Sun's magnetic field and

studies of coronal dynamics and activity and its influences on the interplanetary medium. Studies of the Earth's upper atmosphere, the ionosphere, and the magnetosphere are conducted by those in the Terrestrial Impacts of Solar Output (TISO) section. HAO researchers have made substantial progress in all of the cornerstone areas during the past year, through numerous efforts that have yielded important new results concerning the origins and properties of solar magnetism and related activity, and the dynamics and electrodynamics of the terrestrial upper atmosphere and the solar forcing thereof.



The Magnetic Sun and Variability - Solar Interior and Variability (SIV)

The complex, time-dependent magnetic field of the Sun derives from processes that operate within the convective envelope that occupies the outer 30 % of the solar interior, and in the tachocline, the thin rotational shear layer that straddles the radiative-convective interface. HAO researchers were among the first to recognize that the large-scale meridional circulation that exists in the solar convection zone could have a significant impact on the way in which the dynamo operates, with the timescale of the circulatory flow essentially establishing the period of the Sun's magnetic activity cycle. They are now exploring the predictive capabilites of such "flux transport" dynamos, using observations of the surface meridional flow and poloidal field as model inputs, and examining the consequences for the behavior of subsequent cycles. Simulations performed in this way have made it possible to understand the unusually slow rise and delayed polar field reversal of cycle 23, and to tentatively predict a later onset for the upcoming cycle 24. In addition to its role in regulating the dynamo, the origins and properties of the meridional circulation have also been the focus of active research over the last year. A mean-field model of convection zone dynamics, based on a parameterized description of turbulent energy and angular momentum transport, was used to investigate the conditions leading to solar-like meridional flow and differential rotation, and a theoretical analysis of the circulation component at the bottom of the convective envelope revealed that the extent of its penetration into underlying radiative interior was likely quite limited, contrary to the assumed flow morphology of some dynamo models. The presence of strong, concentrated toroidal fields at the radiative-convective interface was investigated as a possible disruptive influence on a flux transport dynamo, through the effect of the Lorentz force on the deep meridional flow. Results obtained using both kinematic and dynamic models indicate that although the circulation is deflected around regions of strong toroidal field, it still transports the weak poloidal field required for continued functioning of the dynamo, testimony to the robustness of the basic mechanism. Significant progress was also made toward enhancing the realism of numerical treatments of the buoyancy-driven rise of toroidal magnetic flux tubes through the solar convective envelope. The development of a new 3D anelastic MHD code made possible the first such simulations using a spherical shell as the computational domain. The results of test runs that include the effects of the Sun's rotation in modeling the ascent of axisymmetric flux rings were in good agreement with the trajectories derived from previous studies based on a simplified thin flux tube model.

HAO's efforts to detect and study planets in orbit about nearby solar-type stars also yielded noteworthy results during the last year. The Transatlantic Exoplanet Survey (TrES) network, composed of HAO's STellar Astrophysics and Research on Exoplanets (STARE) telescope (sited on the island of Tenerife, Spain) and two similar instruments (located in Flagstaff, Arizona and Mt. Palomar, California) identified a transiting planet from observations of periodic eclipses of a star in the constellation Lyra. The planet (TrES-1) has a mass and radius about 0.75 and 1.04 times the corresponding values for Jupiter, respectively, and is the fifth such object with observable transits.

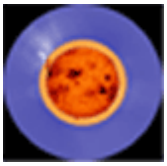
Additional Accomplishments Include:

---Global MHD instabilites of the solar tachocline were treated using more realistic models that include the effects of diffusion, and the hydrodynamic stability of this layer was investigated using a newly developed nonlinear shallow-water code.

---The dynamical structure of turbulent solar convection was studied using high-resolution numerical simulations in full spherical geometry, and improved sub-grid-scale models for unresolved motions were developed.

---Evidence for an asymmetric spatial distribution and a weak north-south alignment of solar supergranules was found, with the large-scale organization of the supergranulation pattern lasting for many supergranular lifetimes.

---Variations in the Sun's radiative output during solar cycle 23 were analyzed in detail, and accurate empirical models were constructed from new measurements of the total solar irradiance and activity indices.



The Magnetic Sun and Variability - Solar Atmosphere and Heliosphere (SAH)

The magnetic fields that emerge from the convection zone into the photosphere in the form of concentrated flux tubes play a pre-eminent role in structuring and forcing the overlying atmosphere, contributing to the dynamics and heating of the chromosphere and high-temperature corona, and

influencing the acceleration of the solar wind. Magnetic fields are also the dominant source of activity in the Sun's atmosphere, driving energetic events such as flares and coronal mass ejections (CMEs), which can significantly perturb the interplanetary medium and produce disturbed conditions in the upper atmosphere of the Earth. Throughout its history, HAO has pioneered the development and use of spectro- polarimetric instruments to investigate the emergence, evolution, and properties of solar magnetic fields. This tradition of leadership was continued during the past year with HAO involvement in a variety of collaborative efforts to design and build new ground- and space-based instrumentation for solar spectro-polarimetry. Prominent among these undertakings has been the Coronal Multi-channel Polarimeter (CoMP), a project funded as an NCAR Strategic Initiative which will enable observers to routinely measure magnetic fields in the corona, a region where direct knowledge of magnetic properties has heretofore been scant. Following its deployment at the National Solar Observatory (NSO) earlier in the year, the CoMP instrument obtained exciting observations of a prominence eruption. HAO also continued its efforts in support of the 4 meter, ground-based Advanced Technology Solar Telescope (ATST), contributing to site survey testing, the design of polarimetric calibration techniques, and the development of Visible Spectrograph (ViSP) instrument, and, in collaboration with the Lockheed Martin Solar and Astrophysics Laboratory (LMSAL), provided the Focal Plane Package for the 50 cm telescope on board the joint Japan/US/UK Solar-B mission. This instrument will be the first precision, high-resolution solar spectro-polarimeter in space. The data acquired by HAO instruments was used in a variety of interpretive and theoretical studies which have revealed more about the dynamic character of the emerging fields that have been implicated in the generation of activity and that influence the large-scale magnetic structure of the corona. A detailed observational study of evolving magnetic fields in the photosphere under active region filaments showed evidence for a field geometry that was consistent with that expected from an emerging, twisted magnetic flux rope. Three-dimensional MHD simulations were used to investigate the response of pre-existing coronal fields to the rise of such a flux concentration, providing insights into the heating, emission, and magnetic helicity injection associated with the emergence process. Twisted magnetic flux ropes confined within closed magnetic structures are also possible precursors to CMEs, allowing the magnetic energy required to drive these events to be built up and stored. HAO researchers conducted theoretical studies to determine the energy storage capacities of two- and three-dimensional magnetic equilbria with embedded flux ropes, and performed numerical simulations to examine the conditions under which an emerging, twisted flux rope can push apart the confining field lines of an overlying coronal arcade to erupt into a CME. Significant progress toward understanding CME-related processes and phenomena was also made through observational studies carried out using the instruments of the Advanced Coronal Observing System (ACOS) of HAO's Mauna Loa Solar Observatory (MLSO). These efforts included a search for for evidence of the presence of flux ropes in the corona prior to the occurrence of CMEs, an investigation of a possible correlation between the accelerations of eruptive prominences and the asymptotic speeds of associated CMEs, a study of the relation between CME-related coronal and chromospheric waves, and an examination of the properties and evolution of transient coronal holes that can develop following the onset of CMEs.

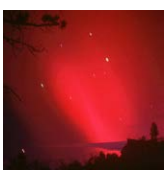
Additional Accomplishments Include:

---A theory for the shapes of spectral lines that show scattering polarization when viewed near the solar limb (the "second solar spectrum") was formulated, and a novel laboratory experiment, supported through an NCAR Opportunity Fund grant, was devised and built to test it.

---Work on the development of fast, robust techniques for inverting spectro-polarimetric observations continued, including the use of artificial neural networks, a method which holds great potential for reliable, near real-time retrieval of magnetic field strengths from data.

---Supported by an NCAR Opportunity Fund grant, an effort was undertaken to measure vector magnetic fields in prominences using filter-polarimetric techniques at the NSO Evans Coronagraphic facility. The Kippenhahn-Schluter prominence-sheet solution was extended and generalized to permit construction of models with small-scale structure that can be used to simulate polarimetric signals for comparison with observations.

---Axisymmetric, two-fluid, MHD simulations of the inner corona and solar wind exhibited episodic releases of massive plasmoids from an unstable equatorial helmet streamer in response to heating of the proton component of the gas; this behavior may be relevant in accounting for the slow solar wind.



The Coupled Geospace System - Terrestrial Impacts of Solar Output (TISO)

The mesosphere, thermosphere, ionosphere, and magnetosphere comprise a region wherein the dynamical, thermodynamical, and compositional conditions are subject to forcings transmitted from both above and below. The waves and tides that are prominent dynamical features of the innermost of these layers are affected by processes occurring lower in the atmosphere, while the outer layers, by virtue their ionization state, are electromagnetically coupled and respond to the prevailing conditions in the solar wind and the state of the interplanetary magnetic field. HAO supports a vigorous and broad program of research aimed at understanding the physics of the Earth's upper atmospheric regions, with particular attention paid to the influence of the Sun's variable

radiative and particulate emissions. Central to these efforts are the suite of geospace models that HAO researchers have developed and maintain both as investigative tools and as a resource for the solar-terrestrial community. In the past year, upgrades were made to the Thermosphere-Ionosphere-Mesosphere Electrodynamics General Circulation Model (TIME-GCM), enhancing vertical and horizontal resolution and updating aeronomic components. Among the investigations yielding noteworthy results that were carried out using the TIME-GCM: an examination of the circumstances leading up to the occurrence of a simulated stratospheric warming, revealing the role of wave-induced changes in the mesosphere as precursors to the event; a detailed study of the factors contributing to the observed seasonal variations of the amplitude of the 6.5-day, zonal wavenumber 1 planetary wave; and, an exploration of the effects of more realistic, spatially (in longitude and latitude) and temporally variable gravity wave sources on mesospheric dynamics. The dynamics and chemistry modules from the TIME-GCM have been adapted and incorporated into the Whole Atmosphere Community Climate Model (WACCM), a collaborative undertaking involving HAO and the Climate and Global Dynamics (CGD) and Atmospheric Chemistry (ACD) Divisons of NCAR. Within the last year, WACCM was extended through the inclusion of a newly developed parameterization for the spectrum of convectively generated gravity waves, and an improved treatment of solar radiation that gives solar heating and photodissociation rates for a large number of chemical species. A WACCM simulation was performed to study the effects of sea surface temperature variations on the structure of the middle and upper atmosphere, and the model is currently being prepared to run over a complete solar cycle to examine the chemical, dynamical, and structural changes that are produced by realistic solar forcing. Significant progress was also made in HAO's efforts to understand the couplings, energetics, and dynamics of the ionosphere and magnetosphere. The feasibility of a new implementation of the Assimilative Mapping of Ionospheric Electrodynamics (AMIE) procedure was demonstrated through application of the method to analysis of a magnetic cloud event from January, 1997. This work represents an important step toward understanding how scale-dependent properties of electromagnetic energy and momentum transfer processes affect estimates for global thermospheric Joule heating. Global-scale, MHD simulations of the solar wind-magnetosphere interaction were performed that enabled HAO researchers to compare computational results for magnetic reconnection in the magnetopause and the field-aligned current density at low altitudes with observations, and to study and compare the properties of isolated substorms with those that occur during magnetic storms. Initial results were also obtained from the new Coupled Magnetosphere Ionosphere Thermosphere (CMIT) model, a product of HAO's collaborative participation in the NSF-supported Center for Integrated Space Weather Modeling (CISM). The CMIT model combines HAO's Thermosphere-Ionosphere Nested Grid (TING) model with the Lyon-Fedder-Mobarry magnetospheric model; results obtained from comparative tests show a more realistic distribution of ionospheric conductances, a more clearly defined auroral oval, and Joule heating enhancements that affected the neutral atmosphere.

Additional Accomplishments Include:

---The new Fabry-Perot Interferometer, designed to measure mesospheric and lower thermospheric winds and tides and the upper thermospheric polar cap convection pattern, was deployed at Resolute, Canada, the future site of the NSF Advanced Modular Incoherent Scatter Radar (AMISR).

---A study of the thermospheric-ionospheric responses to geomagnetic storms at different solar cycle phases found that the initial thermal and compositional recoveries from storm-time perturbations occur more rapidly at solar maximum than at solar minimum.

---An examination of the relative importance of direct penetration and disturbance dynamo electric fields in the storm-time equatorial ionosphere showed that the direct penetration electric field can modify the ionospheric dynamo by changing the neutral wind and conductivity in the F-region ionosphere.

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HAO Achievements

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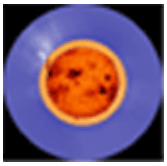
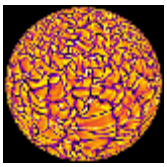
The Earth's Upper Atmosphere
The Ionosphere, Plasmasphere and Magnetosphere



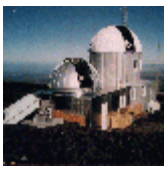
The Magnetic Sun and Variability - Solar Atmosphere and Heliosphere (SAH)

Magnetic Field Observations, Interpretation and Theory
Solar Atmospheric Dynamic and Radiative Processes
Coronal Structure and Dynamics
Physics of the Solar Wind



The Magnetic Sun and Variability - Solar Interior and Variability (SIV)

Radiative Processes and Small-scale MHD in the Convection Zone and Photosphere
Global MHD of the Solar Interior
Extra-solar Stars and Planets



Facilities and Community Support

Support of Community Computational Models
Support of Integrated Community Programs
Observational Facilities and Data Services

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The Coupled Geospace System - Terrestrial Impacts of Solar Output (TISO)

The Earth's Upper Atmosphere
The Ionosphere, Plasmasphere and Magnetosphere

Other HAO Sections SAH | SIV | Facilities

The Earth's Upper Atmosphere

Basic Structure | Variability and Disturbances | Solar Irradiance Effects | Large-scale Dynamics | Gravity Waves

Basic Structure

-Sea Surface Temperature Effects on Middle/Upper Atmospheric Structure- Raymond Roble (HAO) contributed to the NCAR interdivisional effort to study the effects of sea surface temperatures on the structure and composition of the Earth's middle and upper atmosphere. Fabrizio Sassi (CGD) led this effort with contributions from Douglas Kinnison (ACD), Byron Boville (CGD), Rolando Garcia (ACD) and Roble. They forced the lower boundary of the Whole Atmosphere Community Climate Model (WACCM) with observed sea surface temperature (SST) for the period 1950-2000. This period contained several instances of anomalously warm/cold tropical SST, identified by the so-called NINO3 index. The WACCM results revealed anomalies in the structure of vertically propagating planetary waves from the troposphere to the mesosphere. Circulation anomalies in the middle atmosphere were accompanied by large temperature anomalies that were of opposite sign in the stratosphere and mesosphere, the stratosphere being warmer during El Niño events, whereas the mesosphere was colder. Near the summer mesopause, an anomalous source of momentum due to parameterized gravity waves resulted in warming during El Niño. Compositional differences during El Niño/La Niña events also occured, with more ozone depletion occurring during La Nina. Detailed analysis showed statistically significant structure anomaly predictions. The model's mean climatology revealed that Rossby-planetary

waves affected the zonal mean circulation up to about the stratopause, whereas parameterized gravity waves were more important in the El Niño/La Niña response.

-Interferometric Measurements of Upper Atmospheric Winds- Qian Wu (HAO) developed a new Fabry-Perot interferometer (FPI) in collaboration with R. Daniel Gablehouse, Stanley Solomon, and Timothy Killeen (all of HAO). They designed the FPI to measure mesospheric and lower thermospheric winds, tides, and the upper thermosphere polar cap convection pattern using the OH, O 5577 Å and 6300 Å airglow. The wind errors for these emissions are 6 m/s (3 minute integration), 1 m/s (3 minute) and 2-6 m/s (5 minute), respectively. The instrument was tested in Boulder, Colorado and resultant measurements compared favorably with lidar mesospheric neutral wind measurements made nearby in Fort Collins, Colorado and provided by Chiao-Yao She (Colorado State University). Thereafter, the FPI was deployed at Resolute, Canada (75 N), the future site of the National Science Foundation Advanced Modular Incoherent Scatter Radar (AMISR). The neutral wind data obtained at Resolute also demonstrated that the instrument met the design goal and will provide high quality measurements for studies of mesospheric and lower thermospheric dynamics, as well as magnetospheric-ionospheric coupling and upper atmospheric ion-neutral coupling processes in the polar cap.

-Thermospheric Neutral Composition Tongue- Alan Burns and Webin Wang (both of HAO) collaborated with Killeen and Solomon to describe the existence of a "tongue" of neutral composition in the upper thermosphere that is similar to the well-known tongue of ionization. The tongue formed in much the same way that the tongue of ionization does; that is, parcels of air, which are rich in O/N_2, are drawn from the dayside by the anti-sunward winds associated with the neutral convection pattern and transported across the polar cap towards the night side auroral oval. The O/N_2-rich air can only be transported from a small region on the dayside due to the geometry of the transport, so the neutral tongue is narrow like the ion tongue. But, the neutral tongue is different is several ways; it tends to be weaker than the ion tongue, it extends a shorter distance across the polar cap, and it takes longer to form. Once the neutral tongue forms in conjunction with the tongue of ionization, the latter becomes both stronger and longer, but causality in this relationship has yet to be established.

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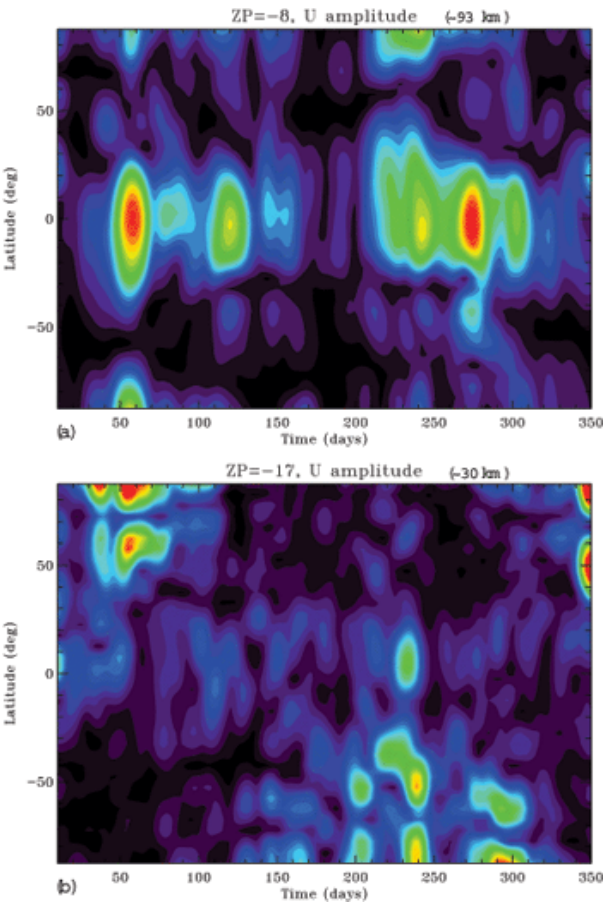
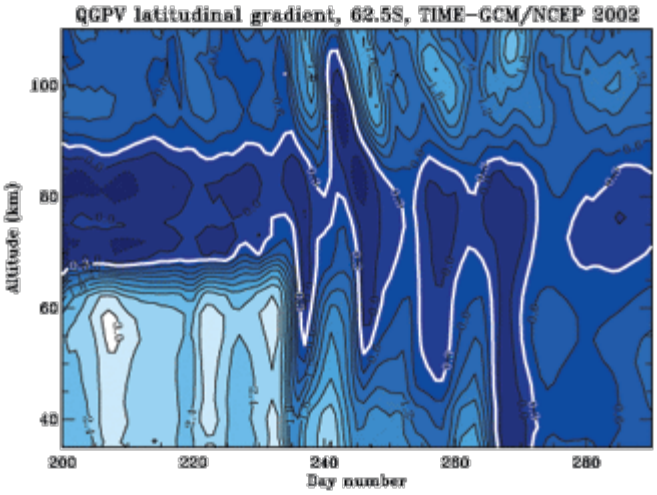
Variability and Disturbances

-Seasonal Variability of the 6.5-Day Planetary Wave- The zonal wavenumber 1 planetary wave of period near 6.5 days is a robust feature in the mesosphere and lower thermosphere (MLT) region with prominent seasonal variability as revealed by ground-based and satellite observations. Hanli Liu (HAO), Elsayed Talaat (Johns Hopkins University), Roble, Ruth Liberman and Dennis Riggin (both of Colorado Research Associates), and J.-H. Yee (Johns Hopkins University) studied this wave and its seasonal variability using a one-year NCAR Thermosphere-Ionosphere-Mesosphere-Electrodynamics general circulation model (TIME-GCM) simulation with its lower boundary specified according to the National Centers for Environmental Prediction (NCEP) re-analysis data for the year 1993. Wavelet analysis of the model output shows that in the MLT region the wave maximizes before and after the equinoxes and minimizes at solstices (see the accompanying Figure). The wave amplitudes at the equinoxes are smaller than the peaks before and after, but still larger than the wave amplitudes at solstices. On the other hand, at the lower boundary near 30 km, the wave peaks predominantly between fall and the following spring. By examining the episodes of maximum and minimum wave amplitude and conducting additional control experiments using the TIME-GCM, Liu and co-authors studied the factors determining this planetary wave structure, along with its characteristics and seasonal variability, in detail. They found that the wave source, mean wind structure, instability, and the critical layers of the wave all affect the wave response in the MLT region and have a strong seasonal dependence. Before and after equinox, the wave follows the waveguide and propagates from the stratosphere to the summer mesosphere/mesopause, where it may be amplified by baroclinic/barotropic instability. Such instability is usually absent from the equinoctial



atmosphere so that there is no wave amplification at equinox. At solstice, the wave decays significantly when propagating away from its winter source due to the strong eastward winter stratospheric jet. In the summer side, the westward jet is also strong and the meridional and vertical extension of the critical layer of the wave is large enough to enclose the instability in the summer mesosphere/mesopause at mid-high latitudes. The wave is thus reflected away and prevented from reaching and amplifying at the unstable region. They also carried out similar studies of the seasonal variation of the quasi-two-day wave, which has zonal phase speed similar to the 6.5-day wave. They showed that both waves exhibit variability in the MLT that closely tracks the lower atmospheric variability associated with these waves within certain windows in a given season, but especially during summer.

-Precursors to a Stratospheric Warming Event- In the 2003 ASR, Liu and Roble reported that the TIME-GCM was able to simulate the major stratospheric warming event (hereafter stratwarm) in the Southern Hemisphere in the year-long simulation of 2002. They subsequently analyzed the event further to reveal a likely mechanism associated with the stratwarm. They explored the possible role of the mesosphere in the dynamical processes using data from both the TIME-GCM and NCEP reanalyses. They found that significant changes in the wind and temperature fields occur in the mesosphere first, due to a strong wave 1 event about a month before the major warming in the stratosphere. Thereafter, a series of wave events during the following month erode the polar jet and alter the transmission conditions for planetary waves at progressively lower altitudes. This helps to set up the atmospheric conditions favorable for the upward and poleward propagation of wave energy, not only for wave 1 but also for wave 2 and 3. At the same time, the jet reversal and the planetary wave surf zone also descend from the mesosphere down to the stratosphere. The preconditioning ultimately leads to an extensive breaking of the polar jet and wave 1 in the stratosphere and thus, the major warming.



The illustrated contours of latitudinal gradient of quasi-geostrophic potential vorticity at 62.5oS exemplify the findings of Liu and Roble and their TIME-GCM simulation of the unprecedented 2002 major stratospheric warming event in the Southern Hemisphere. They found that significant changes in the wind and temperature fields first occur in the mesopshere due to a strong wave 1 event about a month before the major warming in the stratosphere. Then a series of wave events in the following month erode the polar jet and alter the transmission conditions for planetary waves at progressively lower altitudes. At the same time, the jet reversal and the planetary wave surf zone also descend from the mesosphere down to the stratosphere. The preconditioning ultimately leads to an extensive breaking of the polar jet and wave 1 in the stratosphere and thus the major warming.

-Estimates for Sources of Thermospheric Heating- Delores Knipp (United States Air Force Academy) worked with W. Kent Tobiska (Space Environment Technologies), and Barbara Emery (HAO) to estimate the thermospheric heating sources over 29 years for solar cyles 21-23. They reported that the major heating source (~78%) is solar EUV radiation, as specified by the updated SOLAR2000 model. Geomagnetic power included the effects of solar particles, including auroral electrons as filtered through the magnetosphere, and Joule heating. The particle precipitation, estimated using newly intercalibrated hemispheric power indices provided 5-8% of the total power under all conditions. The Joule heat source was estimated from the Thule Polar Cap (PC) index and the Disturbed electrojet (Dst) index using Assimilative Mapping of Ionospheric Electrodynamics (AMIE) Joule heat. The Joule source provided ~16% of the total power most of the time, but ~45% for the top 1% of power events, and up to 70% in some of the top 20 events over the 29 years studied. The most variable power source was Joule heating.

-Solar Cycle Variations in Geomagnetic Storm Reponses- Burns, Killeen, Wang, and Roble completed their study, which quantifies the relationship between solar cycle variations in the background thermosphere and ionosphere and thermospheric-ionospheric responses to geomagnetic storms. Their findings include: larger increases of N_2 mass mixing ratio at much lower winter geomagnetic latitudes during solar minimum than solar maximum due to comparatively more important horizontal advection during solar minimum; less molecular rich high-latitude air during solar minimum with stronger equatorward winds because the pressure gradients driven by solar EUV heating are weaker, rendering the circulation driven by high-latitude Joule heating relatively more important. In contrast to the compositional variations,

storm-time absolute temperature increases are greater during solar maximum than during solar minimum. The initial thermal recovery from storm-time perturbations is faster during solar maximum, but then recovery rates are roughly equivalent after the first 12 hours of the recovery period. The initial compositional recovery also occurs much more rapidly at solar maximum than at solar minimum.

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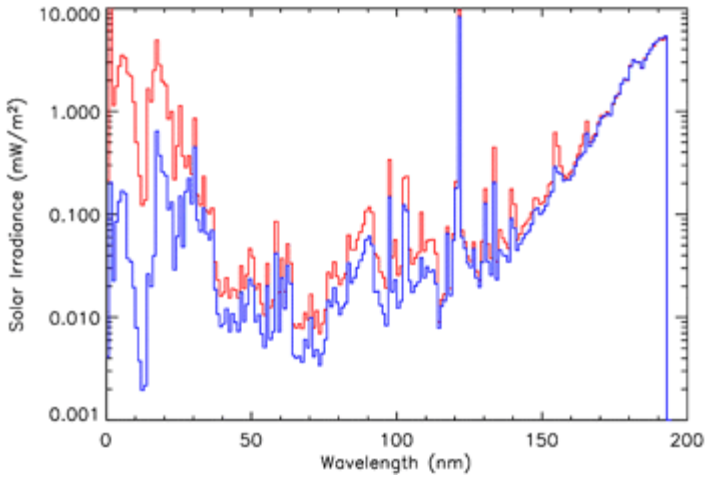
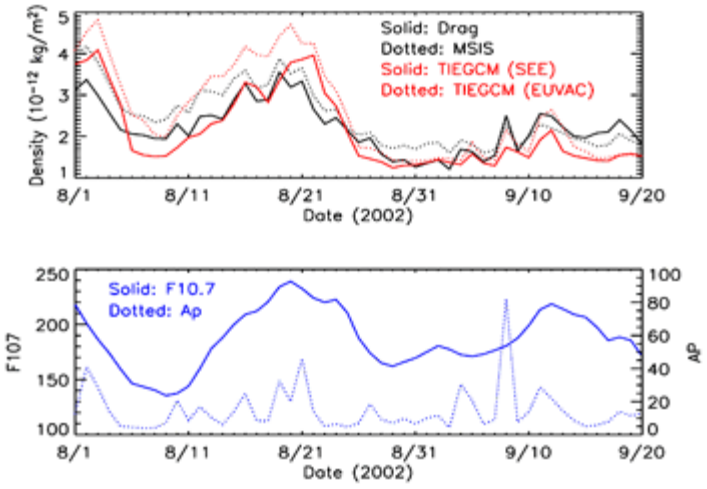
Solar Irradiance Effects

-Initial Results from the Solar Extreme-Ultraviolet Experiment (SEE)- Tom Woods, Frank Eparvier (both of University of Colorado), Scott Bailey (University of Alaska), Phillip Chamberlain (University of Colorado), Judith Lean (Naval Research Laboratory), Gary Rottman (University of Colorado), Solomon, Tobiska, and Don Woodraska (University of Colorado) reported on the initial results from the solar extreme-ultraviolet (EUV) experiment (SEE) on the Thermosphere-Ionosphere-Mesosphere Energetics and Dynamics (TIMED) satellite. Thereafter, Solomon and Liying Qian (HAO) developed a method for applying solar EUV and soft X-ray spectra measured by SEE and by the X-ray photometer system on the Solar Radiation and Climate Experiment (SORCE) satellite to the NCAR TIE-GCM. Qian, Solomon, Roble, and Woods made comparisons between upper thermosphere densities calculated using index-based proxy-model solar inputs and the actual solar measurements. Together with Frank Marcos (Air Force Research Laboratory), these collaborators subsequently reported comparisons with measurements of upper thermosphere densities using the decay rates of orbiting satellites. Solomon and Qian also led the effort to study the upper atmospheric impact of the first full spectral measurements of major solar flares in the extreme-ultraviolet range made by the SEE on the TIMED satellite. Solomon, Gang Lu (HAO), Qian, Art Richmond (HAO), and Woods reported on the ionization, temperature, and density enhancements associated with the flares as modeled by the NCAR TIE-GCM when the SEE measurements were included as inputs to the model.



Solar spectrum in the ultraviolet and X-ray spectral region measured by TIMED/SEE for the X-17 flare on 28 October 2003. Blue line - before flare. Red line - near peak of the flare. Note that while the spectrum longward of 27 nm is measured by a spectrometer and is highly accurate, the spectrum shortward of 27 nm is measured by photometers and there are significant uncertainties in the magnitude and spectral distribution of the irradiance enhancement.

Comparison of models of upper thermosphere density at 400 km during August/September 2002 to measurements using the satellite drag technique. Solid black line - measurement. Dotted black line - Mass Spectrometer Incoherent



Scatter (MSIS-90) empirical model. Solid red line - TIE-GCM with measured solar inputs. Dotted red line - TIE-GCM with proxy-model solar inputs.

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Large-Scale Dynamics

-Studies of Tides and Planetary Waves in the MLT Region- A series of model and measurement comparisons were coupled with diagnostic studies involving the TIME-GCM and the global-scale wave model (GSWM), providing new insight into the behavior and impact of tides and planetary waves in the MLT. Tides are global-scale waves with periods that are harmonics of a solar day. They are the most striking dynamical features in the MLT region, but they can be modulated by more transient planetary waves.

She and Tao Li (Colorado State University), Richard Collins (University of Alaska), Tao Yuan, Bifford Williams (both of Colorado State University), Takuya Kawahara, Joseph Vance, Phillip Acott, David Krueger (all of Colorado State University), Liu and Maura Hagan (both of HAO) reported on the short-term variability of the diurnal and semidiurnal tidal temperature and horizontal winds over Fort Collins, Colorado. They reported modulation of the tidal amplitudes by planetary waves with periods of 3 to 5 days. Michael Taylor, A. K. Taori, D. R. Hatch (all of Utah State University), collaborated with Liu and Roble in an investigation of a semiannual oscillation in mesospheric temperatures observed over Maui, Hawaii. Scott Palo (University of Colorado), Liu, Rolando Garcia (NCAR/ACD), James Russell III (Hampton University), and Martin Mlynczak (NASA Langley) investigated the propagation of the quasi-two-day wave from the middle atmosphere into the thermosphere/ionosphere as observed by the SABER instrument on TIMED and modeled by the TIME-GCM.

Wu, Gablehouse, Killeen, and Solomon studied mesospheric neutral wind data from 1995 to 1999 obtained with a Fabry-Perot Interferometer (FPI) stationed at Resolute Bay, Canada (75N, 95W). A 12-hour wave was the most prominent feature in the neutral winds. The wave amplitude exhibited large day-to-day variations as well as inter-annual variability, whereas the phase of the wave appeared largely invariant. A small phase shift occurring between early to later winter was the noticeable exception, which occurred when early winter data were available. Large westward zonal winds were observed during stratospheric sudden warming events. The most pronounced 12-hour wave variability occurred during the 1995/1996 northern winter season, and may be related to non-linear interactions with planetary waves.

Wu and Killeen also collaborated with David Ortland (Northwest Research Associates), Solomon, Gablehouse, and Roberta Johnson (also of HAO), Rick Niciejewski, Wilbert Skinner (both of University of Michigan), and Steve Franke (University of Illinois) in a study of the migrating (or Sun-synchronous) diurnal and semidiurnal tides deduced from TIMED Doppler Interferometer (TIDI) neutral wind data. They found clear signs of diurnal and semi-diurnal tides in TIDI meridional winds in the MLT region. The TIDI diurnal tide has a vertical wavelength close to 20 km, with an amplitude peak at ~ 97 km. The GSWM diurnal tidal predictions have similar amplitudes, but they peak above 100 km, and have a longer vertical wavelength (~ 25 km). They also reported that TIDI meridional winds are in good agreement with meteor radar measurements made over Maui, Hawaii.

Jens Oberheide (Wuppertal University) led an effort to characterize a second class of diurnal tidal oscillations in the TIDI meridional wind data in collaboration with Wu, Ortland, Killeen, Hagan, and Roble. Their focus was the nonmigrating

diurnal components with particular attention to the westward propagating wavenumber 2 tide, the eastward propagating wavenumber 3 tide, and the zonally symmetric standing (wavenumber 0) tide. They reported the analysis of March 2002 to June 2004 TIDI measurements that were made between 85 and 105 km altitude. The 95 km monthly-averaged meridional tidal winds compared favorably with similar tidal component estimates deduced from UARS satellite data at the same altitude but for a different time period (1992-1995). The TIDI nonmigrating diurnal tidal wind speeds reached amplitudes in excess of 30 m/s, emphasizing the important role of nonmigrating tides in coupling the middle and upper atmosphere. The TIME-GCM and the GSWM predictions indicate that both latent heat release in the tropical troposphere and non-linear planetary wave/migrating tidal interactions are important sources of nonmigrating tides in the MLT.

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Gravity Waves

-Scale Invariance of Temperature and Horizontal Wind Spectra- Liu studied the possible origin and implications of the scale invariance of the vertical wavenumber and frequency spectra of temperature and horizontal wind. The vertical wavenumber and frequency power spectra of the horizontal wind and temperature in the troposphere, stratosphere, and mesosphere often exhibit power law distribution on scales larger than the turbulence inertial range. The spectral slopes are quite independent of altitudes and specific measurement locations, and indicate "universal" scale invariance in the atmosphere. The origin of the universal spectra is yet to be fully understood, though previous studies have suggested possible relation to gravity wave saturation and/or nonlinear interaction of the gravity waves. In this work, Liu demonstrated that 1D (vertical) stochastic systems, subject to adjustment due to convective or shear instability, possess scale invariance similar to that observed in the atmosphere. Such systems can be described by stochastic, nonlinear, diffusive equations, and Liu proved that these equations support scale invariance by applying a dynamical renormalization group (DRG) analysis. The DRG analysis yields scaling indices and provides a plausible explanation and ranges of the variation of these indices. The calculated indices and the variation ranges compared favorably with the values reported in previous studies. Liu also showed that the renormalized diffusion coefficients in such systems are scale dependent, and derived the scaling relations.

-Mesospheric Variability from Stochastic Gravity Wave Sources- Liu, Roble, and Hagan examined mesospheric variability due to stochastic gravity wave sources. As in many other general circulation models, the source of the parameterized gravity wave specified at the lower boundary of the NCAR TIME-GCM is uniform in the longitudinal direction and time, and varies smoothly over latitudes. Such a specification is quite arbitrary, due to the lack of knowledge of the distribution and variability of various gravity wave sources. The source strength and the associated momentum flux are tuned such that the temperature, altitude and strength of the jet reversal in the mesosphere agree with observations. The gravity waves in the real world, evidently, are highly variable spatially and temporally. Liu, Roble, and Hagan explored the impacts of such variability on the dynamics of the mesosphere by using the TIME-GCM and stochastic gravity wave sources in time and in longitude and latitude, while keeping the mean characteristics of the wave sources the same. To isolate sources of variability, no planetary waves (except the thermal tides) were included in the simulation. The resultant mesospheric winds and temperatures displayed increased temporal and spatial variability. The density of the zonal wind power spectrum in the zonal direction at higher wavenumbers was higher than in the control case, and the Nastrom-Gage spectrum was recovered with the spatially random gravity wave sources. This implies that random and local gravity wave forcing in the mesosphere can help distribute energy to smaller scales and contribute to the cascading process of quasi-geostrophic turbulence. Liu, Roble, and Hagan also investigated implications for the tidal variability.

-A New Parameterization for Convectively Generated Gravity Waves- NCAR ASP postdoctoral fellow Jadwiga (Yaga) Beres (HAO/ACD/CGD) implemented a new method of specifying the gravity wave spectrum above convection into the WACCM, in collaboration with Garcia, Boville, and Sassi. This parameterization is interactive with the underlying convection, and introduces realistic spatial and temporal distributions of gravity wave activity, as well as yielding gravity wave characteristics related to the underlying wave source. The new scheme improves the structure of the tropical stratospheric and mesospheric semiannual oscillations in WACCM, and gives insight into the wave motions that might be responsible for extratropical mesospheric forcing. The newly implemented scheme also provides a new direction for gravity wave parameterizations, as the gravity wave forcing is no longer fixed and will follow changes in tropospheric climate. This allows for more accurate studies of effects of changing climate on the middle atmosphere and on examining the feedbacks between the troposphere and the middle atmosphere. Beres also continued her collaboration with M. Joan Alexander (Colorado Research Associates), who led the effort to gain a better understanding of wave generation by convection via comparisons between theoretical gravity wave estimates and numerical simulations results. They also used observations to force a mesoscale numerical model.

-Mountain Wave Studies with an Extended WRF Model- University of Colorado graduate student, Natalie Rooney, collaborated with Liu, and Jimy Dudhia (MMM) to extend the Weather Research and Forecasting Model (WRF) model

into the mesosphere to study the impact of mountain waves in the upper atmosphere. The WRF is a regional, non-hydrostatic model designed for operational weather forecasting, regional climate prediction, air-quality simulation, and idealized dynamical studies. Rooney and colleagues adapted the model and extend it to 90 km. The resultant simulations encountered a numerical instability related to noise introduced by the conventional sigma coordinate. They implemented the hybrid terrain-following vertical coordinate to correct the problem. This change resulted in a more accurate upward integration of the pressure profile in the upper atmosphere, and produced other evidence of improved stability. They performed several tests to verify that the change in the vertical coordinate did not disturb the dynamics of the model. Using their extended version of the WRF model, Rooney, Liu, and Dudhia were able to study the effects of various background wind profiles on the mountain wave propagation. One interesting case study involved a time-varying eastward wind in the troposphere and a constant westward wind in the upper atmosphere. They found that the gravity waves generated by the gusty wind at lower levels can have a wide phase speed spectrum. Some of the transient components were able to penetrate into the upper atmosphere. Since this is a fairly typical summer wind profile, they concluded that it is important to study the effects of these transients on dynamics of the upper atmosphere.

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The Ionosphere, Plasmasphere, and Magnetosphere

Structure and Dynamics | Variability and Disturbances | Coupling Between Geospace Domains

Structure and Dynamics

-Spatial Structure of the Electron Diffuse Aurora- Margaret Chen (Aerospace Corp.), Michael Schulz (Lockheed Martin), Phillip Anderson (Aerospace Corp.), Lu, Glen Germany (University of Alabama), and Martin Wuest (Southwest Research Institute) studied the spatial structure of the electron diffuse aurora during geomagnetic storms. They found that the distributions of precipitating diffuse aurora depend strongly on variation of the magnetotail electron distributions, electron transport, and electron pitch angle scattering. By using two different scatter rate models (e.g., strong uniform diffusion versus a magnetic local time (MLT)-dependent but relatively weaker scattering rate), they found that the simulated storm-time energy flux with strong diffusion tends to be much more intense in the evening sector and much weaker near dawn than what is statistically observed. The most intense electron precipitation under strong diffusion will occur where the electron drift times from the plasmasheet are on the order of the electron lifetime against strong diffusion. On the other hand, the model and data comparison shows that the MLT-dependent but relatively weaker scattering produces a more realistic electron diffuse aurora than with the strong diffusion.

-Predicting the Storm-Time Dst Profile- George Siscoe (Boston University), Robert McPherron (UCLA), Michael Liemohn, Arron Ridley (both of the University of Michigan), and Lu reexamined the so-called Burton et al. equation for predicting the storm-time Dst profile. With the aid of the Ring Current Atmosphere Interaction Model (RAM), they showed that by reformulating the Burton et al. equation such that a quadratic form of the driving term replaces the original linear form, the new prediction algorithm, driven by the polar-cap potential saturation form of the driving electric field, produces an equally good fit to the Dst index as the original Burton et al. equation and the RAM simulations. The form of the quadratic driving term is constructed by specializing a general form given by dimensional analysis.

-Objective Analysis of High-Latitude Ionospheric Electrodynamic Variables- Tomoko Matsuo (CGD), Richmond, and Lu implemented the Optimal Interpolation (OI) method, in conjunction with Empirical Orthogonal Function (EOF) bases and the maximum likelihood method for on-line error covariance parameter estimation, for the objective analysis of high-latitude ionospheric electrodynamic variables. This work is an important step in understanding how scale-dependent properties of electromagnetic energy and momentum transfer processes affect the global thermospheric Joule heating estimation. Their study demonstrated how this methodology may be used to extract information about the temporal coherence of large- and meso-scale electric field variability, for a magnetic cloud event on January 10-11, 1997. They found that the time scale of the dominant modes of electric field variability generally decreased with increasing EOF order and decreasing spatial scale. Compared with the temporal persistence of the Interplanetary Magnetic Field (IMF) and solar wind parameters, the time scale of the spatially coherent part of the electric field variability, on the spatial scale of the EOFs, is shorter. They analyzed the principal components of the electric field variability during two periods when either the IMF B_y or B_z component was relatively steady while the other component varied. The first principal component generally reflected the change in the ionospheric convection pattern predicted by IMF-dependent empirical models, and thus tended to represent changes in the convection that are directly driven by solar wind-magnetosphere interactions. However, they found that the second principal component more strongly correlated with the westward auroral electrojet, suggestive of a link to substorm phenomena.

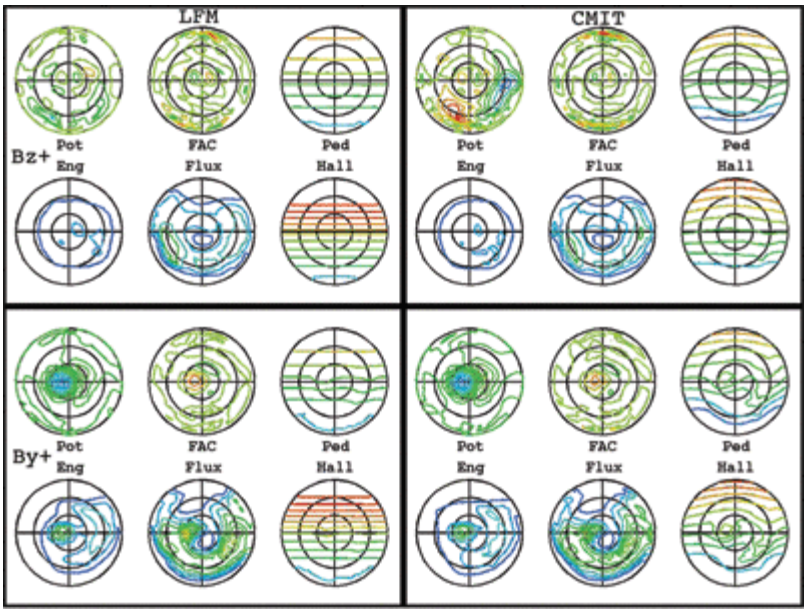
-A Simplified Model for High-Latitude Energy Transfer- At high latitudes the interaction between the ionosphere and the magnetosphere can be expressed by the electromagnetic energy flux. For the static case, the electromagnetic energy flux (Poynting flux) is equivalent to the work done by the Ampere force on the neutral gas and the rate at which the atmosphere is heated by Joule heating. The latter is the dominant part. Numerical models of the upper atmosphere often underestimate the highly varying contribution of Joule heating, since the Joule heat estimated from the model Pederson conductance and model electric fields squared only represents the mean values of the conductance and electric fields, and does not represent their variability. Therefore Astrid Maute (HAO), with the assistance of Jeff France (HAO summer undergraduate student), developed a simplified model of the high latitude energy transfer by analyzing the Poynting flux from the Ion Drift Meter (IDM), the Retarding Potential Analyzer (RPA) data, and the MAGB magnetometer on board the Dynamics Explorer 2 satellite. The simplified model depends on magnetic local time, dipole tilt and the magnetic activity index Ap (or Kp) to be used in the WACCM.

-Simulations of Ionospheric Electric Fields and Vertical Drifts- Geeta Jadhav (HAO visitor, Indian Institute of Geomagnetism) and Richmond examined the quiet-time low-latitude ionospheric electric fields and vertical drifts in the evening sector at equinox as a function of longitude and solar activity, using simulations from a global model with interactive thermosphere-ionosphere dynamics and electrodynamics. The model inputs were held fixed with respect to universal time, in order to evaluate the contributions to longitudinal variations of the equatorial electric fields and drifts associated with zonal variations in the geomagnetic field. The simulated upward evening drift increases with solar activity, in agreement with observations in the Indian, Peruvian and Brazilian sectors. The simulations also agree with observations in finding larger vertical drifts in the American-Atlantic sector than in the East Asian-Pacific sector, generally associated with longitudinal variations in the strength of the geomagnetic field. Relations among the longitude variations of the vertical drift, the conductivity, the eastward wind velocity, the geomagnetic declination, and gradients of the wind and declination were examined, revealing few clear correlations. However, extrema of many of these quantities were noted in the American-Atlantic sector.

-AMIE-Driven Ionospheric Modeling- Pierre-Louis Blelly, J. Fontanari, and Denis Alcayde (all of the Centre d'Etude Spatiale des Rayonnements; CESR) used results from their 13-moment ionospheric TRANSCAR model, driven with 10-minute Assimilative Mapping of Ionospheric Electrodynamics (AMIE) outputs provided by Emery, in a comparative analysis with European Incoherent SCATter (EISCAT) radar data provided by Chantal Lathuillere and Jean Lilensten (both of the Laboratoire de Planetologie de Grenoble). The AMIE ion drifts from cross-tail potential patterns underestimated the maximum ion drifts above the EISCAT transmitter at Tromsø by a factor of 2.5. The AMIE drifts were then used to infer magnetic flux tube transport over the polar cap. AMIE auroral electron patterns were used along with AMIE parallel currents as magnetospheric particle and electron heat flux inputs, respectively, to the ionosphere. The resulting simulation of the electron density and ion and electron temperatures between about 100 and 600 km matched the EISCAT observations well, although some differences were found which could be attributed to the preciptation of electrons with very low energies which are not included in AMIE.

-Magnetic Reconnection in the Magnetopause- Stefan Eriksson, Scott Elkington (both University of Colorado), Tai-Duc Phan (University of California, Berkeley), Steven Petrinec (Lockheed Martin), Henri Reme (CESR, France), Malcolm Dunlop (Rutherford Appleton Laboratory, UK), Michael Wiltberger (HAO), A. Balogh (Imperial College London, UK), Robert Ergun (University of Colorado), and Mats Andre (Swedish Institute of Space Physics) collaborated to compare detailed observations of flank magnetopause reconnection with results from simulations of the magnetospheric configuration performed using the Lyon-Fedder-Mobarry (LFM) global-scale magnetohydrodynamic (MHD) code. Their results suggest that the Cluster spacecraft were passing through the simulated MHD sash region in the Northern Hemisphere on 30 June 2001, while crossing the magnetopause just equatorward of the Southern Hemispheric sash on 29 May 2001. Plasma jets were detected from a location sunward and mostly poleward of the spacecraft on 30 June, but reaching Cluster from a poleward and somewhat antisunward location relative to sc1 on 29 May. The Walen test confirmed that the observed jets flow at the local Alfven velocity in the deHoffmann-Teller frame, and Eriksson and collaborators interpreted them as velocity enhancements due to magnetic reconnection. The observed plasma jet directions compared well with those expected from antiparallel merging in the simulated MHD sash. The local magnetic field shear between the observed magnetosheath and the geomagnetic fields ranged between 162 and 168 degrees in the estimated tangential magnetopause plane for these two events. A projection of antiparallel merging regions and the tilted component merging line onto the magnetopause on 30 June and 29 May together with these Cluster observations support the view that the IMF controls the global location of magnetic reconnection on the magnetopause in contrast to any randomly occurring reconnection process driven by locally fulfilled conditions.

A 3D topological view of the MHD magnetosphere and



the magnetic fields surrounding Cluster sc1 (yellow diamond) from the Eriksson et al. 2004: Two cross-sections of the magnetosphere are shown at z = 0 and y = 0 respectively. A selected number of magnetic flux tubes are displayed with red indicating "open-open" fields, blue depicting "closed-closed" fields, and yellow showing "open-closed" flux tubes.

-Comparison of Simulated/Observed Field-Aligned Currents- Haje Korth, Brian Anderson (both Johns Hopkins University), Wiltberger, John Lyon (Dartmouth College), and Phillip Anderson (Aerospace Corporation) compared global magnetospheric simulation results of the field-aligned current (FAC) density at low altitudes with global two-dimensional distributions of Birkeland currents at the topside ionosphere, derived from magnetic field data of the Iridium satellite constellation. They studied two events with opposite directions of the IMF B_y, 23 November 1999, 1400 -1700 UT, $B_y > 0$, and 31 March 2000, 1500-1800 UT, $B_y < 0$. In both observations and simulations, the configuration of the FACs near noon displayed the expected reversal of sense with latitude corresponding to the sign of B_y. The total Region-1 current in the simulations (2-3 MA) was larger than that derived from Iridium (1-1.5 MA), consistent with known underestimates from Iridium, but there was a deficit of Region 2 in the simulations. The poleward limit of the simulated Region-1 currents was significantly (< 5°) poleward of the observed currents for standard resolution simulations. Doubling the simulation resolution led to a marked improvement in the agreement with the observed spatial distribution of Region-1 FACs. Moreover, the higher resolution led to the appearance of some Region-2 FACs in the November 23 event. The results imply that in addition to including a ring current module to properly account for the particle drift physics, high simulation resolution and improved nighttime ionospheric conductivities are two factors that must be addressed in order to obtain reliable simulation results.

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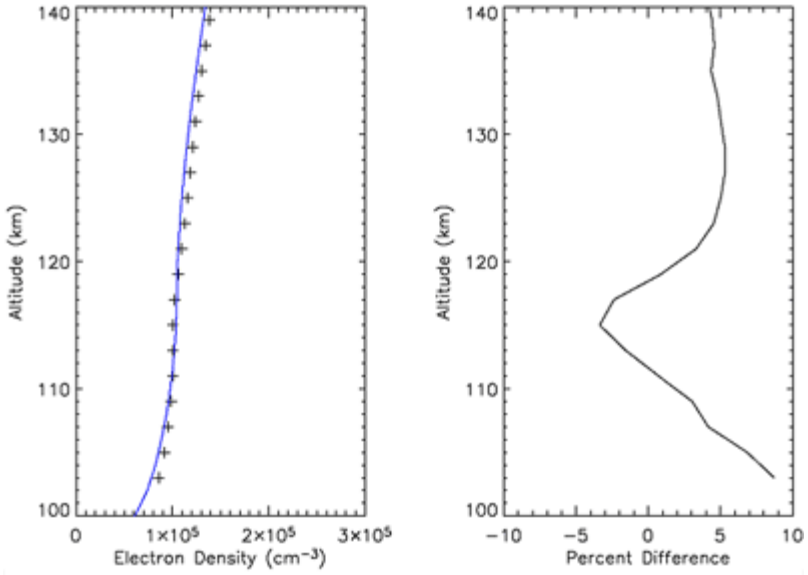
Variability and Disturbances

-Photochemical Modeling of the E-Region Ionosphere- Rick Doe, Jeff Thayer (both SRI), and Solomon performed photochemical modeling of the E-region ionosphere for comparison with electron density measurements made by the Sondrestrom incoherent scatter radar facility during geomagnetically quiet, daytime conditions. Comparisons between electron densities calculated by the NCAR Global Airglow (GLOW) model and measured by the radar were performed for an array of solar zenith angles and solar activity levels, showing good correspondence in both dimensions of this variability. Correspondence of the grand average of seven years of radar data and model runs was remarkable, demonstrating that the solar inputs and ion-neutral chemical parameters are in agreement with the lower ionosphere electron density, at least in a mean sense.



Average electron density profile from seven years of incoherent scatter radar measurements at Sondrestromfjord, Greenland.

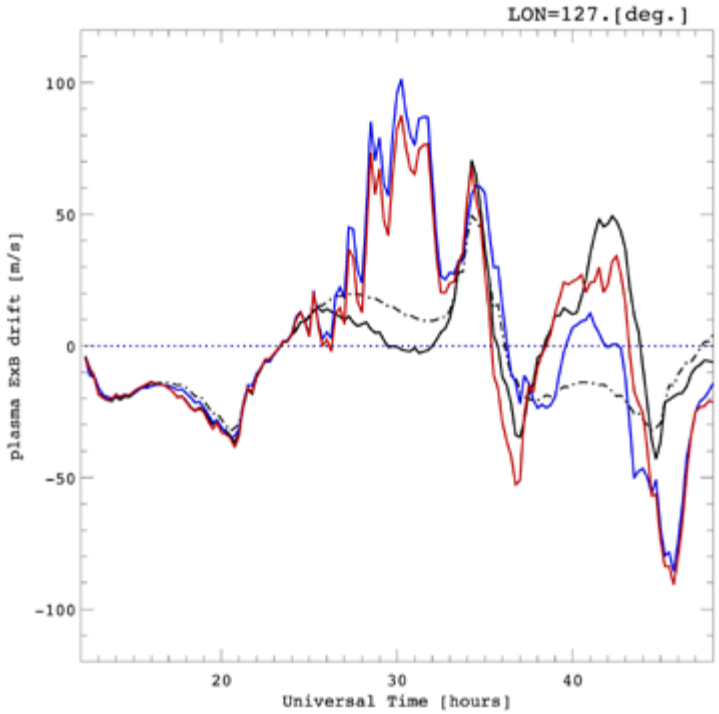
Plusses - radar measurement.
Blue line - GLOW model calculation of electron density for the same array of conditions.
Right panel - percent difference (100 x (measurement - model) / measurement).

-A Statistical Study of High-Latitude Joule Jeating- M. Geoffrey McHarg, Francis Chun (both United States Air Force Academy) worked with Knipp, Lu, and Emery to carry out a statistical study of the high-latitude Joule heating in response to the IMF. They used approximately 9000 Northern Hemisphere (NH) AMIE Joule heat patterns to characterize the Joule heating in terms of the IMF components. They found that during extreme northward IMF conditions, Joule heating is restricted to the high-latitude dayside. During strongly southward IMF condition, Joule heating is located predominantly in the auroral region, with increased heating in the morning sector compared to the evening sector. They also found only a weak IMF B_y effect in the Joule heating distributions.

-Analysis of Peterson/Hall Conductance Variations- Working under the direction of Maute, Linde Clark (HAO summer undergraduate student) used fourteen years of EISCAT data to derive height-integrated Pedersen and Hall conductivities. The conductances were binned by UT, season, solar cycle, and polar cap index, and their variations with these parameters were analyzed and qualitatively compared with conductances derived from the IRI 90 model. Both the Pedersen and Hall conductances show peaks during the night (LT=UT+1), corresponding to times of significant particle precipitation. The Hall conductance exhibits more UT variation than the Pedersen conductance because the Hall conductance is more sensitive to hard particle precipitation. During solar minimum, the conductances show the most UT variation and have the largest values in the autumn. The large nighttime conductance levels in autumn could be attributed to ion velocities.

-Modification of the Ionospheric Dynamo by Penetration Electric Fields- HAO postdoctoral fellow Naomi Maruyama examined the relative importance between direct penetration and disturbance dynamo electric fields in the storm-time equatorial ionosphere. This study was undertaken in collaboration with Timothy Fuller-Rowell, Mihail Codrescu (both NOAA Space Environment Center and University of Colorado), Richmond, George Millward (University College, London), Stanislav Sazykin, Frank Toffoletto, and Bob Spiro (all Rice University). They utilized the Coupled Thermosphere-Ionosphere-Plasmasphere-Electrodynamics (CTIPe) model for their study, and imposed electric fields as specified by the Weimer electric field model and the Rice Convection Model (RCM). They found dominant penetration electric field effects during daytime and at the early stage of the storm (see accompanying figure, results at 05 UT on

March 31) associated with the sudden enhancement of the polar cap potential. As a consequence of the enhancement of the upward drift, the electron density peak is lifted and moved poleward, and the density is increased in the equatorial ionosphere. They found comparable penetration and disturbance dynamo effects at night. The disturbed drift showed a reversal from the downward to the upward direction. Their results demonstrate that the direct penetration electric field can modify the ionospheric dynamo by changing the neutral wind and conductivity in the F-region ionosphere. This modification is preferentially observed during nighttime since the nighttime ionospheric electric field is mainly determined by the F-region dynamo, in contrast to the daytime E-region dynamo driven mainly by the tidal forcing propagating from the lower atmosphere.



An example of the vertical ExB drifts at the magnetic equator obtained from CTIPe for 36 hours starting from 12UT on March 30 2001, at a longitude of 127 degrees. The RCM electric field is imposed from 00UT on March 31 2001. At this longitude sector, 00UT corresponds to 8.47LT. Four different CTIPe simulations are shown. The black dash line is the quiet time reference. The black solid line is the simulation with disturbance dynamo effect only. The blue solid line is the simulation with the penetration electric field only. The red solid line is the simulation including both effects of the disturbance dynamo and penetration electric fields. The disturbance electric field is dominated by the penetration effect at around 05UT on March 31 during daytime and at the early stage of the storm, while the nighttime disturbance observed at around 16UT is determined by the combination of both the penetration and disturbance dynamo electric fields.

-Comparison of Simulated Storm-time and Isolated Substorms- Wiltberger led an effort to compare LFM global magnetohydrodynamic (MHD) simulations of isolated substorms to those occurring during magnetic storms. His collaborators in this study were Elkington, Timothy Guild (Boston University), Daniel Baker (University of Colorado), and Lyon. They found that the August 27, 2001 substorm was fairly typical and isolated as monitored by an extensive set of

satellite and ground-based observations. The LFM simulation results for the interval agreed with some of these observations. The simulation results also showed that thin current sheets developed during the growth phase of substorms and were disrupted, in part, by flows originating in the mid-tail region prior to ionospheric signatures of substorm onset. Detailed analysis of the energy partitioning in the magnetotail showed that the transfer of energy from the lobes into the plasma sheet occured a few minutes before substorm onset. The magnetic storm, which began on March 31, 2001, was one of the largest magnetic storms during the current solar cycle. A very large substorm occurred during this interval with an onset at 0630 UT. Results from the LFM simulation of this period agree with some observations made by the constellation of spacecraft that monitored this substorm. Comparisons between the LFM results for these two events indicate that storm-time and isolated substorms share the same essential features, including the development of intense thin current sheets during growth phase, the disruption of this current sheet linked to activity in the mid-tail region, and rapid recovery phases.

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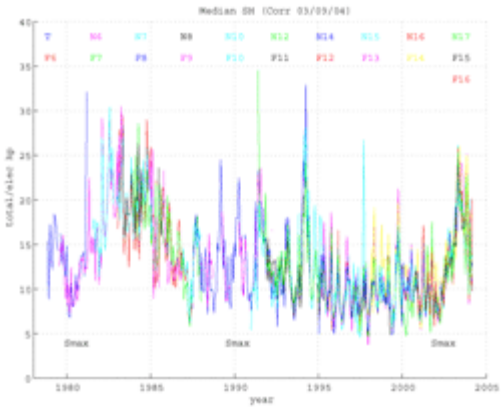
Coupling Between Geospace Domains

-Riometer Observations of Sawtooth Particle Injections- HAO postdoctoral fellow Andrew Kavanagh, Lu, Eric Donovan (University of Calgary, Canada), Geoff Reeves (Los Alamos National Laboratory), F. Honary (Lancaster University, UK), J. Manninen (Sodankyla Geophysical Observatory, Finland), and Thomas Immel (University of California, Berkeley) investigated simultaneous riometer observations in the nightside and dawn-noon sectors during sawtooth particle injections (which are characterized as a series of 2-3 hour, quasi-periodic, energetic particle flux sudden enhancements, followed by gradual decay), measured by the geostationary satellites during the geomagnetic storm on 18 April 2002. They found a good agreement between the nightside riometer absorption in the low-altitude ionosphere and the expected propagating discrete flux enhancement during the four substorms associated with sawtooth injections in the equatorial magnetosphere.

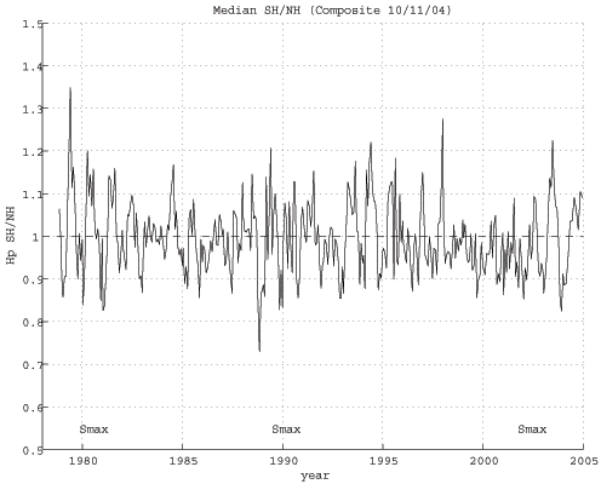
-Inner Magnetosphere-Radiation Belt Coupling During Geomagnetic Storms- Elkington, Baker, and Wiltberger studied the coupling between the inner magnetosphere and the radiation belts during a geomagnetic storm that began on March 31, 2001. This storm was characterized by high solar wind speeds and long intervals of strongly southward interplanetary magnetic field. These conditions led to high levels of magnetospheric convection and significant distortion in the inner magnetosphere. During a period of particularly intense driving by the solar wind, a substorm onset was observed to inject energetic particles into low L-values in the premidnight region of the inner magnetosphere. Particle simulations of keV protons, injected from the plasma sheet into the inner magnetosphere, driven by fields taken from the LFM global- scale MHD simulation, show qualitative agreement with global observations of the event. These results suggest that a weak field region in the near-Earth tail may have served as a source region for the more energetic particles injected into the inner magnetosphere.

-Analysis of Auroral Electron, Ion, and Total Hemispheric Powers- Barbara Emery and Weibin Xu (both of HAO) combined twenty-six years of low-energy auroral electron and total hemispheric power indices from 21 NOAA and DMSP satellites to produce both hourly and daily median and average composite indices for the Southern and Northern Hemispheres. The SEM-2 NOAA satellites also provided estimates of the auroral ion hemispheric power over the last 6 years. Daily median intersatellite correlations exceeded 70% most of the time after contamination or degradation issues were addressed, and the median daily values usually agreed within 5% overall, after making baseline adjustments that ranged within a factor of two. Initial corrections were made to eliminate sunlight contamination, data dropouts over the auroral oval, the degradation of sensors over time, high spurious count rates, and increased noise at the end of a satellite lifetime. Adjustments were also made in most satellites so that the ratio of the south to north electron or total hemispheric power was approximately one over a year. The first accompanying Figure shows the adjusted 27-day median of daily median Hp values for the Southern Hemisphere for all satellites. The ratio of the concurrent median daily hemispheric power from both hemispheres in the second Figure shows that the winter values are almost 30% higher than the summer values during solar maximum, and about 5% higher in solar minimum conditions. The winter/summer concurrent ratios of the ion hemispheric power are opposite to those of the electrons, showing increases in the concurrent summer to winter ratios of about 27%, independent of solar cycle as seen in the third Figure. Ions contribute most to the total in quiet conditions. Kp and Ap are strongly correlated with the electron and the ion daily hemispheric power, with correlation coefficients of about 0.8 for the electrons, and about 0.6-0.7 for the ions. The Hp adjustments will be revised with new estimates using the latest DMSP calibration corrections in FY2005.

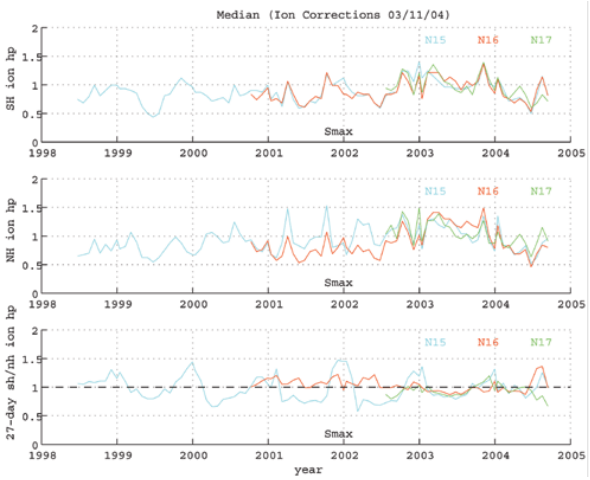
Southern Hemisphere (SH) median 27-day total or electron hemispheric power from daily medians from



21 NOAA and DMSP satellites after corrections, deletions and adjustments are made to a composite standard (TIROS SH and DMSP-F06 NH).



Southern/Northern Hemisphere (SH/NH) composite median, 27-day total, or electron hemispheric power from daily composite medians from 21 NOAA and DMSP satellites.

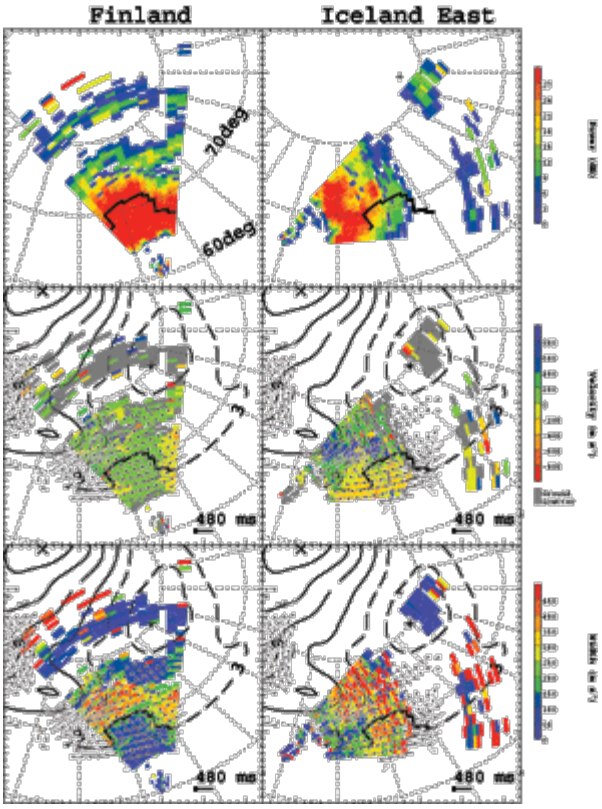


Southern (SH), Northern (NH), and ratio (SH/NH) median 27-day ion hemispheric power from daily medians from three NOAA satellites from ions < 20 keV after the adjustments for ion hemispheric power are applied.

-Initial Results from the CMIT Model- Wiltberger and Wang worked with Burns, Solomon, Lyon, and Charles Goodrich (Boston University) to report on initial results with the new Coupled Magnetosphere Ionosphere Thermosphere (CMIT) model for the Center for Integrated Space Weather Modeling (CISM). CMIT combines the LFM model with the Thermosphere-Ionosphere Nested Grid (TING) model. The LFM uses the ideal MHD equations to model the interaction between the magnetospheric plasma and the solar wind. The CMIT magnetosphere-ionosphere interaction requires the conservation of current flowing between the magnetosphere and the ionosphere. TING solves the mass, momentum, and thermodynamic energy equations for the global thermosphere and ionosphere. The TING model results replace the simple 2D ionosphere within the LFM, while the LFM results replace the empirical cross-cap potential drop and field-aligned currents in TING to produce the CISM CMIT Model. Comparisons between the CMIT results for a series of steady IMF with the results from the stand-alone LFM and TING models show that the component models have been successfully coupled. The CMIT ionospheric conductances show a more realistic distribution driven by EUV radiation, as well as a more clearly defined auroral oval. In addition, the CMIT simulation resulted in Joule heating enhancements that affected the neutral atmosphere by producing temperature increases and stronger winds.

-Analysis of Doppler Spectral Width Parameter Behavior-

ASP postdoctoral fellow Emma Woodfield (HAO) continued her investigations into the behaviour of the Doppler spectral width parameter returned by coherent high frequency radars such as the SuperDARN (Super Dual Auroral Radar Network) array. This study was carried out in collaboration with Steve Milan (University of Leicester, UK), Keisuke Hosokawa (Kyoto University, Japan), Mark Lester and Adrian Grocott (both University of Leicester, UK). The interest in this parameter is centered on its potential for locating and tracking the open/closed magnetic field line boundary through clear changes from low (< 200 m/s) to high (> 200 m/s) values. Studies of geomagnetic reconnection and global dynamics have been performed previously with the aid of this ionospheric proxy. Woodfield investigated the causative mechanisms behind the regions of large spectral widths, and also assessed the validity of using this proxy. She examined the spectral width boundaries from overlapping radars in both statistical and case-study data, and showed that the pointing direction of the radar can have a crucial effect on where the spectral width boundary is, and consequently, on its use as a proxy. There are similarities in the spectral width parameter behavior measured by the two overlapping radars in the study: both show the same seasonal dependence for lower spectral widths in the summer and both observe the cusp region clearly. The case-study results are not consistent with the expected effects of plasma convection. After eliminating propagation and instrumental effects as likely causes of high spectral widths, Woodfield concluded that they are attributable to the directional dependence of electric field variations, possibly caused by low frequency electromagnetic waves.



This figure taken from Woodfield et al., 2004 shows how the radar spectral widths can behave differently in overlapping radars. These plots are all from the 2256 UT scan of both radars on 16th October 1999. The radar scans are shown on a magnetic local time (MLT)/magnetic latitude grid with midnight at the bottom. From top to bottom the rows show backscatter power (signal to noise), line of sight Doppler velocity and line of sight Doppler spectral width. The thick black line on each panel shows the 200 m/s spectral width boundary from the Finland radar. The bottom four panels have the potential map technique equipotential contours and plasma velocity vectors overlaid to show the convection pattern. The first important observation is the Iceland East spectral width data (bottom right panel) shows consistently high widths where the Finland radar shows consistently low widths. The other key point to note is that where the spectral widths should be enhanced in the Iceland East data (at the edge of the convection cell close to the flow reversal boundary) they are in fact very low and where the influence of plasma convection is expected to be low (below the flow reversal boundary where the flow is approximately parallel to the line of sight of the radar), the widths are distinctly elevated.

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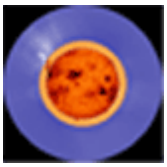


The Magnetic Sun and Variability - Solar Atmosphere and Heliosphere (SAH)

Magnetic Field Observations, Interpretation and Theory
Solar Atmospheric Dynamic and Radiative Processes
Coronal Structure and Dynamics
Physics of the Solar Wind

Other HAO Sections SIV | TISO | Facilities

Magnetic Field Observations, Interpretation and Theory

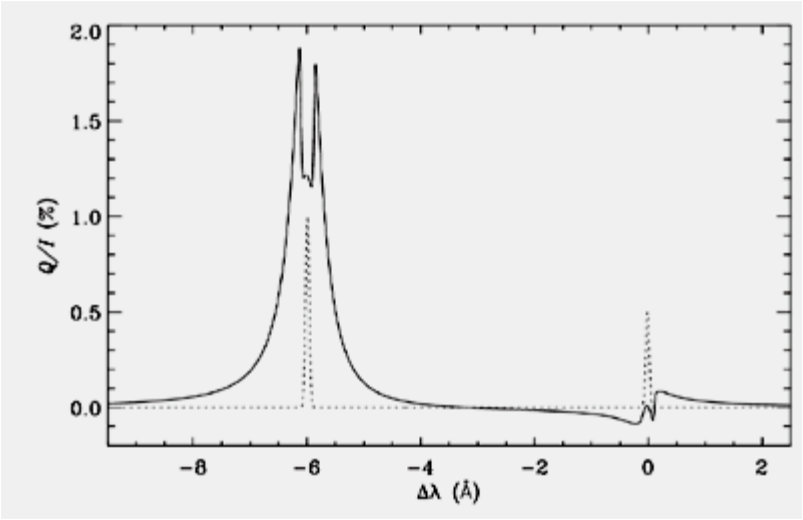
Diagnostic Techniques for Solar Magnetic Fields | Magnetic Observational Studies | MHD Theory and Models | Instrumentation for Inference of Solar Magnetic Fields

Diagnostic Techniques for Solar Magnetic Fields

HAO continues to explore new techniques for inferring magnetic fields in the solar atmosphere. This year progress was realized in two areas: the atomic physics of resonance scattering of polarized radiation in the presence of magnetic fields, and in the techniques used to extract vector magnetic fields from Zeeman-induced polarization.

-The Second Solar Spectrum of the Sodium D Lines-

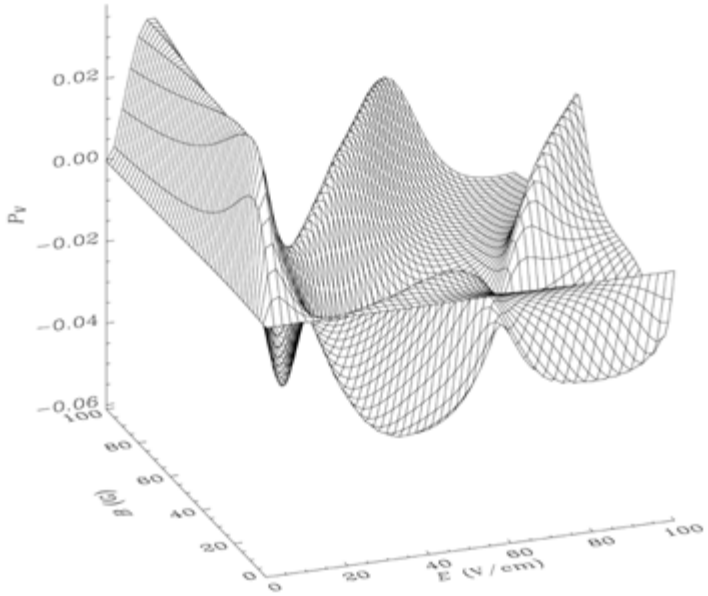
The "second solar spectrum" (i.e., polarization of the solar spectrum, primarily due to scattering, seen prominently near the solar limb) has drawn a great deal of attention during the past decade as a promising new avenue for exploration of



both solar magnetic fields and the physics of scattering of polarized radiation in an ionized plasma. Much of the detailed quantum physics of radiation scattering is, however, still not well understood, and there has been an ongoing debate on the source of the "enigmatic" observed shapes of the neutral sodium D1 and D2 polarization profiles. This year, Roberto Casini (HAO) derived a formulation of resonance scattering in a collisionless, magnetized plasma, in the limit of complete frequency redistribution, in order to investigate in more depth the formation of the second solar spectrum. In particular, he realized that the combination of quantum interferences between fine structure levels and the magnetic Hanle effect could provide an explanation of the line shape of Stokes Q/I of neutral sodium (Na) D1. An earlier attempt by Landi Degl'Innocenti (1998) to explain the second solar spectrum of the Na D1 and D2 lines relied instead on the effect of atomic polarization in the hyperfine structure levels of the ground state, leaving out the possible role of magnetic fields. That attempt was successful in reproducing the spectral line shape of D2, but required an ad-hoc assumption on the amount of ground-level atomic polarization, which could not be computed self-consistently. It also provided for an anti-symmetric shape of the Q/I profile of D1, which has been questioned by several observations. In the present formulation, Casini verified that the presence of a magnetic field can change the symmetry of the D1 profile, so it might become possible to finally explain why different observations of D1 have shown different degrees of anti-symmetry in that profile. Besides providing a possible qualitative explanation of the observations, the magnetic dependence of the symmetry of D1 is also of interest as a potential new diagnostic of weak magnetic fields in the chromosphere. Casini, in collaboration with Rafael Manso Sainz (HAO postdoc) and Javier Trujillo Bueno (IAC), is working to implement radiative transfer in the formalism, to verify if this can be sufficient to reproduce the observations for both D1 and D2.

-Laboratory Experiment For Scattering Polarization- In recent years, improvements in observational techniques for solar polarization have resulted in detailed spectral profiles of solar lines that show scattering polarization when viewed near the solar limb (the "second solar spectrum"). The behavior of this polarization, especially in the presence of solar magnetic fields, is not well understood, as theorists have difficulty matching the features of the solar profiles with synthetic ones. With support through the NCAR Opportunity Fund, Steve Tomczyk (HAO) and Casini have assembled an optical pumping experiment to measure resonance scattering polarization in the sodium D-lines under controlled conditions of illumination and in the presence of an ambient magnetic field. The experiment consists of a laboratory sodium vapor embedded in a pair of Helmholtz coils with optics for illuminating the vapor and collecting the light scattered at 90 degrees. The polarization of the scattered light as a function of wavelength is analyzed with a Liquid Crystal polarimeter and a tunable Fabry-Perot spectrometer. The experimental setup is now complete and measurements will be made in the near future. This project also involves E. Landi Degl'Innocenti (University of Florence, Italy) and A. Lopez Ariste (CNRS, France) as scientific collaborators.

-Hydrogen Resonance Scattering with Magnetic and Electric Fields-
Casini developed a formalism to treat resonance scattering polarization in hydrogen lines when both a magnetic field and an electric field are present. This work is driven in part by new observations indicating the presence of anomalous Stokes V polarization profiles in H a. The interest for this problem comes from the significant sensitivity of hydrogen polarization to the electric Hanle effect, that is, to the modification of radiation-induced atomic polarization determined by the presence of an electric field. This was studied by Favati, Landi Degl'Innocenti, and Landolfi (1987) in



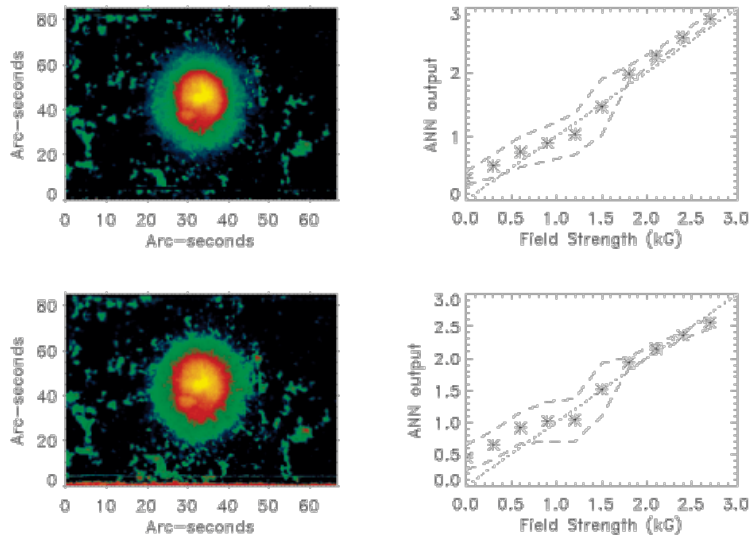
the case of Lyman a, neglecting atomic polarization in the ground level. Casini generalized that problem, allowing for the possibility of an arbitrary number of hydrogen levels (only limited by computational resources), and allowing for atomic polarization of the ground level. This represents a fundamental advance in that both magnetic and electric fields are included in the formalism. From the work of Favati et al., it was known that significant levels of atomic orientation can be created for sufficiently large electric strengths (of the order of 100 V/cm). As a consequence, one should expect a significant amount of net circular polarization from resonance scattering in hydrogen lines. However, the required electric strengths to attain observable levels of atomic orientation are of little interest for solar applications, as the very low resistivity of solar plasmas is not conducive to the creation of strong electric fields. Things are different if a magnetic field is also present.In such a case, the electric field can act as a "catalyst" of the atomic orientation induced by the magnetic field itself. In particular, the rearranging of the atomic level structure induced by even a small electric field (of the order of 1 V/cm) is sufficient to enhance the effect of the alignment-to-orientation conversion mechanism induced by the magnetic field, so that observable levels of net circular polarization can be produced for field configurations that are compatible with the physics of solar plasmas.

-Anomalous H a V-profiles in Prominences- In collaboration with A. Lopez-Ariste (CNRS, France), and several others Casini investigated the possible physical mechanisms that could be responsible for the anomalous (i.e., non-Zeeman) Stokes V profiles of H a found in several spectro-polarimetric datasets of prominences, obtained with the Advanced Stokes Polarimeter (ASP) between 1996 and 2003. The occurrence of such anomalous profiles was also confirmed by recent observations with THEMIS (Telescopio Heliografico para el Estudio del Magnetismo y de Inestabilidades Solares). Casini and collaborators concluded that these anomalies in Stokes V line shapes are not likely to be due to instrumental polarization because they are not consistently present within each dataset, and also, because simultaneous observations in He D3 (whose formation in prominences is rather well understood) showed the theoretically expected polarization profiles. Computational tests on the degree of net circular polarization induced by the prominence magnetic field, via the alignment-to-orientation conversion mechanism, ruled out the possibility that this could be the physical process responsible for the observed signals. In order to achieve a sufficient amount of atomic orientation, very large magnetic strengths (of order 1000 G) must be invoked, whose occurrence in prominences is highly improbable. Furthermore, at such large field strengths the contribution to Stokes V from the Zeeman effect would completely dominate. A more plausible physical explanation could be that the H a radiation from the photosphere, incident on the prominence, is circularly polarized (e.g., because it comes from a magnetically active region), while the prominence is subject to bulk motions such that the moving atom "collects" only one state of the circular polarization of the incident radiation. This would tend to produce an anomalously high level of atomic orientation directly from irradiation, so the scattered radiation from the atom would naturally possess a large degree of net circular polarization (even in the absence of a prominence magnetic field). However, the conditions that need to be met for such a process to be efficient (a large Zeeman-effect circular polarization from the photospheric layers) probably do not occur in those quiescent prominences where the anomalous V signals have been observed. An alternative, and more intriguing, explanation could be that they reveal the "catalytic" effect of microscopic electric fields for the atomic orientation induced by the prominence magnetic field.

-The HeI 1083 nm Multiplet as a Chromospheric Magnetic Field Diagnostic- In collaboration with Trujillo-Bueno, Collados, Centeno-Elliot (all of the IAC), and Landi Degl'Innocenti (Arcetri), Hector Socas-Navarro (HAO) continued work on a theoretical study of the formation of polarization profiles in the interesting He I 1083 nm multiplet (Socas-Navarro et al. 2004b), and on the analysis of observations from the TIP infrared polarimeter in Tenerife. This work is particularly timely, given the capabilities of the new HAO/NSO visible/infrared polarimeter SPINOR to observe this multiplet in

conjunction with other photospheric or chromospheric lines.

-New Spectro-Polarimetric Inversion Strategies- During the past few years, Socas-Navarro and others at HAO have been actively pursuing new fast (ideally, real-time), robust techniques for inverting spectro-polarimetric observations. The new generation of instruments currently under development will deliver data at enormous rates that cannot be processed using existing least-squares inversion procedures. Socas-Navarro has conducted research both to optimize existing techniques (Socas-Navarro 2004b), and to develop new strategies based on machine learning and pattern recognition. In particular, the use of artificial neural networks shows great promise of becoming a new standard for the analysis of spectro-polarimetric data (see the accompanying Figure).



Inversion tests with an Artificial Neural Network (ANN). An ASP map was processed using an ANN with 4 layers and 80 neurons per layer. The entire map was inverted in about 5 seconds using a Pentium 4 processor at 2.4 GHz. Upper panels: Test with synthetic data. Lower panels: Test with real observations. Left: Intrinsic magnetic strength retrieved by the ANN. Right: Median and standard deviation of the scatter plot.

-Community Spectro-Polarimetric Analysis Center (CSAC)- A new NCAR Strategic Initiative, the Community Spectro-Polarimetric Analysis Center (CSAC), was approved in FY04. Through this initiative, HAO and NCAR will continue their leadership role in the analysis of solar polarimetry for the inference of the magnetic field vector in the solar atmosphere. A host of new instruments, both space- and ground-based, will be producing large amounts of precision spectro-polarimetric data in the near future. The CSAC will standardize and optimize analysis of these data, and provide the analysis tools to the solar community. The program also plans significant involvement of the solar community. The initiative will also support continued investigation into advanced methods of analysis, including pattern recognition and artificial intelligence methods for extracting the field vector from polarimetric data. Of particular importance is the CSAC effort in support of the Solar-B mission.

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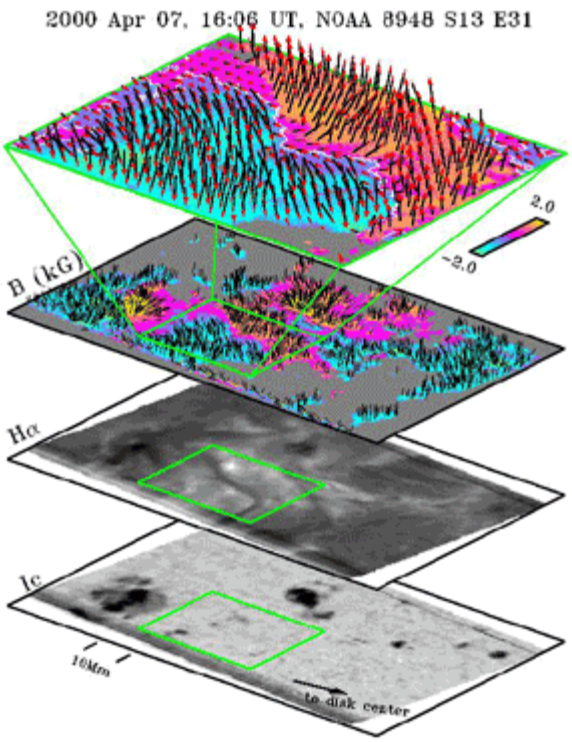
Magnetic Observational Studies

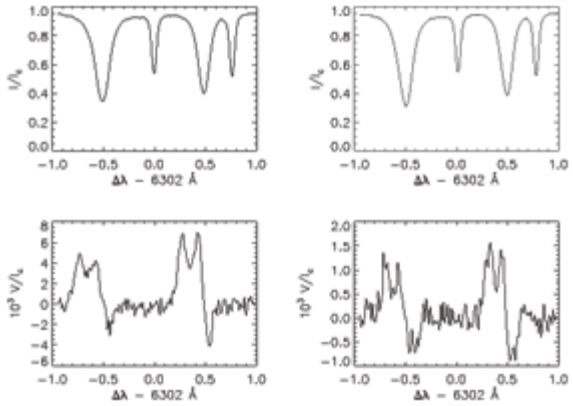
-Observational Evidence for Photospheric Flux Rope Emergence- Bruce Lites (HAO) has completed a study of vector magnetic field evolution in the photosphere under active region filaments (prominences as seen against the solar disk). Examination of several years of data from the Advanced Stokes Polarimeter (ASP) has revealed the evolution of narrow, low-lying filaments as seen in H a, which occur away from sunspots in active regions. Such filaments occur commonly in active regions, and if their occurrence can be associated with the development of twist in the photospheric magnetic field, this would be strong evidence in support of the supposition that ropes of magnetic flux, born in the solar interior, rise through the solar surface into the atmosphere to inject the magnetic helicity that is now believed to influence the large-scale development of the solar corona. Two cases were examined in detail by Lites, one of which is shown in the accompanying Figure. These cases indeed show strong evidence for twisted magnetic fields in the photosphere immediately under the filaments, in that the fields have a concave-upward geometry and significant shear along the filament.



A perspective plot of the data for 2000 April 07 shows the orientation of the vector magnetic field in the vicinity of the photospheric polarity reversal under a chromospheric filament (prominence seen against the solar disk). The lowest image is 630 nm continuum, showing nearby sunspots. The next image up is H a line center, showing the location of filaments. The third image from the bottom is signed intrinsic magnetic field strength, indicated by the color bar, with equal length "hair" superimposed to display the orientation of the magnetic field. The top image is a perspective presentation of the field vector (sampled more sparsely than the observations) in the vicinity of the polarity reversal, with signed field strength presented as a color scale in the same way as the plane below it. This image shows that the photospheric vector field under the filament is "concave-upward" and highly sheared with the horizontal field aligned along the filament. This field geometry is that expected from an emerging, twisted rope of magnetic flux.

-High-Angular Resolution Studies of Quiet Sun Magnetism- Magnetic fields present in the quietest regions of the Sun, the solar "internetwork" regions, may play a crucial role in heating the upper solar atmosphere away from active regions. A recent measurement using filtergraph polarimetry and post-observation image reconstruction suggests that most intergranular lanes are occupied by kiloGauss magnetic field concentrations. The net unsigned flux of the quiet internetwork regions from that study is more than double that of prior estimates based on spectro-polarimetry from ASP, albeit at a somewhat lower angular resolution. As these filtergraph data have much lower sensitivity to polarization than the prior ASP observations, it was deemed worthwhile to repeat those ASP quiet Sun measurements using the higher angular resolution of the DLSP (Diffraction-Limited Spectro-Polarimeter). Lites and Socas-Navarro (2004) reported on such observations obtained with the DLSP and the NSO low-order adaptive optics system in September 2003. Compared to the filter-based observations these new observations are better than 10 times more sensitive to polarization, and they have similar angular resolution. The spectro-polarimetric observations of Lites and Socas-Navarro neither reveal ubiquitous occurrence of strong flux concentrations in all intergranular lanes, nor does the net unsigned flux show a large increase over the prior ASP measurements. This study then suggests that there is not a lot of hidden unsigned flux distributed over all size scales, otherwise the new observations would show a large increase in unsigned flux.

-Supersonic Upflows in the Quiet Photosphere- Socas-Navarro and Rafael Manso Sainz (HAO) have found evidence of supersonic upflows in the quiet photosphere. {{reference figure supersonic.eps here}} They speculate that these events might be the signature of exploding magnetic elements during an aborted field amplification process by convective collapse. The small-scale structure of the magnetic field in the quiet Sun is also a subject in which HAO scientists have made significant advances during the past year. (Socas-Navarro et al. 2004a; Socas-Navarro 2004a).



Stokes I (upper panels) and V (lower panels) profiles corresponding to two different locations harboring supersonic upflows in the quiet photosphere. Notice the double-peaked structure of the Stokes V blue lobe, clearly showing a highly Doppler-shifted component.

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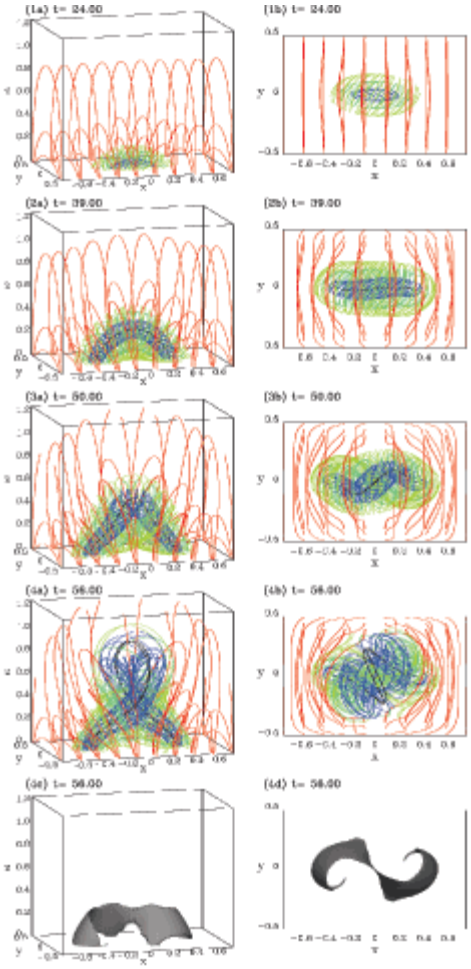
MHD Theory and Models

-Simulations of Flux Rope Emergence into a Magnetized Atmosphere- Fan and Gibson (2003, 2004) have developed 3D MHD simulations that demonstrate the emergence of a twisted magnetic flux tube into a pre-existing coronal potential magnetic arcade. The motivation is to investigate the dynamic evolution of a coronal magnetic field in response to the emergence of significantly twisted structures, and to understand the nature of observed X-ray sigmoids. In these MHD simulations, the treatment of the energy equation and the thermodynamics of the coronal plasma are drastically simplified by using an isothermal equation of state. The focus is the evolution of the coronal magnetic field under conditions of high electric conductivity and low plasma ß. The simulations show that the line-tied emerging flux tube becomes kink unstable when sufficient amount of twist is transported into the corona. For an emerging tube with a left-handed twist (which is the preferred sense of twist for active regions in the northern hemisphere), the writhing of the tube resulting from the kink instability is also left-handed, producing a forward S-shape for the tube axis as viewed from the top, opposite to the inverse S-shaped X-ray sigmoid morphology preferentially seen in the northern hemisphere. However, the writhing motion of the tube and its interaction with the ambient coronal magnetic field also drives the formation of an intense current layer, which displays an inverse S-shape, consistent with the morphology of X-ray sigmoids.

Panels [1a]-[4a] and [1b]-[4b] show the 3D evolution of the coronal magnetic field, when driven at the lower boundary by the emergence of a twisted flux rope into an overlying coronal arcade (red field lines). Field lines in the rope are color-coded based on the flux surfaces of the initial tube they belong to. When the emerged rope became substantially kinked (panels [4a] and [4b]), a curved layer of highly concentrated current formed an inverse-S shape as viewed from the top (panels [4c] and [4d]) (From Fan and Gibson 2003).

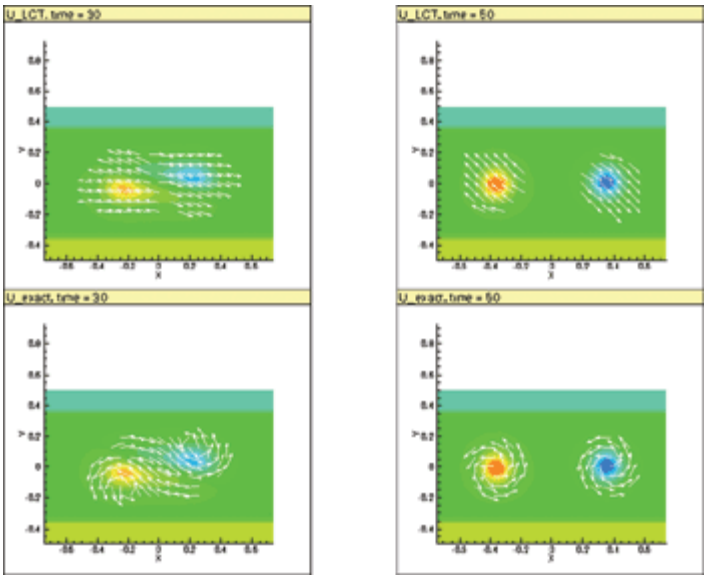


-Magnetic Free Energy in Coronal Flux Ropes- Gibson, Boon Chye Low (HAO), and collaborator Rekha Jain (University of Sheffield, UK) are working on a parameterized study of magnetic free energy, using an analytic flux rope model in a coronal atmosphere (Gibson et al. 2002). A potential field configuration is analytically determined with the same boundary condition as the non-potential model field, allowing calculation of the magnetic energy difference between the two systems. This free energy is a critical indicator of the amount of energy that can be released in a coronal mass ejection (CME). Because the model is analytic, it will be possible to do a parameter study to investigate how properties such as magnetic field strength, region size, and degree of magnetic twist combine to affect free energy.

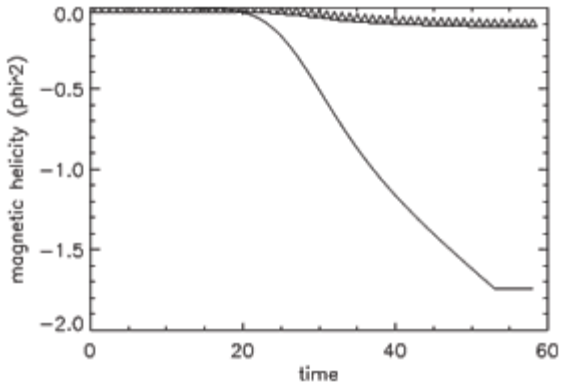
-Testing Extrapolations of Photospheric Fields into the Corona- It is fairly standard procedure to use the photospheric magnetic field, which is well-observed, to extrapolate a coronal magnetic field. Gibson, Fan, and collaborators K. D. Leka and G. Barnes (both of CoRA), Cristina Mandrini (IAFE), Pascal Demoulin (University of Paris, France) and Tom Metcalf (LMSAL) are directly testing such methods by providing the lower boundary condition of the Fan and Gibson (2003, 2004) emerging flux rope simulation as proxy for the photospheric field, and comparing resulting predictions to properties of the, a priori known, coronal field. Preliminary results show that Fourier-transform-constant a extrapolation techniques fail to reproduce the flux rope field. In particular, the amount of twist required to reproduce the extent and height of the flux rope leads to unphysical artifacts, due to limitations of the numerical techniques.

-Simulations of Magnetic Helicity Injection into the Corona- Gibson, Fan, and collaborators George Fisher (University of California, Berkeley), Mandrini, and Demoulin (Gibson et al. 2004) have studied how apparent horizontal motions of magnetic elements at the photosphere caused by an emerging flux rope might be interpreted. In particular, they showed that local correlation tracking (LCT) analysis (Welsch et al. 2004) of a time-series of magnetograms taken from the lower boundary condition of the Fan and Gibson (2003, 2004) simulation leads to an underestimate of the amount of magnetic helicity transported into the corona by the flux rope, largely because of undetectable twisting motions along the magnetic flux surfaces which do not change the normal magnetic field. High-resolution observations of rotating sunspots may provide better information about such rotational motions, and Gibson and co-workers found that if the separated flux rope legs were taken as proxies for fully formed sunspots, the amount of rotation that would be observed before the region became kink unstable would be in the range 40-200 degrees per leg/sunspot, consistent with observations (Brown et al. 2003). However, this amount of observed rotation is again well short of the total amount of twist carried into the corona by the flux rope, and in general the study indicated that using photospheric motions to

determine helicity injection is prone to significant underestimation, at least to the extent such injection arises from emerging twisted fields. This is important because estimates of helicity input to the corona have been used to quantify its energetic state, and, on longer time-frames, to estimate the source term of the "helicity budget" which traces magnetic twist from emergence all the way out to twist in magnetic clouds observed passing the Earth.



Apparent photospheric horizontal velocities, calculated explicitly for the Fan and Gibson (2003, 2004) simulation. The velocity vectors of the actual motion of photospheric foot points of magnetic field lines (bottom panels) and the velocity vectors calculated using LCT analysis of magnetogram time series (top panels) are shown with arrows. Vectors represent direction of velocity tangent to the photosphere; the length of vectors in this figure are uniform and do not represent velocity magnitude.



Total helicity injected through the photosphere as a function of time, as calculated exactly using known vertical velocity of the simulated flux rope emergence in combination with the normal magnetic field (solid line), and as calculated using Local Correlation Tracking of a time-series of the normal magnetic field to establish an apparent horizontal velocity of magnetic elements (triangles). Helicities are normalized to the total flux in the twisted flux tube.

-Modeling Coronal Flux Tube Emergence and Evolution- In July, 2004, a workshop on observational constraints for coronal magnetic flux rope modeling was held at the University of California, Berkeley Space Science Laboratories to gain input on how best to use observations for a data-constrained run of the Fan and Gibson (2003, 2004) simulation of a flux rope emerging into a coronal atmosphere. Yuhong Fan, Sarah Gibson (both HAO), Graham Barnes (Colorado Research Associates), and collaborators Janet Luhmann, Steve Ledvina, Bill Abbett, Yan Li, Loraine Lundquist, Brian Welsch (all of the University of California), Rich Nightingale (LMSAL), and David Alexander (Rice Univ.) attended. As a result of this workshop, a run of the flux rope simulation based on AR 8038, May 12, 1997 is planned. Observations of global line-of-sight magnetograms will constrain the size, location, and field strength of the emerging flux rope relative to a background dipole coronal field into which the rope emerges. Once the simulation is run, the model results will be compared a posteriori to a range of observations. The distribution and evolution of observed vector magnetic field can be compared to the evolving model field. The separatrix surfaces and current sheets formed in the simulation will be compared to X-ray sigmoids, and dipped magnetic field to the region's filament. The solar disk projection of the density-depleted flux rope cavity will be compared to dimming events seen in X-ray and EUV. Apparent photospheric magnetic field element motions will also be compared to LCT analysis of magnetograms, and sunspot rotation observed in white light to model magnetic field line foot point motion.

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Instrumentation for Inference of Solar Magnetic Fields (Ground-based Instrumentation | Space Instrumentation)

HAO continues its role as a leader in development of instrumentation for remote sensing of the magnetic field in the solar atmosphere. This tradition dates back nearly 40 years when HAO programs were initiated to measure precisely the spectral variation of the polarization of light emitted by the Sun: it is the polarization of light that carries the most prominent signature of the strength of the magnetic field as well as its orientation. The approach of precise, spectrally-resolved observations ("spectro-polarimetry") has proven to yield the most accurate measures of the field vector, along with the important accompanying information on the thermodynamic state of the solar plasma. Currently, a major fraction of new solar instrumentation programs world-wide embraces spectro-polarimetry, indicating the central role that magnetic fields demand for understanding solar variability. This trend is due in no small measure to HAO's long-term commitment to solar spectro-polarimetry.

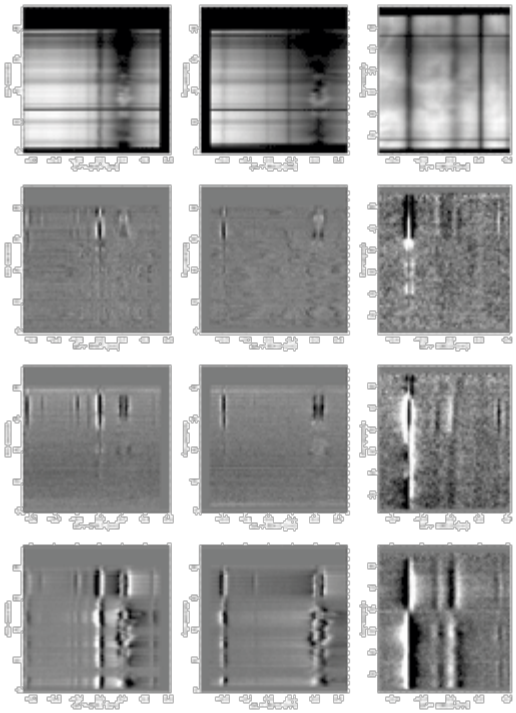
At HAO, a number of instrumentation programs now underway focus on various aspects of observations of the solar magnetic field. Most of these efforts are collaborations with other institutions, both nationally and internationally. It is clear that the community continues to look to HAO for expertise in both the engineering and scientific aspects of solar magnetic field observation. Presented in the following is a brief description of the various HAO programs to measure fields in the lower solar atmosphere (photosphere and chromosphere), along with their current status. New instrumentation to measure fields in the corona and in solar prominences is also presented in the Coronal Structure and Dynamics section.

Ground-Based Instrumentation

-ASP: Advanced Stokes Polarimeter- The ASP is perhaps the one single instrument that spurred development of the array of new solar spectro-polarimetric instrumentation. Observations from this instrument provided the first highly quantitative measurements of the full field vector with spatial resolution adequate to isolate, if not fully resolve, some solar structures. Deployed in 1991 at the National Solar Observatory (NSO) Dunn Solar Telescope (DST), its continued usage over the past 12 years as a facility research instrument operated by NSO has proven of enormous scientific benefit. It continues to be in high demand by many observers, but now suffers from aging electronics. It will continue to be operated until the replacing instrumentation, SPINOR and DLSP described below, become fully operational. Bruce Lites is the lead scientist for ASP.

-SPINOR: Spectro-Polarimeter for Infrared and Optical Regions- The infrared spectrum offers substantial scientific advantage over the visible for studies of solar magnetism: magnetic splittings of spectrum lines increase linearly with wavelength relative to their intrinsic widths, and a few spectral features offer better sensitivity or more easily understood interpretation for chromospheric magnetic fields. There is a large potential scientific pay-off for observations combining simultaneous visible and IR spectro-polarimetry. These issues, along with increasing demand for flexible spectro-polarimetry and the need to ultimately replace ASP, have led this year to the development of the new SPINOR facility instrument. It will permit simultaneous observations of multiple lines anywhere in the wavelength range 0.4 to 1.6 microns. Furthermore, it is mated to the new NSO adaptive optics system, permitting measurements of consistently better angular resolution than ASP. The system recycles some hardware from ASP, but most of the optics and electronics of ASP will be replaced. A very successful observing run of the preliminary configuration of SPINOR was completed in June, 2004, with further modifications and improvements due in the near future. Hector Socas-Navarro is the lead scientist for SPINOR.

These initial observations of infrared Stokes spectra from SPINOR demonstrate the power of the new instrument to provide diagnostics of chromospheric vector magnetic fields through observations of the ionized calcium infrared lines and the infrared neutral helium line. Rows from top to bottom are Stokes I,Q,U,V, and columns are (left to right): Ca II 849.8 nm, Ca II 854.2 nm, and He I 1083.0 nm. Stokes Q,U panels saturate at +/- 1%, Stokes V at +/- 2%. The variation of the polarized Stokes Q,U,V



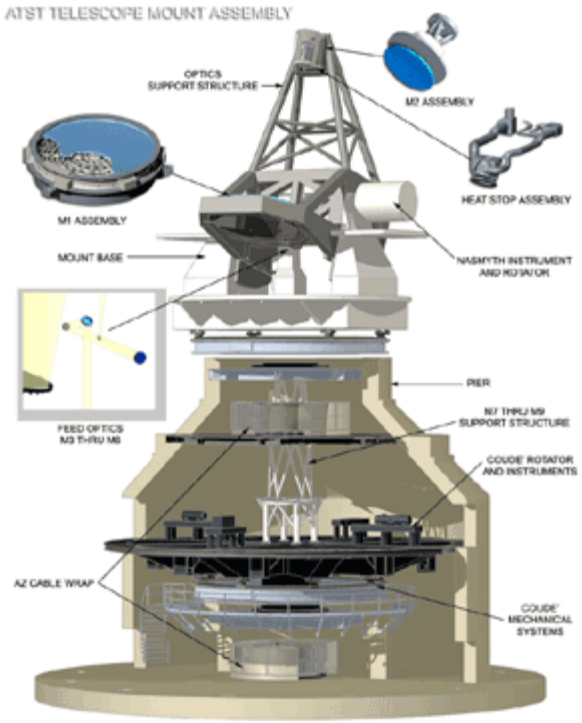
profiles along the slit as viewed at high angular resolution suggest a high degree of structuring of the chromospheric vector field.

-DLSP: Diffraction-Limited Spectro-Polarimeter- As described in the 2003 Annual Report, the DLSP is intended to expand the capabilities of ASP in another direction -- toward very high angular resolution. Much of the demand for ASP observing time is for observations of photospheric vector magnetic fields. The DLSP is optimized to provide the highest angular resolution spectro-polarimetry for the photospheric Zeeman-sensitive neutral iron absorption lines at 630 nm. The DLSP is an instrument whose configuration will remain fixed and stable, and which is mated to the NSO second-generation adaptive optics system. Its fixed optical configuration will permit standard data reduction techniques to be developed, thus greatly reducing the effort needed for visiting observers to analyze their data. During FY04 the second phase of the DLSP hardware development has been implemented: new cameras and data system (the first phase version used the ASP cameras and data system), and integration into the new NSO adaptive optics system. Several observing runs concentrated on optimizing the performance of the system, and it should be ready soon for release as a facility instrument at NSO. Bruce Lites is the lead scientist from HAO, and K. Sankarasubraminan is the lead scientist at NSO.

-POLIS: POlarimetric LIttrow Spectrograph- POLIS is a ground-based prototype of the spectro-polarimeter to be flown on the Sunrise high altitude balloon platform. Stationed at Tenerife, Canary Islands, Spain, it is a collaborative program between the Kiepenheuer-Institut für Sonnenphysik (KIS), Freiburg, Germany and HAO. In late 2003, simultaneous observations were carried out of photospheric vector fields and the ultraviolet ionized calcium chromospheric lines at 397 nm. Like the instruments at the NSO DST, POLIS also is mated to an adaptive optics system. It is anticipated that soon POLIS and SPINOR or DLSP will be able to carry out sustained measurements of developing active regions over more than half of a 24-hour period, thus considerably aiding the study of the evolution of active region vector magnetic fields. Bruce Lites is the HAO lead scientist for POLIS, and in Germany, Thomas Kentischer and Wolfgang Schmidt lead the effort at the KIS.

-ATST: Advanced Technology Solar Telescope- The ATST is a project for a large-aperture solar telescope. With its 4 meter diameter primary mirror, the ATST will have a collecting area 16 times larger than the largest existing solar telescope and will be able to operate at the diffraction limit thanks to an advanced adaptive optics system. This project has been ranked by the Decadal Survey of Astronomy and Astrophysics as the most important ground-based initiative for the next decade. HAO is involved in this project at several levels. One of the most important milestones this year is the production of the final Site Survey report, due in October 2004, which will be used by the project to select on of the three remaining candidate sites (Big Bear, CA; Haleaka, HI; or La Palma, Spain). HAO has developed one of the inversion codes for the analysis of the image quality data, and has coordinated NCAR-wide efforts to validate the measurements of the site survey instrumentation (Hill et al. 2004). The NCAR Atmospheric Technology Division (ATD) has participated in the site survey testing efforts with Mike Susedik, Tom Horst, Steve Oncley, and Gordon MacLean, among others, contributing, and support has been received from NOAA through the Boulder Atmospheric Observatory. The polarimetric calibration of a 4 meter telescope is another problem that the ATST team has had to address. Kim Streander and Paul Seagraves (both HAO) presented a technique that makes use of sunspot observations to calibrate the telescope. Additionally, Socas-Navarro has developed two other techniques that are purely instrumental and do not

require any assumptions about polarization of sunlight. HAO is responsible for the development of one of the most important instruments of the ATST, namely, the Visible Spectrograph (ViSP). This instrument will allow for high-precision, sensitivity and angular resolution spectro-polarimetry simultaneously in several spectral domains in the visible and near infrared up to 1.6 microns. David Elmore (HAO) and Socas-Navarro are leading the design efforts for ViSP. Some of the concepts (achromatic optics and wavelength diversity) have been proven by SPINOR up to 1 micron. Future work should confirm these concepts for the entire ViSP range.



Schematic representation of the ATST baseline design.

-HAO Initiative to Measure Coronal Magnetic Fields- This is a project funded as an NCAR Strategic Initiative which aims at developing instrumentation to measure magnetic fields in the solar corona. The Coronal Multi-channel Polarimeter (CoMP) instrument consists of an electro-optically tunable birefringent filter capable of observing the coronal emission lines of Fe XIII at 1074.7 and 1079.8 nm and the prominence line of He I at 1083 nm, coupled with a polarimeter and a large format HgCdTe detector. The instrument is able to create simultaneous images of the corona in two wavelengths corresponding to the emission line and continuum. Significantly, the instrument was deployed at the 20-cm "One Shot" coronagraph at the NSO Sacramento Peak Observatory in January of 2004 with the first observations with the instrument obtained during an observing run in March, followed by additional observations in campaigns carried out in May and August. The observations in March produced exciting observations of a prominence eruption which were the subject of a press release at the June meeting of the American Astonomical Society.

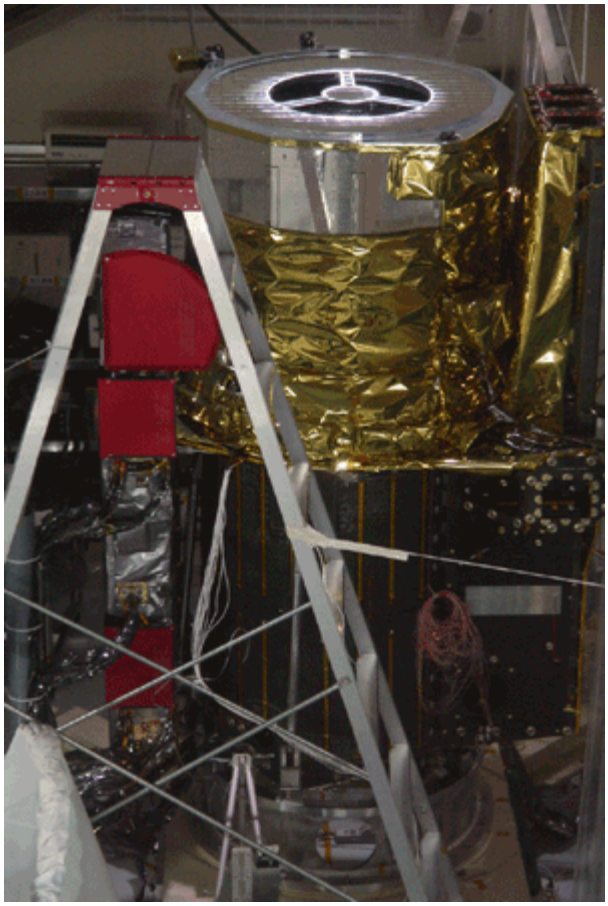
-Prominence Magnetometer at the NSO Evans Coronographic Facility- As described in the HAO Annual Scientific Report for 2003, new diagnostic techniques for measuring magnetic fields in solar prominences, along with increased interest in prominence fields in association with coronal activity and CMEs, have heightened the importance of renewed efforts to measure the magnetic field vector in solar prominences. Casini (lead scientist), Elmore, Greg Card (HAO), and Tomczyk devised a blueprint for an upgrade of the Evans coronagraph to enable a program of prominence observations using filter-polarimetry in both the D3 and 1083 nm lines of neutral helium. An NCAR Opportunity Fund grant is allowing the purchase of optics and mechanical parts. This project also involves Manso-Sainz, Lopez-Ariste, M. Semel (Observatoire de Paris, France), and J. Trujillo-Bueno (IAC, Spain) as scientific collaborators.

-Polarimeter Errors at High Angular Resolution- Solar polarimeters operating at high angular resolution are affected by time-variable image motion and blurring due to seeing, if the rate of modulation of the polarization signal is less than about 400 Hz. This effect is well-known to produce "cross talk" among the Stokes polarization parameters, and some precision solar polarimeters, like ASP, are designed to minimize the seeing-induced cross talk. Now that many ground-based high-resolution solar observing facilities are being fitted with adaptive optical (AO) correction for seeing, it is important to understand how such systems might influence the polarimetric accuracy. Phil Judge (HAO), along with Elmore, Lites, Christoph Keller and Thomas Rimmele (both of the National Solar Observatory), have carried out a study of cross talk effects to be expected from observations with AO systems (Judge et al. 2004). They find that the tip-tilt

correction is essential for high resolution polarimetry.

Space Instrumentation

-Solar-B- The Solar-B space mission is currently the centerpiece of HAO's magnetic field measurement program. Solar-B is a Japanese space mission with substantial collaborations from the US and the UK. It will fly the first ever precision high-resolution solar spectro-polarimeter in space. Lockheed Martin Solar and Astrophysics Laboratory (LMSAL) and HAO are providing the Focal Plane Package (FPP) for the 50 cm Solar-B optical telescope. To be launched in the summer of 2006, this mission will provide the first continuous, seeing-free, high-resolution measurements of the solar vector magnetic field. In FY04, the instrument was mated to the telescope (see the accompanying Figure) and extensive testing and calibration have been carried out. The instrumentation and telescope appear to exceed expectations so far. Solar-B promises to be a milestone mission for solar physics. Bruce Lites is the lead scientist from HAO in the Solar-B program.



The Solar-B Optical telescope and associated instrumentation is shown illuminated by sunlight during cleanroom tests at the National Astronomical Observatory of Japan (NAOJ) in August, 2004. The 50-cm aperture telescope is the large, vertically mounted central structure. To the left, behind the stepladder, is the telescope Focal Plane Package (FPP), also mounted vertically. The red objects on the side of the FPP are thermal radiators for the electronics. Sunlight tests were carried out to verify the full system performance and to calibrate the instrument.

-Sunrise- Even the high angular resolution of Solar-B cannot access the crucial spatial scales of the solar atmosphere comparable to a photospheric scale height (about 70 km). Processes crucial to the heating of the upper solar atmosphere occur on these size scales, and must be observed in quantitative detail in order to reveal the physics of solar variability. With its 1 meter diameter aperture (twice that of Solar-B), the Sunrise telescope will achieve this resolution in the visible, and it will achieve a resolution about twice that in the ultraviolet (220 nm) accessible at balloon altitude. The Sunrise mission will fly a precision spectro-polarimeter for visible wavelengths (the descendant of POLIS), a spectrometer for the interesting chromospheric ionized Magnesium resonance lines at 280 nm, an ultraviolet imager to achieve the highest angular resolution solar observations to date, and a precision imaging vector magnetograph on a long-duration Antarctic balloon flight. All of these tools are needed to operate simultaneously to explore the physics of the interaction of fine-scale magnetic structures with the solar atmosphere. HAO and ATD are providing the balloon gondola, telescope pointing system, and the solar power system. HAO is providing electronic cameras and a data system for the spectro-polarimeter. Spain is providing the imaging magnetograph, and Germany is providing the telescope, the ultraviolet imager, the spectrograph, and the fine pointing and active telescope alignment systems. HAO and ATD are on schedule to provide a gondola and other systems for a test flight from the continental US in May, 2005. The telescope and other systems have met with some delays in Europe. It is anticipated now that a second test flight from the continental US will be needed to verify the telescope system. On this schedule, the Antarctic flight will probably

occur in late 2008. Bruce Lites is the HAO lead scientist for Sunrise.

-SDO/HMI: Solar Dynamics Observatory/Helioseismic and Magnetic Imager- The HMI instrument on SDO will be the first space instrument to provide routine measurements of the full vector magnetic field over the entire solar disk, in addition to providing helioseismic measurements that continue the time series started by the Michelson Doppler Imager (MDI) on the SOHO spacecraft. Tomczyk (Lead scientist), along with Elmore, Lites, Norton, Johnathan Graham (HAO Graduate Research Assistant) and Tony Darnell (HAO) have participated in the program to develop the filter-based magnetograph based at Stanford University. HAO brings to this program its expertise in instrumentation for precision polarimetry and in analysis of polarimetric data. SDO is expected to be launched in April, 2008.

Solar Atmospheric Dynamic and Radiative Processes

Radiative Diagnostics

Radiative Diagnostics

-Formation of the Helium Ultraviolet Resonance Lines- Neutral and ionized helium lines are important diagnostics of conditions in the upper solar chromosphere. Because of the high abundance of He and the high excitation potential of the He I and II lines, they sample regimes of temperature and density for which other atomic species in the solar atmosphere have little sensitivity. The formation of the ultraviolet lines and continua of helium is also intimately tied to the formation of helium lines in the visible and near infrared that are useful diagnostics of chromospheric magnetic fields. In two papers (Pietarila and Judge 2004, Judge and Pietarila 2004), Anna Pietarila (HAO Newkirk Graduate Assistant) and Judge have examined afresh the formation of the helium spectrum. Using a multi-faceted approach embracing radiative transfer and detailed analyses of spacecraft observations, they examined the long-standing issue of why the helium resonance lines are anomalously brighter than is predicted by various models which give good agreement for intensities of other species. They suggest that neutral helium atoms from cool regions may diffuse across magnetic field lines to hot regions where they can emit strongly, a process that does not occur for charged ions.

-Time-dependence of Atomic Level Populations in Evolving Plasmas- Phil Judge has investigated the general algebraic properties of the system of rate equations describing the radiative and collisional statistical equilibrium (SE) of an atomic system in the non-LTE regime. Using Gershgoring's theorem, he was able to identify properties of the eigenvalue problem for the SE matrix that clarify how different time-scales in the evolution of an atomic system come about, when in the presence of the simultaneous action of ambient radiation and atomic collisions in an evolving plasma. This analytic approach allows one to foresee the fundamental behavior of an atomic system, thereby making it possible to decide a priori which atomic levels are necessary to consider to properly describe the evolution of the atomic populations, given the thermodynamic properties of the plasma.

-Magnetic and Acoustic Heating in Solar and Stellar Atmospheres- Continuing an effort to understand the dynamics of the upper atmosphere of the Sun (chromosphere, transition region, low corona), Phil Judge studied UV spectra of the Sun, taken with the SUMER (Solar Ultraviolet Measurements of Emitted Radiation) instrument on board SOHO, and of the Sun-like star a Cen A, taken with the STIS (Space Telescope Imaging Spectrograph) instrument of the Hubble Space Telescope (HST). In collaboration with Mats Carlsson (University of Oslo, Norway) and Robert Stein (Michigan State University), he used radiation hydrodynamics simulations of the emission in the C II lines at 1335 Å, to test the hypothesis that acoustic wave dissipation could be the origin of the "basal" component of chromospheric heating. Comparison of these simulations with spectral and time-series data taken with SUMER shows that acoustic wave dissipation can only be responsible for a fraction of the observed UV intensity of the chromospheric internetwork in the C II lines, and also that the predicted oscillation frequency of the radiation output is several times larger than the observed one. Judge, Carlsson, and Stein argued that magnetic heating, rather than acoustic wave dissipation, is more likely responsible for the observed basal and internetwork emission in the C II lines. Judge, in collaboration with Steven Saar (Harvard/Smithsonian Center for Astrophysics), Carlsson, and Thomas Ayres (University of Colorado), converted SUMER intensity data to Sun-as-a-star fluxes, and compared them with STIS data for the solar-type star a Cen A and the low-activity star t Cet. They found strong evidence of magnetic heating of the corona of t Cet, and concluded that the heating mechanisms responsible for the chromospheres of all three stars must be similar.

Coronal Structure and Dynamics

Coronal Mass Ejection Studies | CME-related solar atmospheric phenomena | Coronal Structure and its Evolution

Coronal Mass Ejection (CME) Studies

-Relative Magnetic Helicity in Equilibrium Magnetic Fields- Mei Zhang (NCAR Afficilate Scientist, National Astronomical Observatory, China) and Boon Chye Low (HAO) investigated the nature of relative magnetic helicity in equilibrium magnetic fields in unbounded domains. As is well known, the total magnetic energy of a force-free magnetic field in an unbounded space anchored to an inner boundary is bounded above by a value defined entirely by the boundary flux distribution. Zhang and Low are using a simple formula (discovered by Zhang) for the relative total helicity of an external, axisymmetric, force-free field anchored to a unit sphere, to theoretically determine similar upper bounds for the total relative helicity of force-free magnetic fields.

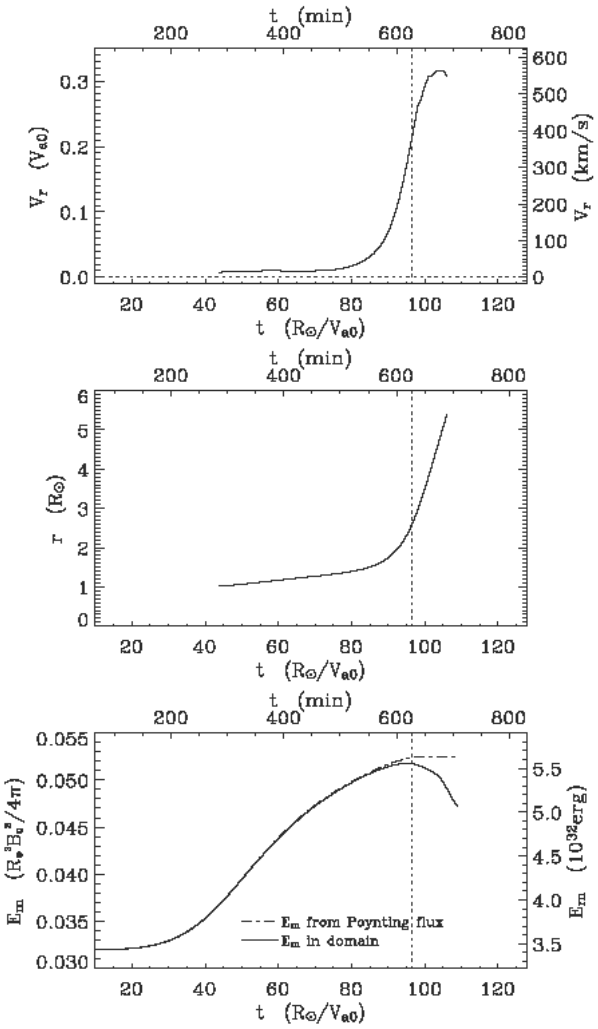
-Numerical Investigations of 2D Magnetic Equilibria- Gordon Petrie (HAO/SCD Visiting Scientist, University of Athens, Greece) is developing a finite-element code to treat two-dimensional, equilibrium magnetic fields, in order to conduct studies of such equilibria in parameter regimes not previously investigated. The theory of Low and Zhang (2002) describing the two kinds of CMEs and their possible relationship to inverse and normal prominences motivates this study. The prominence observations of Lin, Penn and Kuhn (1998) showing a reversal of sign of the axial magnetic field of the prominence suggests that the magnetic configurations in prominences may be richer than previously thought. A two-dimensional hydromagnetic study is a first step toward exploring new possibilities for prominence magnetic structures.

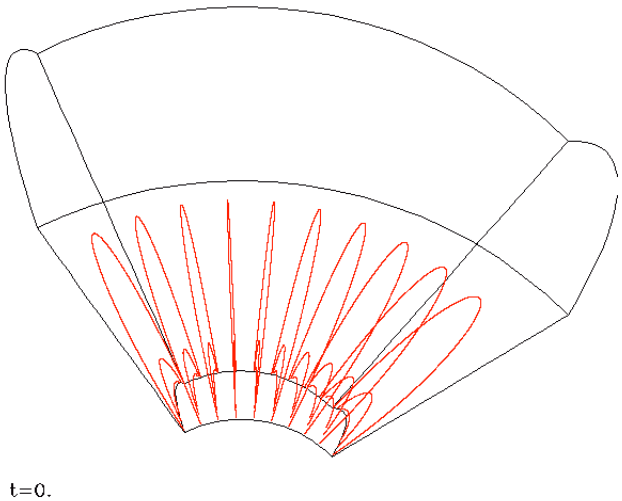
-Collaborative Studies of 2D and 3D Magnetic Equilibria- The collaboration between HAO (Low, Zhang), SCD (Natasha Flyer, Steve Thomas), and the University of Colorado (Bengt Fornberg) continues to study axisymmetric equilibrium fields external to a unit sphere. In a previous publication (Flyer et al, 2004), it was shown that an equatorial magnetic flux rope in a force-free magnetic field may store energy above the Aly open field limit. But the excess energy above this limit is small, of the order of less than 8 percent, confirming other similar results. A systematic parameter search of the solutions by Zhang and Flyer shows that the 8 percent limit is common, and may be related to a bound on the total relative helicity of the force-free fields in unbounded domain. A new study introducing plasma pressure and gravitational stratification of a static atmosphere in equilibrium with the field shows that flux ropes embedded in the atmosphere may break the 8 percent limit on the energy in excess of the Aly limit, provided mass is loaded in strategic parts of the magnetic structure. A high-precision numerical solver, capable of treating the governing, nonlinear, elliptic partial differential equation, was developed for this project.

This collaboration has expanded to treat force-free magnetic fields and fields in static equilibrium in the presence of pressure and gravitational forces in realistic three-dimensional geometry. A complete generalization is not possible because three-dimensional magnetostatic problems are intractable in general. Low reduced the governing equations to a more tractable form describing a large sub-set of the general solutions which retains three-dimensionality and holds the potential of modeling the rich field topologies of observed coronal structures (Low, 1991). Included in the sub-set are the force-free magnetic fields. The reduced governing equations require the proper formulation of boundary conditions which hitherto have been elusive and poorly understood. This obstacle has been removed, and the door is open for generating fully three-dimensional equilibrium magnetic field for modeling solar coronal magnetic structures (Low 2005, in prepartation). The powerful numerical solver developed by Flyer and Fornberg for treating axisymmetric force-free magnetic fields can be extended to treat this class of three-dimensional problems. Ellen Zweibel (University of Wisconsin) has joined the HAO/SCD/Colorado collaboration.

-Flux Emergence and the Evolution of the Coronal Magnetic Field- Yuhong Fan and Sarah Gibson (both of HAO) have extended the numerical simulations of coronal flux ropes to 3D spherical geometry, so as to address the question of magnetic energy storage and release in coronal mass ejections. In an earlier study, Sturrock et al. (2001) have considered a 3D coronal magnetic field that consists of a twisted magnetic flux rope anchored at both ends, confined within an external potential arcade, as a possible configuration for CME precursors. Through an order of magnitude estimate, they found that with a moderate amount of total twist (less than 2 full field line winds), the free magnetic energy associated with the twisted magnetic flux rope is sufficient for the flux rope to rupture through the arcade and extend to infinity as a CME, without opening up all the arcade field. Fan modeled this dynamic scenario by performing isothermal, low-beta MHD simulations of the evolution of the coronal magnetic field as a twisted, line-tied magnetic flux rope is transported slowly into the corona previously occupied by a potential arcade field. The simulations show two distinct phases for the evolution of the coronal magnetic field (see the accompnaying Figure and Movie). In the earlier phase,

the coronal flux rope evolves quasi-statically with both the magnetic energy and twist being built up as a result of flux emergence. In this stage the rise velocity is nearly constant, being about 0.01 times the characteristic Alfven speed (top panel of the Figure), and the magnetic energy evolution accurately tracks the energy build-up due to the Poynting flux through the lower boundary (bottom panel of the Figure). When sufficient twist and magnetic energy are transported into the corona, the flux rope undergoes a significant acceleration (top panel of the Figure) and is able to rupture through the overlying arcade, producing a CME-like eruption (see the Movie). The flux rope continues to accelerate after the flux emergence is stopped at t=97 (as marked by the vertical dotted lines in the Figure), and the rise velocity reaches about 550 km/sec when the flux rope begins to exit the outer boundary of the domain at r = 6 R?. In this latter dynamic phase of the evolution, the flux rope becomes kinked, which facilitates the loss of confinement of the flux rope by changing its orientation at the apex such that it becomes easier for the flux rope to part and erupt through the arcade field. A sigmoid shaped current layer develops as a result of the onset of the kink instability (Fan and Gibson, 2004), and there is significant magnetic energy release in the eruption phase as can be seen in the bottom panel of the Figure.





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CME-related solar atmospheric phenomena

-CME-related Coronal and Chromospheric Waves- Although Moreton waves have historically been observed in Ha data, more recently waves have also been observed in chromospheric He I (?=1083nm) images obtained at the Mauna Loa Solar Observatory. In an effort to better understand the nature of chromospheric waves and their relationship to coronal waves observed in EIT data, Holly Gilbert (HAO), Barbara Thompson (Goddard Space Flight Center), Tom Holzer (HAO), and Joan Burkepile (HAO) focused on two events in which waves are observed simultaneously in He I and Fe XII (?=195Å), lines formed in the chromosphere and corona, respectively (Gilbert et al, 2004). Comparing the waves observed in these two lines allows the determination of the spatial relationship between coronal and chromospheric waves, and thus aids in the understanding of the underlying physics of waves in the solar atmosphere. The main goal of this work was to begin an investigation into whether coronal and chromospheric waves are both mechanical (e.g., MHD waves) by looking at their spatial relationship. Gilbert and colaborators found the chromospheric

waves in these two events to be roughly co-spatial with their coronal counterparts, indicating they are not mechanical in nature but are chromospheric imprints of mechanical waves propagating through the corona. This conclusion is based upon the nature of the formation of the He I absorption line.

Another study involving chromospheric waves was completed by Gilbert and Holzer (2004) where the focus is on the same two wave events observed in He I from their previous work. Two interesting phenomena occur in these wave events: the waves are visible in the He I velocity data and multiple waves are observed for each event. The velocity signal provides evidence for the downward propagation from the corona to the chromosphere of a slow-mode hydromagnetic wave generated at the front of the fast coronal hydromagnetic wave. In this work, it is also suggested that the observed multiple waves indicate more than one driving mechanism may be involved.

-A New Technique for Estimating Prominence Masses- Prominences are cool condensations of partially ionized plasma in the million-degree corona. They often appear in absorption when the sun is viewed in EUV emission lines formed at coronal temperatures. The coronal EUV radiation at wavelengths less than 504Å undergoes Lyman continuum absorption by both hydrogen and helium (i.e., the coronal radiation ionizes hydrogen and helium atoms from their ground states). It is presently unclear what role prominences play in the initiation and dynamics of CMEs, although erupting prominences are strongly correlated with CMEs. The masses of prominences involved in CMEs are not generally measured, but the accurate determination of such masses may help in assessing the dynamical importance of prominences in CME events. Gilbert, Holzer, and Robert MacQueen (HAO) have developed a new technique for deriving prominence mass, one that uses observations of coronal radiation in the Fe XII (19.5 nm) spectral line, which is absorbed by prominence material. This new method makes it possible to consider the effects of both foreground and background radiation in the analysis, and it can be applied to both quiescent and erupting prominences by using two versions of the method, labelled as the "spatial-interpolative" version and the "temporal-interpolative" version. Gilbert, Holzer and MacQueen find that when both versions can be applied to the same event, the temporal-interpolative approach yields the more accurate results. They have applied both versions to an erupting prominence observed on 1999 July 12 (this prominence had an associated CME), and find that the two approaches result in similar mass determinations:$(6.0 \pm 2.5) \times 10^{14}$g for the temporal-interpolative approach and $(7.4 \pm 4.6) \times 10^{14}$g for the spatial-interpolative approach (Gilbert, Holzer and MacQueen, 2004).

-Observational Studies of Prominence Acceleration- Giuliana de Toma (HAO), Holzer, Burkepile, and Gilbert are carrying on an observational study of prominence acceleration, aimed at investigating the relationship between the acceleration of eruptive prominences and the speed of their associated CMEs, in order to better understand the acceleration phase of prominences in the low corona. This study considers events near or at the solar limb when eruptive prominences observed in Mauna Loa Solar Observatory (MLSO) ground observations show a clear association with CMEs. To determine the prominence acceleration, Ha observations from the MLSO/Polarimeter for Inner Coronal Studies (PICS) instrument are used. This instrument obtains observations off limb with a broadband filter of about 1.0 nm, and on disk with a narrower filter of about 0.05 nm. The broad filter of the MLSO/PICS instrument used with the occulting disk avoids a common problem with narrow band filters where the prominence material can disappear because it is Doppler-shifted out of the instrument band pass. The MLSO/PICS instrument also has the advantage of a wide field-of-view, extending from 1.01 solar radii to ~2.3 solar radii in the east and west directions, and a high temporal cadence of 3-minute which is crucial for measuring trajectories accurately. Previous coronagraph observations have shown that the prominence material of a CME moves slower than the leading front, but that the two appear to travel outward as a unit. It is thus expected that the prominence acceleration in the low corona will be related to the acceleration of the CME itself and can be a good indicator of the CME final velocity. To test this hypothesis, the plane-of-sky projection of the maximum radial accelerations of the eruptive prominences are compared with the projected asymptotic velocities of the corresponding CMEs. Preliminary results from this study show that, while there is a broad range of observed accelerations for prominences, there appears to be a correlation between the prominence maximum acceleration and the CME asymptotic velocity. In particular, all CMEs with $v > 600$ km/s have accelerations of the order of 20 m/s^2 or larger and all fast CMEs with $v > 900$ km/s have accelerations greater than 100 m/s^2.

-Composite Kippenhan-Schluter Prominence Models- Low and Petrie have generalized the classical Kippenhahn-Schluter prominence-sheet model. They showed that one-dimensional Kippenhahn-Schluter solutions, each representing a thin vertical layer of magnetized plasma, can be stacked against one another in a collection of such layers to form a prominence rich in small-scale structure, without losing the equilibrium among the Lorentz, plasma and gravitational forces. Moreover, for each such composite solution, each layer may be given a uniform motion of an arbitrary magnitude in its plane, in which case, this hydromagnetic state is described by the steady state equations. These solutions present an opportunity to perform forward modeling of the polarimetric signals one might expect to encounter in the observation of prominence magnetic fields. A collaboration has been set up with Roberto Casini (HAO) and Haosheng Lin (NCAR Affiliate Scientist, University of Hawaii) to exploit this opportunity in support of observational efforts at HAO and Hawaii to observe prominence magnetic fields with new techniques and instrumentation. Low and Petrie are also investigating the theoretical freedom to prescribe arbitrary sliding motions between the vertical

prominence plasma sheets, both as a basic hydromagnetic problem and as representations of the motions observed in real prominences.

-Formation and Dissipation of Magnetic Tangential Discontinutities- Low, Petrie and Zhang investigated the formation of magnetic tangential discontinuities between vertical magnetic flux surfaces in a stratified atmosphere. This is generally a three-dimensional effect with variations in the two dimensions of each flux surface and variations in the third direction perpendicular to the surfaces. They have found analytical solutions describing such discontinuities in force equilibrium. These explicit solutions provide an opportunity to analyze the dynamical consequences of magnetic reconnection dissipating the tangential discontinuity. Spontaneous magnetic dissipation of tangential discontinuities within prominences is being investigated as a mechanism whereby fully ionized plasma can drain from prominences and magnetic flux escape into the atmosphere.

-Transient Coronal Holes Observed in the He I 1083 nm Line- Observations from Yohkoh/SXT and SOHO/EIT have shown that dimming regions often appear on the solar disk near the location of a CME. Brightenings in He I 1083 nm are also visible in observations made at MLSO that form at the same time and are co-spatial with the EUV intensity dimmings observed from space. The He I 1083 nm brightenings are induced by a decrease of the overlying coronal radiation. The EUV and X-ray dimmings and He I 1083 nm brightenings can thus be interpreted as different manifestations of the decreased coronal density caused by the ejection of coronal material, that is, as transient coronal holes. de Toma, Holzer, Burkepile and Gilbert have studied six cases when transient coronal holes developed in association with a CME onset and were seen in He I 1083 nm and in the EIT Fe XII 19.5 nm line. They find the transient coronal holes at the EUV wavelengths observed by EIT and in the IR He I 1083 nm line form at the same time, within the 12-minute cadence of the EIT observations and there is good agreement in both shape and size of the holes at these wavelengths. The high, 3-minute temporal cadence of the He I 1083 nm observations taken at MLSO allows them to determine the appearance and evolution of transient coronal holes accurately and to study the relationship with other manifestations of activity at the CME onset. They find the transient coronal holes typically form during the impulsive phase of the flare, and follow the CME onset by several minutes to up to an hour. Transient coronal holes tend to form within regions of weak magnetic flux (5-20 Mx/cm^2) and their formation time varies from between 20 minutes to about an hour.

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Coronal Structure and its Evolution

-Multi-Wavelength Determination of Coronal Holes- In collaboration with the Center for Integrated Space Weather Modeling (CISM), de Toma, Nick Arge (NOAA) and Gibson have worked on the validation of coronal models. As part of this effort, models and observations of coronal holes have been compared. Coronal holes have been historically observed as regions of reduced emission on the solar disk in X-Ray and EUV wavelengths, or as regions of reduced brightness in coronagraph images at the limb. They can also be seen as relatively bright regions in He I 1083 nm. They are usually identified with the footpoints of magnetic field lines that open into the heliosphere, as derived from potential field model extrapolations. Since the appearance of coronal holes is different at different wavelengths, and since we do not have observational data to determine which regions on the Sun have open or closed magnetic field lines, the identification of coronal holes has always been difficult. de Toma, Arge, and Gibson have used relative intensity images in EUV wavelengths from SOHO/EIT, ground-based observations in the He I 1083 nm line, Ha line, and magnetograms in an attempt to identify coronal hole regions in a more objective way. Data are assembled in the form of synoptic maps, and a set of criteria based of the intensity contrast and the magnetic property of coronal holes are used to identify them using an automatic procedure. Ha and magnetograms are used to identify filament channels and to resolve the ambiguity with coronal holes. The observed coronal holes are then compared with the modeled ones and used to evaluate the model accuracy and the model sensitivity to the initial conditions.

-Observable Properties of Coronal Magnetic Flux Ropes- Gibson, Fan, and collaborators George Fisher (University of California, Berkeley), Cristina Mandrini (Instituto de Astronomía y Física del Espacio, IAFE, Argentina), and Pascal Demoulin (University of Paris, France) (Gibson et al., 2004) have considered the observable properties of a magnetic flux rope in the corona, as modeled in Fan and Gibson (2003, 2004). In particular, the structure, evolution, and relative location and orientation of S-shaped, or sigmoid active regions and filaments were compared to topological features of the magnetic flux rope, testing the theories that: 1) X-ray sigmoids appear at the regions of the flux rope known as bald patch-associated separatrix surfaces (BPSS), where, under dynamic forcing, current sheets can form leading to reconnection and localized heating; and that 2) filaments are regions of enhanced density contained within dips in the magnetic flux rope. Analysis demonstrates that the shapes and relative orientations and locations of the BPSS and dipped field in the emerging flux rope are consistent with observations of X-ray sigmoids and their associated filaments. Moreover, current layers indeed form along the sigmoid BPSS as the flux rope is driven by the kink instability, which is

evidence in support of the theory that X-ray sigmoids appear when this critical topological surface is dynamically forced.

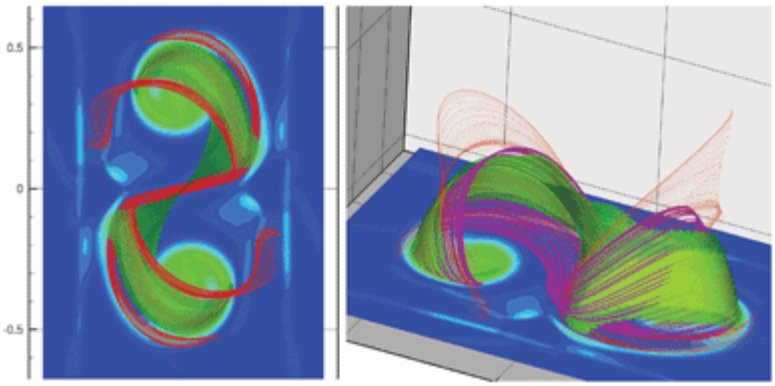
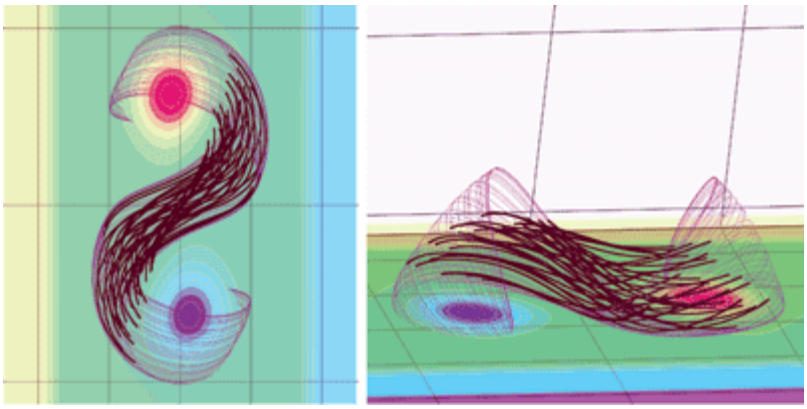
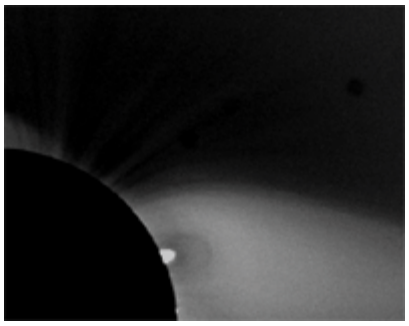


Figure: Comparison of t=56 BPSS (red field lines) to current sheets (yellowish-green isosurfaces). (right) Same, with t=39 BPSS also shown (purple field lines). Color contours at bottom boundary represent magnitude of current at photosphere (same color scaling as coronal isosurfaces).

Figure: Two views of t=39 BPSS (purple field lines) and dipped field representing filament (brown) (note, dipped field has been filled from the dip bottom up a distance .1 L or to where the field direction becomes horizontal, whichever comes first. L is the shorter of the horizontal lengths of the simulation domain). Color contours at lower boundary represent normal component of the magnetic field at the photosphere.





-Coronal Cavities, Flux Ropes, and CMEs- Gibson, David Foster (HAO), Burkepile, and Andrew Stanger (HAO) are investigating the currently debated question of whether or not magnetic flux ropes are present in the corona prior to a CME, or whether they are formed during eruptions. This is important to establish because a flux rope precursor is a reservoir of magnetic energy, so observations that can be clearly associated with a flux rope are strong indicators for eruption. Good candidates for flux rope precursors are observed quiescent white light coronal cavities. It has long been established that CMEs often possess three parts, a front, a cavity, and a bright core. Even in cases where no core (identified with the erupting prominence) can be found, a cavity is often present. Observations of the low solar corona, such as those taken by HAO's MLSO, demonstrate that this three-part structure can be present well before the eruption, as a helmet streamer, embedded white light cavity, and prominence core. As in the case of CMEs, sometimes the prominence itself is not visible, but the helmet and cavity are. Magnetic flux rope models provide a physical explanation for the cavity, forming a region of depleted density surrounding the prominence core (Low and Hundhausen, 1995). The quiescent cavities observed in white light are thus consistent with a precursor magnetic flux rope in the corona. Gibson, Foster, Burkepile and Stanger are currently studying quiescent cavities using MLSO Mark IV coronagraph data and tabulatng their sizes, shapes, locations, orientations, intensity contrasts, and relation to CMEs. They are also conducting an analytic study of how cavity appearance changes using a modified three-dimensional density model (Gibson et al. 2003) to quantitatively model cavity density.

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Physics of the Solar Wind

Quasi-steady processes | Transient processes

Quasi-steady processes

-New Transport Equation for Fully Ionized Gases- Mari Anne Killie, Åse Marit Janse, Øystein Lie-Svendsen (all of the University of Oslo, Norway), and Egil Leer (NCAR Affiliate Scientist, University of Oslo, Norway) have worked on the development of new transport equations for fully ionized gases, which improve the description of Coulomb collisions compared to fluid transport equations that are in common use today (Killie at al. 2004). The main motivation for this work has been to improve the description of energy transport and collisional forces in the solar corona and transition region, which in turn are important for understanding, for example, the origin of the solar wind mass flux, as well as coronal abundances of helium and minor ions.

-Solar Wind Minor Ion Energy Budget- Lie-Svendsen and Ruth Esser (University of Tromsø, Norway) have also studied the energy budget of minor ions in the corona and solar wind, using a solar wind model extending from the chromosphere to 1 AU (Lie-Svendsen and Esser 2005). The model results show that coronal heavy ions become very hot, with temperatures that may easily exceed 10^8 K. This occurs even without strong heating of the ions, because the minor ion energy loss is small unless they become hot. However, without preferential heating of the minor ions (that is, a coronal heating rate per particle larger than for protons), the collisional coupling to protons causes extremely large minor ion abundances in the corona, which are ruled out by observations.

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Transient processes

-Transient Outflows from Closed Coronal Loops- The solar wind model mentioned in the preceding paragraph has been used by Eirik Endeve, Lie-Svendsen, Leer, and Viggo Hansteen (all of the University of Oslo, Norway) to study the outflow of solar wind plasma from closed coronal loops that periodically open into the solar wind. The main finding is that such loops do not seem to be a source of helium-rich material that can explain the high helium abundances that have occasionally been observed in situ in the solar wind (mainly in association with coronal mass ejections). The reason is that in closed regions, the high density leads to collisional coupling between a-particles and protons, causing a low a-particle temperature in the corona. The a-particles therefore do not have sufficient (thermal) energy to escape from the gravitational potential when the flux tube is opened. Only many hours, or even days, after opening will an enhanced a-particle flux emerge.

-MHD Simulations of the Inner Corona and Solar Wind- Endeve, Holzer, and Leer (Endeve et al. 2004) have used an MHD simulation to study heating of electrons and protons in an axially symmetric model of the solar corona, extending from the coronal base to 15 solar radii. To consider heating of electrons and protons separately, as well as the collisional coupling between the particle species, a two-fluid description of the electron- proton plasma is used. A steady coronal heat input, uniform base pressure, and dipole field boundary conditions produce a magnetic field configuration similar to that seen with white-light coronagraphs during quiet-Sun conditions: a helmet streamer is formed in the inner corona around the equator, surrounded by coronal holes at higher latitudes. The plasma inside the helmet streamer is in hydrostatic equilibrium, while in the coronal holes a transonic solar wind is accelerated along the field. The collisional coupling between electrons and protons becomes weak close to the coronal base. In the case of proton heating, the thermal structure along open and closed field lines is very different, and there is a large pressure jump across the streamer- coronal hole boundary. When the simulation is run on a long time scale, the helmet streamer becomes unstable, and massive plasmoids are periodically released into the solar wind. These plasmoids contribute significantly to the total mass and energy flux in the solar wind. The mass of the plasmoids is reduced when electrons are heated. In a model that is not axisymmetric, it is possible that this streamer instability can give rise to the slow solar wind.

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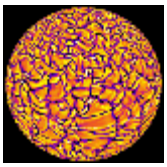

The Magnetic Sun and Variability - Solar Interior and Variability (SIV)

Radiative Processes and Small-scale MHD in the Convection Zone and Photosphere
Global Hydrodynamics (HD) and Magnetohydrodynamics (MHD) of the Solar Interior
Extra-solar Stars and Planets

Other HAO Sections TISO | SAH | Facilities

Radiative Processes and Small-scale MHD in the Convection Zone and Photosphere

Synthesis of radiative outputs | Flux Tube models | Supergranulation | Turbulence models

Synthesis of radiative outputs

-Synthetic Models of the Solar Spectrum- P. Fox (HAO), with O. R. White (HAO), J. Fontenla, J. Harder (both University of Colorado, Laboratory for Atmospheric and Space Physics [LASP]), E. Avrett and R. Kurucz (both Harvard Smithsonian Center for Astrophysics) continue to develop comprehensive, semi-empirical, synthetic models of the solar spectrum. Fox worked with Thuillier (CNRS, France) to make detailed comparisons between the SOLSPEC solar spectrum observed on shuttle flights and the SunRISE synthesis for solar activity levels early in October, 1992. Extremely good agreement was found over the wavelength range 900 nm to 2.4 microns, especially for the slope of the spectrum. Fox investigated the natural redundancy and coherency in the solar spectrum, identifying wavelength regions where both continuum and line variations due to solar activity have similar magnitude and sign response, and where they do not. Fox presented the latest status on the compliance of the SunRISE spectral synthesis to the ISO-DIS 21348 (for solar irradiances) which will be published in Advances in Space Research as part of the standards compliance process. Fontenla, with colleagues at LASP and HAO, made comparisons between spectra from the Spectral Irradiance Monitor (SIM) instrument on board the Solar Radiation and Climate Experiment (SORCE) spacecraft and the synthesis calculations, initially between 300 nm and 1 micron (Fontenla et al. 2004)

-Solar Irradiance Variability During Cycle 23- Giuliana de Toma and collaborators have conducted a detailed analysis of the variation in the Sun's radiative output during solar cycle 23. At the onset of solar cycle 23, the Total Solar Irradiance (TSI) appeared to be increasing faster than expected relative to estimates derived from San Fernando Observatory (SFO) solar image analysis (de Toma et al., 2001). This early observation forced comparison with similar results from cycle 22. Careful study of the TSI record by the Solar and Heliospheric Observatory (SOHO)/VIRGO team removed this discrepancy with ground-based estimates and gives a solid basis for study of cycle 23.

As cycle 23 evolved from the minimum of sunspot activity in 1996 to the maximum in 2000-2002, it was obvious that cycle 23 was quite different from its immediate predecessors, with significantly lower magnetic activity. Cycle 23 not only had fewer sunspots, but they were on average smaller and had weaker magnetic flux than in cycle 22 (Livingston, 2002). Average sunspot number, sunspot area, and facular area decreased by approximately 33%, 37%, and 45%, respectively, between the maxima of cycles 22 and 23. In contrast to this decrease in magnetic activity, observations showed that the strength of the TSI cycle did not change significantly in cycle 23. TSI values during the maximum phase of cycle 23 are comparable to those measured in the more active cycles 22 and 21. This is because TSI is more sensitive to the balance between dark sunspots and bright faculae/plages than to their individual values. It also indicates that reconstructions of TSI back in time, when only the sunspot record was available, are likely to have large uncertainties.

de Toma and co-workers extended (de Toma et al., 2004) their empirical models to the maximum phase of cycle 23 using the new measurements of TSI and activity indices. An important finding was the consistency between the TSI record and their regression fits, due to the improvement in both TSI and the activity indices time series in the last two years. Analysis of these new observational data resolved the questions about differences in TSI measurements and empirical estimates between solar cycles 22 and 23 raised in our earlier study. de Toma and co-workers now find that the TSI increase from solar minimum to maximum in cycle 23 agrees with estimates from irradiance indices. They are able to fit the TSI record from 1986 to the present to rms accuracy of 130 ppm, which is comparable to that reported for precision of the TSI measurements, provided indices containing all information from the solar disk are used. The best fits come from the new full-disk indices developed at SFO and the Mg II 280 nm index. They also find that a quasi-periodic TSI variation with a period very close to 1 year occurs between 2000 and 2003. It cannot be accounted for by errors in orbital determinations for either the SOHO or ACRIMSat satellites. This periodicity also remains with a lower amplitude in the residual between TSI and the best surrogate. Although this annual variation is then not completely accounted for in the analysis, de Toma and co-workers suggest that it may originate from the timing of sunspot emergence in the maximum of cycle 23 and the differences in lifetimes of dark and bright structures on the Sun.

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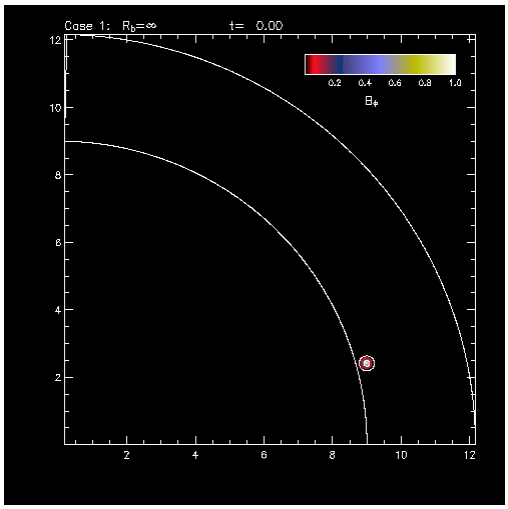
Flux Tube Models

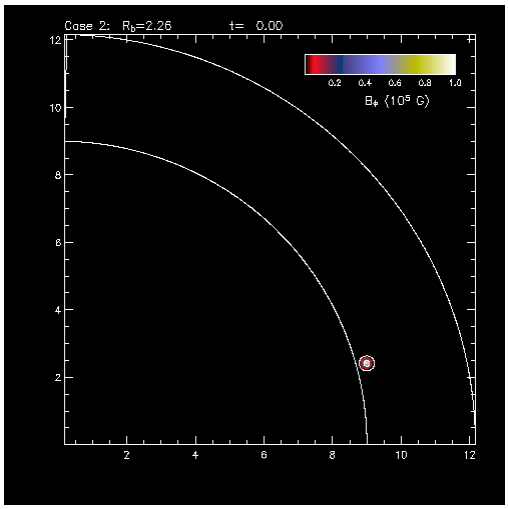
-Simulations of Rising Flux Tubes with a New 3D Anelastic MHD Code- Yuhong Fan (HAO) has made significant progress in developing a code that solves the 3D anelastic MHD equations in a spherical shell. In this code, the equations are discretized spatially using a staggered finite-difference scheme, and are advanced in time with an explicit two-step predictor-corrector time stepping. An upwind, monotonicity-preserving interpolation scheme is used for evaluating the fluxes of all the advection terms. The constrained transport algorithm is used to guarantee (to machine round-off errors) that the magnetic field satisfies the divergence-free condition, and a method of characteristics that is upwind in the Alfven waves is used in evaluating both the **v** times **B** field in the induction equation and the Lorentz force in the momentum equation. The elliptic pressure equation is solved at every sub-timestep using a preconditioned conjugate-residual scheme with an implicit Richardson preconditioner (Skamarock, Smolarkiewicz, and Klemp 1996). Fan is now testing the code by performing 2D axisymmetric MHD simulations of the buoyant rise of twisted, toroidal magnetic flux rings in the solar convective envelope, and comparing the result with the previous studies by Choudhuri and Gilman (1987) based on a highly simplified thin flux tube model.

The three movies below show three different simulations where a weakly twisted toroidal flux ring, initially in thermal equilibrium with the surroundings (and hence buoyant), starts its ascent from the base of the solar convective envelope at 15° latitude. The three different simulations correspond to cases with the magnetic Rossby number $R_b = v_{A0} / 2OH_p$ (where v_{A0} is the Alfven speed at the initial tube center, O is the angular speed of solar rotation, and H_p is the pressure scale height at the base of the convection zone) equal to, respectively, infinity (i.e. ignoring solar rotation), 2.26 (corresponding to an initial tube field strength of 105 G), and 3.85 (corresponding to an initial tube field strength of 1.7 times 105 G). When solar rotation is ignored, the magnetic flux tube simply rises radially (see the movie for Case 1, which shows the evolution of the tube cross-section in the meridional plane). Here, the flux tube is sufficiently twisted that most of the magnetic flux rises cohesively in the head of the tube, with some flux pulled into to wake behind. With the solar rotation included, the Coriolis force acting on the flux ring becomes important compared to the magnetic buoyancy force when the initial field strength B_0 of the toroidal flux ring goes below about 105 G. In Case 2, where B_0 =

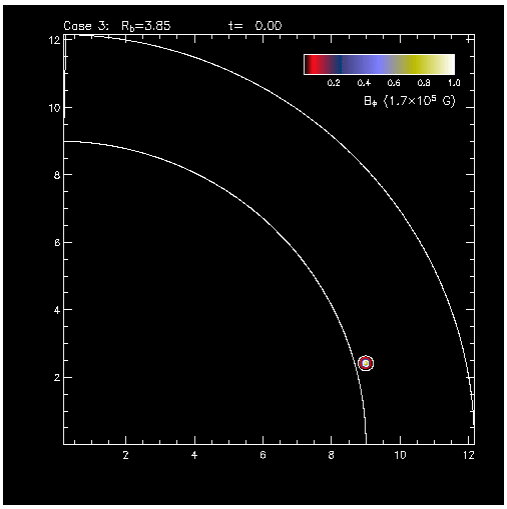
105 G (see the movie for Case 2), the rising trajectory of the cohesive head of the tube cross-section is nearly radial during its rise in the lower half of the convection zone but is deflected to become nearly parallel to the rotation axis in the outer half of the solar convection zone. The tube emerges at 31° latitude, compared to its initial latitude of 15°. When the initial field strength is increased to 1.7 times 105 G (see the movie for Case 3), the rising trajectory for the cohesive head of the tube cross-section becomes radial with little poleward deflection. At this field strength, the Coriolis force remains small compared to the magnetic buoyancy of the flux ring during the entire rise through the solar convective envelope. More simulations are being carried out to explore the parameter space. After studying the axisymmetric rise of toroidal flux rings, Fan will then perform 3D simulations of the non- axisymmetric emergence of initially toroidal magnetic flux tubes through the solar convective envelope.



Case 1: Movie (click image for larger view)



Case 2: Movie (click image for larger view)



Case 3: Movie (click image for larger view)

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Supergranulation

-The Spectrum of the Solar Supergranulation- Mark Rast (HAO), together with Jason Lisle and Juri Toomre (both of the Joint Institute for Laboratory Astrophysics [JILA], University of Colorado), demonstrated that the spectrum of the solar supergranulation is strongly influenced by the existence of multiple scales of motion within the solar photosphere, each of which exhibits a different rotation rate with respect to a stationary observer. Supergranules were shown to be asymmetrically distributed in space, exhibiting a weak north-south alignment. This large scale organization of the supergranular pattern is persistent in time, spanning many supergranular lifetimes, and rotates in the prograde direction

at a rate that is faster than the supergranular pattern itself.

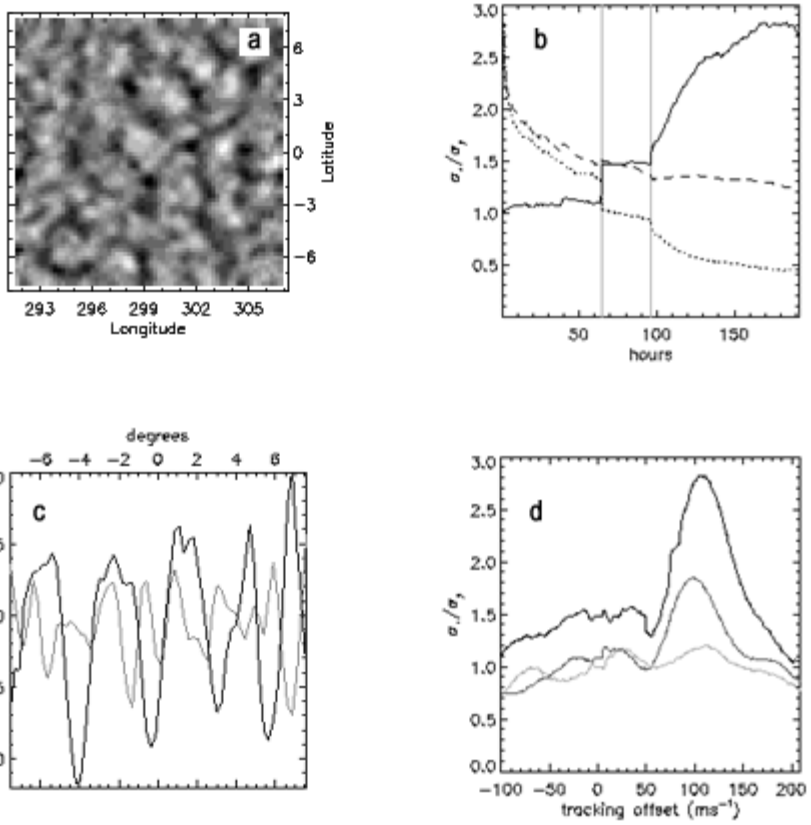

Figure a shows a horizontal flow divergence map of a 15x15 degree equatorial region of the Sun after tracking it at a rate 100 m/s faster than the Carrington rate and averaging 192 images over an eight day time series. The weak north-south alignment of the supergranular cells is apparent even to the eye. **Figure b** plots the y and x averages of the image in **Fig. a** plotted as a function of longitude (dark curves) and latitude (light curves), respectively. The temporally averaged divergence field shows variation with longitude that is noticeably greater than its variation with latitude. As seen in **Figure c** the ratio of the standard deviation in longitude to that in latitude (s_x/s_y) depends on the averaging time interval, with that ratio approaching three for long averaging times. It also depends on the rate at which the solar photosphere is tracked (**Figure d**) with the vertical alignment of the supergranular flow exhibiting a maximum when the region is tracked at a rate 110 m/s greater than the Carrington rate, about 20 m/s faster than the rate at which the equatorial supergranulation itself superrotates. These results are discussed in detail in Lisle et al, 2004.

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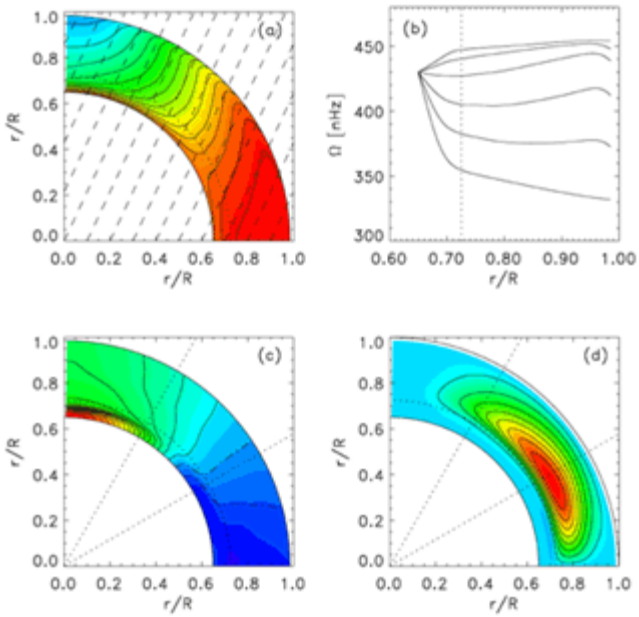
Global Hydrodynamics (HD) and Magnetohydrodynamics (MHD) of the Solar Interior

Differential Rotation, Meridional Circulation and Global Convection | Global MHD of the Tachocline | Solar Dynamos: Physics and Predictions | Inferences about Interior Global MHD from Surface Observations

Differential Rotation, Meridional Circulation and Global Convection

-Mean-Field Models for Differential Rotation and Meridional Flow-

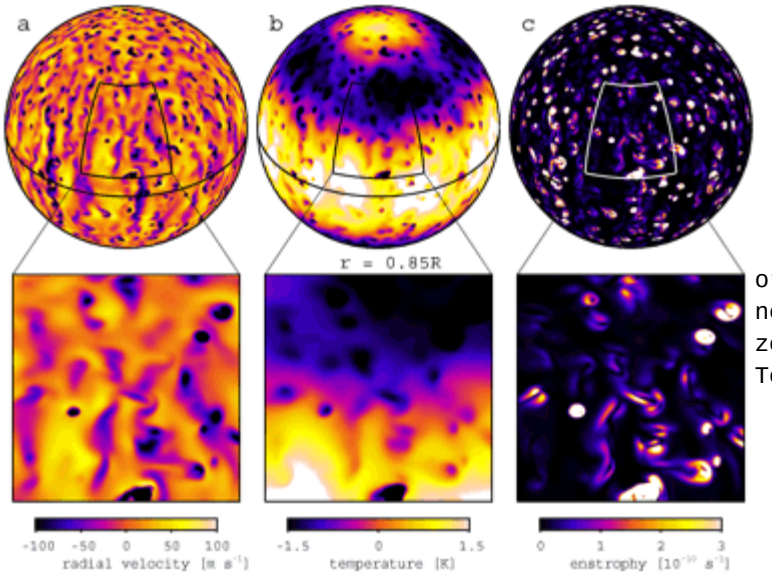
Even though many details of the solar differential rotation are known from helioseismology to a large extent, theoretical approaches still have problems in explaining the observed pattern. Differential rotation has been primarily addressed using two approaches in the past: 3D full-sphere simulations of compressible convection, and axisymmetric mean-field models that parametrize processes (turbulent diffusivities, turbulent angular



momentum transport) on the convective scale. While 3D simulations have been successful in predicting the correct amplitude of the differential rotation, the computed profile is still closer to the Taylor-Proudman state (with cylindrical differential rotation) than the observed pattern (contours of constant O show an inclination of about 25° to the axis of rotation). Axisymmetric mean-field models have recently been used to show that solar-like differential rotation is possible if the rotation-induced anisotropy of the convective energy flux is taken into account, an effect that leads to a temperature difference of a few degrees K between pole and equator (Küker & Stix 2001, and references therein). Matthias Rempel (HAO) has developed a mean-field model for differential rotation in order to address the specific question of whether a sub-adiabatic tachocline, in conjunction with turbulent heat conductivity within the convection zone and overshoot region, can break the Taylor-Proudman constraint requiring the differential rotation to be constant on cylinders in the case of isentropic stratification. Rempel found that the entropy perturbation generated in the sub-adiabatic tachocline is sufficient to explain the observed deviations from the Taylor-Proudman state, if the contribution of the convection zone is more or less neutral. If a non-adiabatic convection zone is considered, then roughly the lower 40-50% of the convection zone is required to be sub-adiabatic (due to non-local convection effects), otherwise additional effects like anisotropic heat transport are needed to explain the observed differential rotation. The accompnaying Figure shows a solution in which the convection zone is sub-adiabatic up to 0.8375, $R_?$. The observed 25° inclination of the O contours to the axis of rotation is reproduced very well. The meridional flow predicted by this approach shows a counter-clockwise flow (if the radial angular momentum flux is negative), which is observed through helioseismology in the upper-half of the convection zone. Such a flow is favorable for flux-transport dynamo models, where the equatorward meridional flow at the base of the convection zone ensures the equatorward propagation of magnetic activity throughout the solar cycle.

-Simulations of Global-Scale Solar Convection- High-resolution numerical simulations of turbulent solar convection which incorporate the full spherical geometry of the convective envelope are continually being improved and extended by Mark Miesch (HAO) and collaborators (principally A. S. Brun of Saclay, CEA, France, J. Toomre, M. Browning, and B. Brown, all of JILA and the University of Colorado, and N. N. Mansour, M. Rogers, and Y.-N. Young, all of the Center for Turbulence Research at NASA Ames Research Center and Stanford University). As Miesch and his co-workers achieve ever higher resolution and consequently more turbulent parameter regimes, new dynamics are emerging, and the flows are becoming increasingly dominated by isolated, intermittent downflow plumes, as can be seen in the accompanying Figure. Recent hydromagnetic dynamo simulations by Brun, Miesch & Toomre (2004) in particular have achieved unprecedented spatial resolution and are providing new insight into the generation and transport of magnetic fields in the solar convection zone and their feedback on large-scale flows such as differential rotation. Other areas of recent emphasis include the development of improved sub-grid-scale models for unresolved motions and more realistic treatments of the complex boundary regions near the top and bottom of the convection zone. We have also initiated an investigation into the propagation of acoustic waves in the solar interior and their interaction with flow fields, thermal inhomogeneities, and magnetic structures (Mansour et al. 2004; Miesch, Mansour & Rogers 2004). This project promises to elucidate the (forward problem) of helioseismology, providing essential theoretical support to ongoing observational efforts.

Radial velocity (a), temperature (b), and enstrophy (c) patterns are shown in a high-resolution simulation of turbulent solar convection. Images are shown as



orthographic projections for a layer near the middle of the convection zone (simulation by Brun, Miesch & Toomre).

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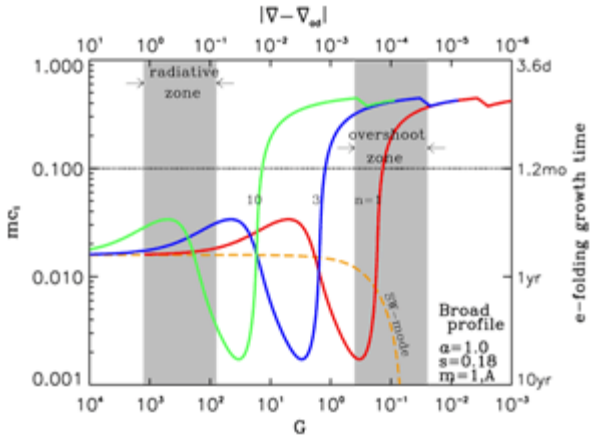
Global MHD of the Tachocline

-Nonlinear HD and MHD Instabilities in the Tachocline- Mausumi Dikpati (HAO) has been developing a spectral code to study the nonlinear evolution of HD and MHD shallow-water instabilities in the solar tachocline. Starting from the so-called primitive equations, Dikpati has completed the purely HD part of the nonlinear shallow-water code which is now producing results showing that the solar tachocline latitudinal differential rotation stabilizes by forming high-latitude prograde jets. The tendency for jet formation was previously predicted in the linear calculations of Dikpati and Gilman (2001). By representing the scalar variables (the tachocline thickness with deformable top surface) in terms of the scalar spherical harmonics and the vector variables (velocities and magnetic fields) in terms of vector spherical harmonics (as described in Morse and Feshbach 1953), a fully explicit spectral code has been developed. Currently, Dikpati is using this code to explore the amplitude of the jet that can be produced with a given initial energy in the system, by employing the third-order Adams-Bashforth predictor corrector method for the time evolution. Dikpati is making further progress in developing the semi-implicit time-evolution scheme in which the linear terms, such as gravity wave-type terms in the pure HD case, are being treated implicitly and, the other non-linear terms explicitly. This semi-implicit scheme will allow time steps that are considerably larger than the limit set by the CFL criteria. The code has several computation-intensive modules which are parallelized using OpenMP directives for faster throughput in shared memory machines, such as dual-Xeons and in a single bluesky node.

-Limits on the Penetration Depth of the Solar Meridional Flow- An issue that has recently emerged in the dynamo community concerns the characteristics of the meridional flow in flux-transport dynamo models. It has been suggested by a number of authors (e.g. Nandy & Choudhuri 2002; Guerrero & Munoz 2004) that in order for the flux-transport models to produce magnetic cycles in agreement with solar observations, the meridional flow must penetrate deep within the convection zone, even through and beneath the region of strong toroidal field known as the tachocline. In response to this suggestion, Gilman and Miesch (2004) investigated the ability of a meridional flow to penetrate the convection zone in a hydrodynamic, rotating, thin shell model. They found that the two boundary layers present (the well-known Ekman layer, and less well-studied buoyancy-diffusion layer) restricted the penetration of the circulation to depths much smaller than that required by the above-mentioned authors. In a continuation of this project, Joanne Mason (HAO) and Gilman have recently started to investigate how the inclusion of a magnetic field would affect the above results. Preliminary calculations reveal the existence of an additional boundary layer, the Hartmann layer, which is expected to limit the penetration depth of the meridional flow even more.

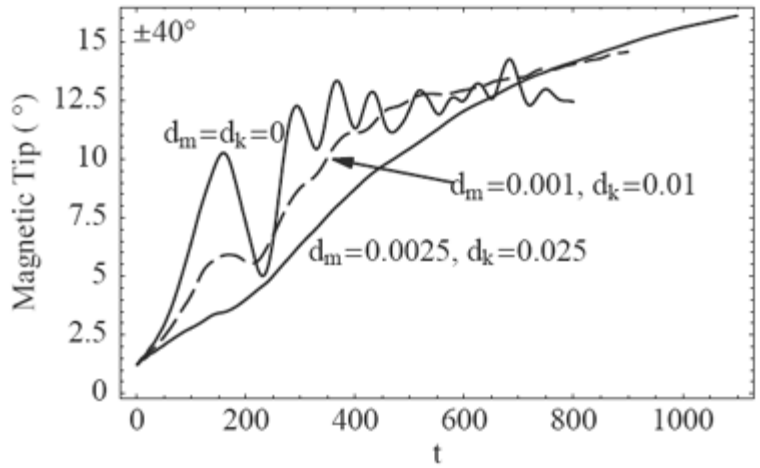
-Thin-Shell Modeling of the Solar Tachocline- The solar tachocline is a thin layer of strong rotational shear located near the base of the solar convection zone. By exploiting its thin radial extent, much progress can be made in understanding its dynamics through both linear analysis and nonlinear simulation. Recently, Miesch and Gilman (2004) have developed a tachocline model based on the thin-shell limit of the 3D MHD equations. The resulting system can be regarded as the MHD generalization of the HYdrostatic Primitive Equations (HYPE) often used in meteorology. Gilman, Dikpati, and Miesch (2004) have used the HYPE system to study joint instabilities of the differential rotation and toroidal magnetic fields in the solar tachocline. For strongly stable stratification and relatively weak field strengths, the HYPE results coincide with previous instabilities found in 2D and shallow-water systems, with peak growth rates of several

months. However, if the stratification is nearly adiabatic or if the toroidal fields are strongly super-equipartition, we find a distinct mode of instability characterized by nonzero vertical wavenumbers and high growth rates (of order days; see Figure). Work is proceeding to understand the nature of these high- growth-rate modes and their implications for the Sun.



Growth rates are shown for tachocline instabilities as a function of reduced gravity, G (bottom axis), for vertical wavenumbers n=1 (red), n=3 (blue) and n=10 (green). The growth rate for shallow-water modes is also shown for comparison (dashed line). The left and right vertical axes indicate, respectively, the non-dimensional growth rate and the corresponding dimensional growth time. Ranges of G characteristic of the solar overshoot region and radiative zone are indicated (Gilman, Dikpati & Miesch 2004).

-Global MHD Instabilities in a Diffusive Tachocline- Mausumi Dikpati, Paul Cally (NCAR Affiliate Scientist, Monash University, Australia), and Peter Gilman have developed a more realistic 2D model for global MHD instabilities in the solar tachocline, by including diffusion in the form of kinetic and magnetic drag (following a Newton's cooling law formulation). This instability has previously been studied by Dikpati, Cally, Gilman and others for the case of an idealized tachocline with no kinematic viscosity and magnetic diffusivity. Since radial diffusion is more important than latitudinal diffusion in the thin solar tachocline, diffusive decay of flow and magnetic fields can be considered as proportional to those variables. Dikpati, Cally, and Gilman found that, for solar-like toroidal magnetic fields of strength about 100 kG, instability exists for a wide range of kinetic and magnetic drag parameters, providing a mechanism for enhanced angular momentum transport in latitude, which could explain why the solar tachocline is so thin. From a detailed parameter space survey, they set upper limits of 5×10^{11} cm^2 / s and 3×10^{10} cm^2 / s for kinematic viscosity and magnetic diffusivity, respectively, such that this instability occurs in the solar tachocline on a timescale shorter than a sunspot cycle. They found that magnetic drag has much more influence than kinetic drag in damping this instability. This happens because the sink due to magnetic drag dissipates perturbation magnetic energy faster than the vorticity-sink from kinetic drag dissipates perturbation kinetic energy. Consequently, in presence of a small magnetic drag, the non-solar-like clam-shell pattern found by Cally to be the inevitable final state of a broad magnetic profile undergoing an ideal MHD tachocline instability, does not occur in a diffusive tachocline; a banded profile, however, still tips with no reduction in tip-angle. Dikpati, Cally, and Gilman have also examined how tipping may affect various surface manifestations of magnetic features, such as the latitudes and orientations of bipolar active regions.



Tip angle (degrees) as a function of (dimensionless) time for 10° Gaussian bands of peak field strength 105 G with various drag coefficients, for bands initially placed at 40° latitude.

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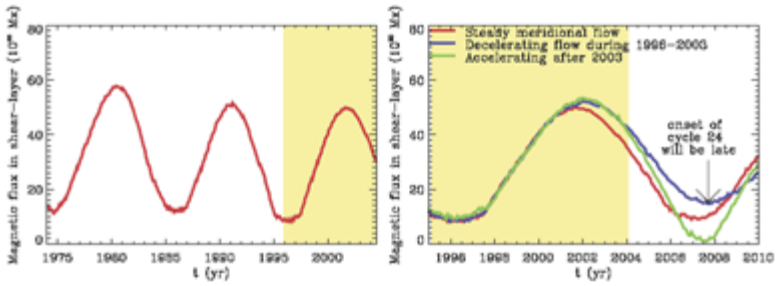
Solar Dynamos: Physics and Predictions

-A Non-Axisymmetric Flux-Transport Dynamo Model- Dikpati (HA0) is leading a multi-year effort to develop a non-axisymmetric flux-transport dynamo model, in collaboration with Eric McDonald (HAO), Peter Gilman (HAO) and Ad Van Ballegooijen (Harvard/Smithsonian Center for Astrophysics). Building on the 2D kinematic flux-transport dynamo models and their successes in reproducing many large-scale longitude-averaged solar cycle features, Dikpati and collaborators will now be theoretically investigating the mechanism for producing the longitude-dependent solar cycle features, such as "active longitudes" and sector boundary structures. Formulating the large-scale, non-axisymmetric magnetic field components in terms of scalar potentials, Dikpati has derived the evolution equations for the axisymmetric as well as non-axisymmetric magnetic fields. Since the large-scale longitude dependence has been Fourier analyzed in this model, the resulting equations are coupled partial differential equations in radius, latitude and time. Dikpati is leading the development of a numerical scheme based on the Peaceman-Rachford Alternating-Direction-Implicit method to solve this coupled system of complex PDEs. The model will first be run by switching off the large-scale source of non-axisymmetry, in order to investigate which are the dominant non-axisymmetric features produced in this case. Then the large-scale non-axisymmetry will be introduced into the model, using the knowledge gained from the theory of global MHD instabilities in the tachocline to guide the development of the model.

-Predicting the Onset of the Upcoming Cycle 24- Understanding solar cycle mechanisms and predicting the features of an upcoming cycle have become an increasingly necessary and challenging task for our technological society. In the past, the so-called "precursor method" predicted some cycles well, but not the current cycle 23, which has behaved anomalously (de Toma et al. 2004). Following the postulate of previous authors (Schatten et al. 1978) that there is "magnetic persistence" or a memory of past magnetic fields in the Sun, and demonstrating the physical origins of such a memory in a flux-transport dynamo model of the solar cycle, Dikpati and collaborators (2004) recently built the first physical model for large-scale solar cycle prediction. Dikpati et al. (2004) have been able to show why solar cycle 23 behaved anomalously, and therefore why its features were not accurately predicted. By incorporating observed dynamical variations of some of the dynamo ingredients, namely, the surface poloidal field source and the meridional circulation, Dikpati and co-workers showed that a 10-20% weakening of the large-scale, surface poloidal field source in cycle 23 relative to the previous cycle 22 was the primary reason for the substantial delay in the polar reversal of cycle 23. Helioseismic observations indicate that the meridional flow speed decreased systematically during 1996-2002, and that it remained slow until March 2004. Dikpati et al. have shown that this systematic decrease in the meridional flow speed caused the unusually slow rise of cycle 23. They have also made a preliminary prediction (Dikpati et al 2004) that the onset of the upcoming cycle 24 should be delayed, not starting until late in 2007 or early in 2008.



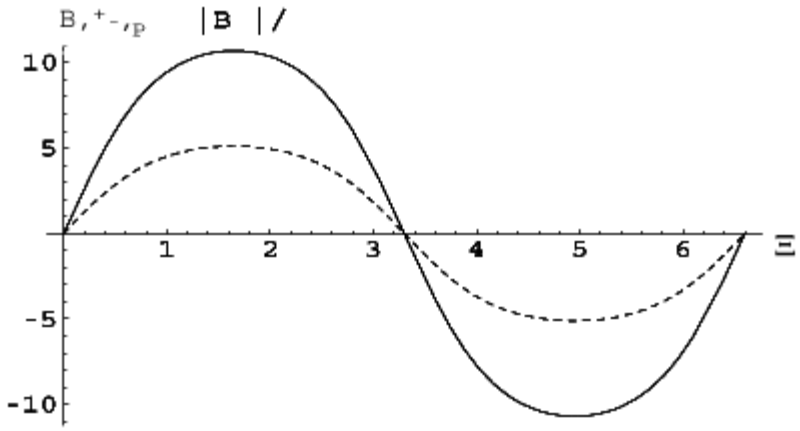
Left frame shows the dynamo-generated magnetic flux (computed from the fields that exceed about 40 kG), as a function of time, in the shear layer (computed from the peak field above 40 kG). Right frame shows the extension of the model beyond the present, by assuming three different variations for the meridional flow noted in the curves. The yellow patch denotes the time-span for which observed surface flow data is available. If the flow continues to be slow during next few years, the dynamo-generated magnetic flux would follow the blue curve, whereas it will follow green curve if flow accelerates. In both cases, preliminary calculations indicate that the onset of cycle 24 will be late.

-Solar Torsional Oscillations: Theory Versus Observation- The feedback of the Lorentz force on the meridional flow and differential rotation in the convection zone leads to variations in the rotation rate with the solar cycle, which are known as torsional oscillations. Although this oscillation pattern has been detected in helioseismic observations down to the base of the convection zone, it is uncertain how reliable the inversions at the convection zone bottom are. The dynamo model with Lorentz force feedback developed by Rempel yields torsional oscillations as part of the dynamo solution. In order to test the accuracy of the helioseismic inversions, Rempel used his model to provide Rachel Howe (National Solar Observatory [NSO]) with simulated torsional oscillations data from which an artifical helioseismic data set could be constructed. Howe, Rempel, and collaborators (Howe et al. 2004) found that most features present in the artificial data could be recovered through the inversion process, even when realistic noise was added to the data.

-Depth Dependence of Turbulent Diffusivity in the Sun- Night Song, E. J. Zita (both Evergreen State College),

together with Dikpati and McDonald, have studied the influence of various diffusivity profiles on the evolution of the large-scale, diffuse magnetic fields of the Sun. The only estimate available for the value of the diffusivity in the solar surface layers comes from the mixing-length model for convection, and not much is known about how it should vary as a function of depth down to the base of the convection zone or below it. Dikpati and collaborators constructed various theoretical profiles for the depth-dependent diffusivity, and used an an advective-diffusive flux-transport model to study how each profile affected the production of certain magnetic features at the surface. They compared the model output with observed solar magnetic features, and evaluated the successes and drawbacks of each profile, in order to determine which among them was most relevant to the Sun.

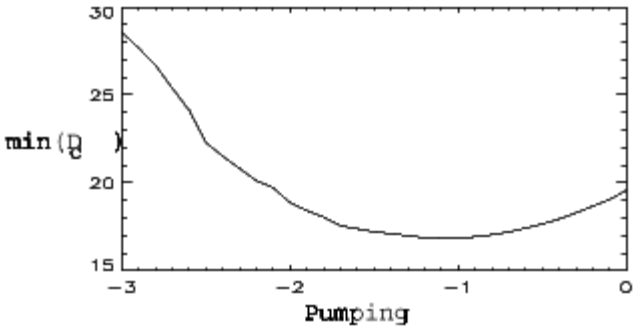
-Dynamo Models with Spatially Separated Generation Layers- Both the interface dynamo model and the traditional Babcock-Leighton dynamo are characterized by the two generation mechanisms operating in spatially disjoint regions. Due to this spatial separation, the models admit many interesting properties in addition to their ability to generate magnetic fields. In the case in which the a and O-effects are assumed to operate in sufficiently thin parallel layers that they can be described mathematically by d-functions, the interface model has been shown to admit both long wave modes with small wavenumber, and short wave modes with wavenumber comparable to the depth of the region responsible for the a-effect (Mason et al. 2002). Although dynamo theorists have primarily concentrated on the short wave mode and analyzed its capability to produce magnetic cycles in analogy with the solar cycle, it is necessary to investigate the long wave mode as well. Using weakly nonlinear theory and a multiple scales technique, Mason (HAO) and Edgar Knobloch (University of Leeds, UK, and University of California, Berkeley) have derived an equation that governs the slow evolution of the amplitude of the long wave mode. The evolution equation takes the form of a modified Korteweg-de Vries equation, the solutions of which are described by snoidal waves: nonlinear waves of magnetic activity that propagate towards the equator as observed in the Sun. The leading order contributions to both the toroidal and poloidal fields are shown together in accompanying Figure.



The leading order contributions to the toroidal field (solid line) and poloidal field ($|B_P|$ for ? = p and $|B_P|$ for ? = p, dashed line) taken at the interface between the tachocline and convection zone (? denotes a reference frame traveling with speed v northwards with respect to an already equatorwards moving frame ?).

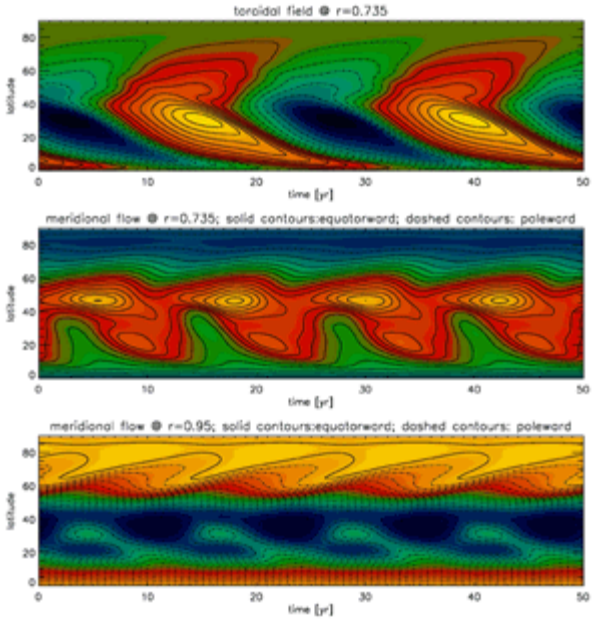
A further consequence of the two generation mechanisms operating in spatially separated regions is that the dynamo is only efficient in so far as the magnetic flux may be transported between the two regions. It is believed that the magnetic buoyancy instability is responsible for the transport of newly generated toroidal flux from the tachocline to the convection zone (Parker 1955), and that the magnetic pumping mechanism returns the poloidal field to the tachocline for the cycle to repeat. The turbulent compressible penetrative convection studies of Tobias et al. (2001) illustrate the ability of the strong vortical downflows to wrap up the magnetic field and drag it downwards with them as they penetrated the stable overshoot region. Mason, David Hughes, and Steve Tobias (both of the University of Leeds, UK) have investigated the effects of incorporating the pumping mechanism into a kinematic, axisymmetric, mean-field model, and have shown that there exists a preferred magnitude of pumping at which the dynamo is at its most efficient (see the second accompanying Figure). Current studies of a nonlinear extension to the above described model are aimed at investigating the effect that the pumping mechanism has on the phase difference between the poloidal and toroidal fields. Preliminary results show that the pumping mechanism changes this phase relation and also has an effect on the period of the magnetic cycle.

The minimum of the critical dynamo number governing the onset of the dynamo



instability as a function of the magnitude of the pumping. The diffusion is constant throughout the convection zone and tachocline, but the pumping operates only within the convection zone. The dynamo is most easily excited with a pumping of magnitude approximately 1.1 (the negative sign illustrates the direction of pumping from the convection zone to the tachocline).

-Flux-transport Dynamos with JxB Feedback- Flux-transport dynamos have proven to be successful in modeling the evolution of the large-scale solar magnetic field. However, these studies addressed the transport of magnetic field by the meridional circulation in a purely kinematic regime. The toroidal field strength at the base of the solar convection zone, as inferred from studies of rising magnetic flux tubes, is around 100 kG, and thus is orders of magnitude larger than the equipartition field strength estimated from a meridional flow speed of a few m/s. Therefore, it is crucial for flux-transport dynamos to include the feedback of the jxB force on the meridional flow. Rempel, Dikpati, and Keith MacGregor (HAO) addressed this problem using two approaches: (1) a kinematic model in which the feedback is parametrized in terms of a non-linear quenching of the meridional flow in regions exceeding a certain field strength; and (2), an MHD approach in which the full set of hydrodynamic equations together with the dynamo equations is solved. In this latter approach, the mean-field differential rotation model developed by Rempel is used to compute both the differential rotation and the meridional flow, which are then used to evolve the magnetic field through the dynamo equations. The Lorentz force is allowed to feedback on the differential rotation and meridional flow, leading to a dynamo that operates in the "dynamic" regime. A typical solution for the magnetic field (butterfly diagram) and meridional flow is shown in the Figure.



Butterfly diagrams of the toroidal field strength at r=0.735 $R_?$ (the range is around -13 kG to +13 kG), the equator-ward meridional flow velocity (the range is around -0.1 m/s to +1.2 m/s), and the poleward meridional flow at r=0.95 $R_?$ (the range is around -4.5 m/s to +0.4 m/s). The Lorentz force feedback changes the meridional flow significantly throughout the convection zone. In regions of strong field (around 10 kG) at the base of the convection zone the flow speed is significantly reduced (by around 50%). Near to the surface the Lorentz force has the tendency to significantly weaken the poleward flow above 50° latitude. Above 60° latitude a second cell forms with a reversed flow direction.

In this combined investigation of kinematic and dynamic dynamo models, Rempel, Dikpati, and MacGregor found that flux transport dynamos work even with significant feedback of the Lorentz force on the meridional flow and differential rotation for two main reasons: (1) the meridional flow avoids regions of strong toroidal field, but still transports the weaker poloidal field that is the source for the toroidal field via the O-effect; and (2),the transport capacity of the meridional flow is much larger than estimates based on its energy density suggest, since it is driven by the small difference of several large forces, namely, the Coriolis force, viscous force, and buoyancy/pressure force. The dynamical model sets an upper limit of about 30 kG to the strength of the toroidal field that can be transported. Stronger fields will either move towards the pole or reach an equilibrium, depending on how well angular momentum is conserved within the toroidal band. In this case, a dynamo with equator-ward propagating toroidal field would still be possible, since the meridional flow can transport the weaker poloidal field, which provides the source for the toroidal field. The strong toroidal field would reach an equilibrium state in which the magnetic tension is compensated by the Coriolis force of an prograde jet. Rempel, Dikpati, and MacGregor found as a further result that the feedback of the Lorentz force can produce in conjunction with the hotter pole (required for balance of differential rotation) a reverse polar cell in the meridional flow that varies with the dynamo phase as found by Haber et al. (2002).

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Inferences about Interior Global MHD from Surface Observations

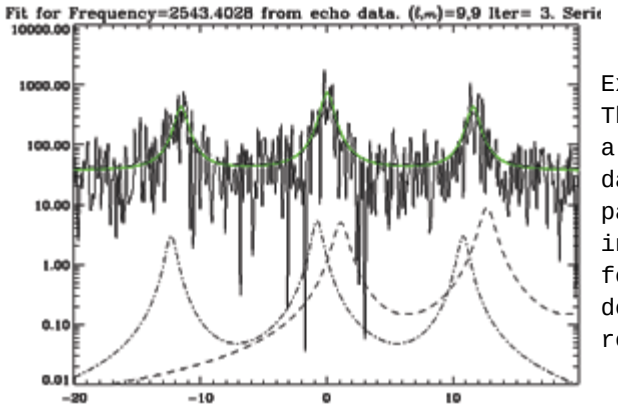
-Surface Signatures of Internal Magnetic Fields- Aimee Norton (HAO) and Gilman used solar surface magnetism data to search for signatures of the toroidal magnetic field and its solar-cycle dynamics. They were interested in what can be learned about the dynamical behavior of the interior toroidal magnetic field from the statistical study of solar surface magnetism. Through analysis of sunspot data over significant time periods, Norton and Gilman partially recovered certain properties of the interior toroidal field. They analyzed both Kitt Peak magnetogram data and continuum intensity sunspot data from the Michaelson Doppler Imager (MDI) on board the Solar and Heliospheric Observatory (SOHO) spacecraft to search for the following solar toroidal band properties: width in latitude and the existence of a tipping instability (longitudinal m=1 mode) for any time during the solar cycle. This tipping has been predicted by recent theoretical work using a nonlinear model of a 2D MHD tachocline. In order to determine the extent to which toroidal field dynamics can be recovered, Norton and Gilman modeled artificially generated sunspot distributions from sub-surface toroidal fields that were assigned certain properties. They found that a relatively wide toroidal band, 15-25° in latitude over which sunspots emerge, best fit the data.

A tipping of 5° early in the solar cycle, gradually decreasing to 0° as the band moves equatorward is compatible with both the MDI and Kitt Peak data and modeling efforts. Norton and Gilman also analyzed and modeled the MDI data in two time periods when the toroidal band was at high and low latitudes, since the tipping amplitude is predicted to be greater at high latitudes. The analysis indicated a tip was more likely to exist for high latitude data, but it was on average <5°, which was consistent with modeling results. They found that the band widens from 15-20°; early in the solar cycle to 20-25° late in the solar cycle. This could be explained by magnetic drag spreading the toroidal band due to altered flow along the tipped field lines. The tipping instability is difficult to recover with the analysis techniques used by Norton and Gilman when the toroidal band width is much greater than the tipping amplitude. In addition, the existence of a prograde jet that acts to stabilize the band against tipping, or the presence of modes with m > 1 if the toroidal magnetic field is of order 20 kG would either suppress the instability or make it difficult to measure.

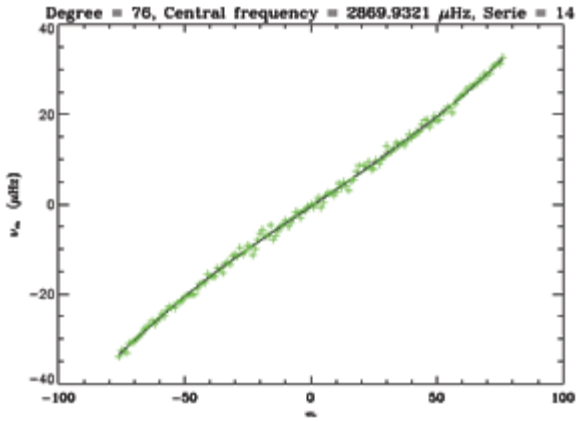
-LOWL/ECHO-Extraction of Mode Parameters and Science Ojectives- David Salabert (HAO) is currently working on the analysis of the helioseismic data acquired by LOWL/ECHO (Experiment for Coordinated Helioseismic Observations) network, built and operated by HAO since 1994. Such data can be analyzed to constrain the structure and rotation of the solar interior. The LOWL/ECHO instruments observe the solar oscillations as perturbations of the radial velocity over the surface of the Sun. This is accomplished by taking images in narrow bandpass filters displaced slightly redward and blueward of a solar absorption line. A velocity image is obtained from the difference between the two intensity images. Modes are separated in the data by projecting the velocity images onto spherical harmonic functions. The time series of each mode coefficient is then Fourier transformed in time to yield a power spectrum which has discrete peaks at the mode eigenfrequencies. Accurately determined eigenfrequencies are the basic data product of this instrument. The internal structure and rotational characteristics of the Sun can be determined from these frequencies. In a first step, the estimation of the solar radius from the images was computed with a better accuracy; thus, the decomposition of the velocity images in spherical harmonics is more accurate, thereby improving the quality of the time series of each mode. However, the spherical harmonics are not orthogonal over the observed area, so the observed Fourier spectra in the case of resolved observations, are a linear combination of different modes. The correlation between the Fourier spectra of each individual mode is represented by the leakage matrix. To extract correct mode parameters for a particular mode, it is necessary to have a good knowledge of the other modes which leak and interfere with the studied mode in the Fourier domain. Before undertaking any extensive analysis, Salabert is working on the leakage matrix problem to obtain good estimates of leaked modes, and thus extract reliable mode parameters. Then the so-called a-coefficents for each degree, representing the shift in frequency induced mainly by the internal rotation, can be estimated.

Salabert, in collaboration with Sebastien Jimenez-Reyes (Insítuto de Astrofísica de Canarias, Spain) and Michael Thompson (NCAR Affiliate Scientist, University of Sheffield, UK) is using LOWL/ECHO data to study the Sun's internal rotation. Of particular interest is the rotation rate near the tachocline, the transition zone between the solid rotation of the radiative interior and the differential rotation of the convection zone. The solar magnetic field is believed to be generated in this shear layer, therefore observations of the dynamics of this region are extremely important. In both ground-based GONG (Global Oscillations Network Group) data and space-based MDI data, an oscillation of period about 1.3 years of the rotation rate near the tachocline has been observed. The existence of this periodic change in the tachocline needs to be confirmed, and Salabert will utilize the long time series of LOWL/ECHO data as an independent check, to search for these tachocline variations. Time series of 108 d over 6 years of LOWL data have been computed and decomposed onto spherical harmonics. The resulting Fourier spectra are currently being analyzed in order to study the dynamics of the tachocline. In additon, Salabert is utilizing the LOWL/ECHO data to place better constraints on the structure and rotation of the solar core. The study of the solar core requires the measurement of p-modes of low degree, which penetrate deeply into the Sun. The LOWL/ECHO instruments have the advantage that they are optimized for observing the low degree modes, unlike GONG and MDI. The capability for observing low degree oscillations, together with the longer time series of LOWL/ECHO data compared to GONG and MDI, make these observations very valuable for

placing constraints on the structure and rotation of the deep solar interior. The existence of a single-instrument helioseismic data base extending back over a decade in time also makes it possible to study manifestations of solar activity in the interior. Mode parameters obtained from the LOWL/ECHO data over 10 years of operation will be used to follow the evolution of the near surface dynamics, and more importantly, to search for signatures of variations of the dynamo with the solar cycle in the dynamics and structure of the tachocline.



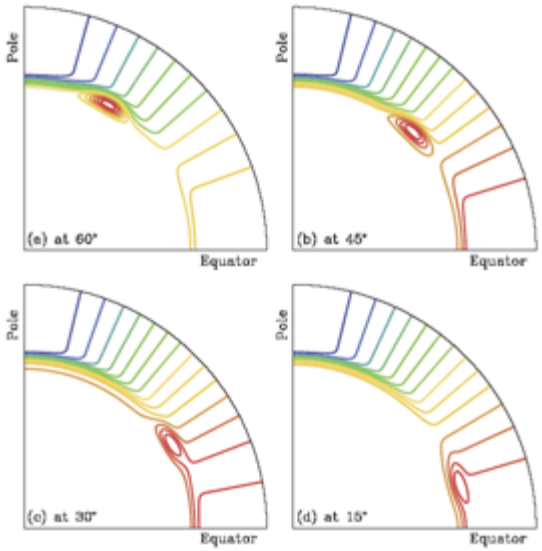
Example for the mode l=9, m=9 at 2543.4 μHz. The p-mode parameters are extracted by fitting a Lorenztian profile (green solid line - the dashed line corresponds to the initial parameters). The first sidebands are included in the profile. The m-leakage and the l-leakage for this mode l=9, m=9 are represented by the dot-dashed line and the dashed line, respectively.

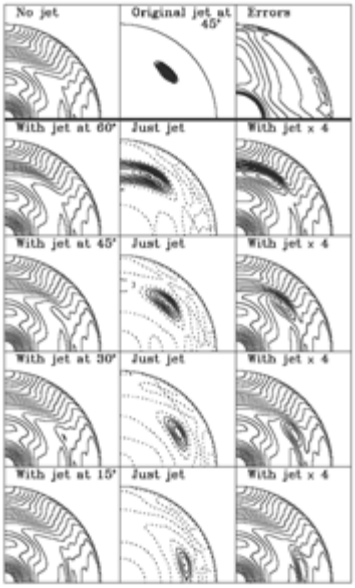


Fitted frequencies for the mode of angular degree l=76 at 2869.9 μHz. The a-coefficients, representing the shift in frequency induced mainly by the internal solar rotation, are computed as Clebsch-Gordan coefficients (solid line).

-Detecting Tachocline Jets- Tachocline toroidal fields are likely to exist in the form of narrow bands, at least during some phases of the solar cycle. Recent theoretical studies show that a narrow toroidal band in the solar tachocline can be held in equilibrium against its poleward slip due to the curvature stress by the Coriolis force produced by a prograde jet inside the band. Previous attempts to detect convection-zone jets using 7-month GONG data have been made, but to date, no clear evidence of jet-like flows has been detected. Recently, Dikpati, Gilman, Thierry Corbard (Observatoire de la Cote d'Azur, France), Jorgen Christensen-Dalsgaard (NCAR Affiliate Scientist, Aarhus University, Denmark), and Thompson (University of Sheffield) have explored the use of long-term GONG data, in order to detect the amplitude, width and the latitude-location of jets that could exist in addition to background zonal flows. Using the latitudinal force-balance equation for toroidal bands in a typical solar tachocline, they generated artificial helioseismic data containing jets. They then inverted these synthetic observations in an effort to recover the jets. Following validation of the technique through experiments of this sort (see the accompanying Figure), they are applying it to the inversion of real data from different epochs.

Jet and total internal rotation including background for a 20° band with 60 kG peak field, assuming that balance is entirely between magnetic curvature stress and Coriolis force.





Top row: top left panel shows the inversion of jet-free artificial data; top center panel shows a jet (without any inversion) arising from a 20° band at 45° latitude for comparison with the width and strength of the features in the panels beneath it; top right panel shows the formal errors on the inversions. Each subsequent row shows the inversion experiment for a differently located jet, as indicated: the first column shows inversion of data with the jet included; the second column shows the difference between the previous inversion and the inversion with no jet present (as in top left panel); the third column shows the inversion with the jet enhanced by factor of 4. The full inversions have contours every 10 nHz, with contours at 300 nHz (near pole), 350 nHz, 400 nHz and 450 nHz bold. The panels in column 2 show contours every 2 nHz, with the 4 nHz and 8 nHz contours bold; the zero contour is shown dotted. The error contours (top right panel) are at 1 nHz spacings, with the 4 nHz and 8 nHz contours shown bold; errors increase with depth.

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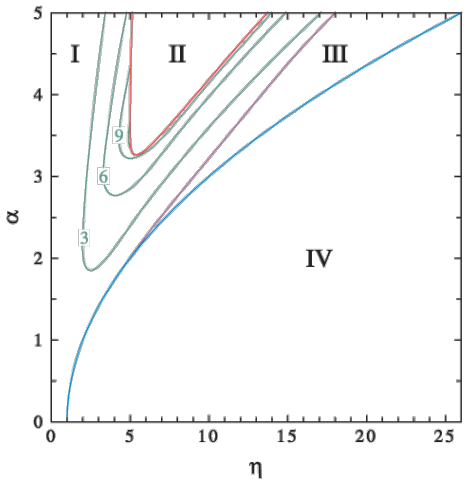
Extra-Solar Stars and Planets

-SCF Models of Differentially Rotating Stars- The computation of stellar models that consistently include effects arising from rapid, non-uniform rotation is a formidable task, requiring the solution of Poisson's equation in addition to the equations governing the internal structure of a star. To avoid this difficulty, researchers have often utilized methods based on approximate expressions for the gravitational potential that are strictly valid only in the limit of vanishing rotation. In an effort to develop an approach to this problem that is both more accurate and more widely applicable, Stephen Jackson, Keith MacGregor, and Andrew Skumanich (all of HAO) have devised a new version of the self-consistent-field (SCF) method for calculating the structure of a rotating star. As originally implemented in the 1970's, the

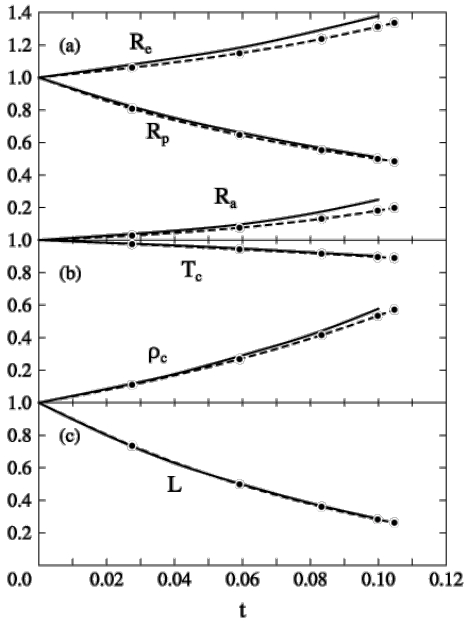
SCF method was capable of producing consistent, converged models only for stars more massive than 9 $M_?$ and, as a result, received limited use as a tool to investigate how rotation affects stellar properties.

The SCF method as reformulated by Jackson, MacGregor, and Skumanich is an iterative scheme, initialized by specifying one-dimensional trial distributions of the temperature and pressure (each normalized by their central values), and a two-dimensional trial function describing the shape of constant-density surfaces. The normalized trial density distribution itself follows from the equation of state, and is used as the source term in Poisson's equation to determine the gravitational potential. For a rotation law in which the angular velocity depends only on the perpendicular distance from the axis of rotation, the total potential and its equipotential surfaces can then be evaluated and used in solving the stellar structure equations. This step yields updated temperature and pressure distributions, and allows the process to be restarted and continued to convergence. When self-consistency of the normalized temperature and pressure profiles has been attained, the corresponding central values are adjusted in order to bring them closer to the physical conditions at the center of the final equilibrium configuration. The entire procedure is then begun again and repeated until an acceptable level of agreement between the current and previous central values has been obtained.

Jackson, MacGregor, and Skumanich have carried out an extensive series of tests, including comparisons with models computed using other techniques, to validate the revised SCF method. Their results indicate that the method yields converged models for chemically homogeneous, main sequence stars of all masses, and is capable of treating cases in which rapid, differential rotation causes the photospheric shape of a star to deviate significantly from sphericity. They have shown that the models can be characterized by two quantities measuring the degree and rate of differential rotation, and have delineated the regions in the corresponding two-dimensional parameter space wherein equilibrium stellar models can be obtained (see first accompanying figure). They have also surveyed how basic model properties such as photospheric size and shape, central thermodynamic conditions, and luminosity depend on the presumed internal rotational state of the star (see second accompanying figure). To interpret the behavior of many of the attributes of computed upper main sequence models, they have derived an approximate, semi-analytic model in which the outer, radiative envelopes of such stars are treated polytropically. To compare the model properties with the observed characteristics of rotating stars, Jackson, MacGregor, and Skumanich have begun work on synthesizing the shapes of spectral lines formed in a differentially rotating stellar photosphere. Although the effects of gravity darkening have yet to be incorporated, preliminary results suggest that differential rotation of the kind used in their recent models for the Be star Achernar (Jackson, MacGregor, & Skumanich 2004) is difficult to detect through analysis of photospheric absorption line profiles. After updating some of the input physics and adding a mixing-length treatment of convection, Jackson, MacGregor, and Skumanich anticipate using the modified SCF method to address a variety of problems; these include an examination of the structure and properties of a rapidly and differentially rotating young Sun, an investigation of the circumstances under which stars of intermediate mass can have rotationally induced convective envelopes, and a study of extremely distended, highly flattened configurations as representations of star/disk systems.



Map of rotational parameter space for 6 $M_?$ stars showing regions where converged models can and cannot be obtained. The quantity a is a measure of the degree of differential rotation, while ? is the ratio of the axial rotation rate to the critical rotation rate at the equator on the surface of the star. The four green lines are contours on which the ratio of the rotational kinetic energy to the gravitational potential energy, t, assumes values of 3, 6, 9, and 12%, respectively. Region I, the domain over which converged models can be readily obtained, is separated from Region II by the red line, from Region III by the purple line, and from Region IV by the blue line. Regions II and III are domains in which equilibrium models presumably exist but cannot be obtained with the present code. Some of the models in these two regions apparently have level surfaces with toroidal topology, and some or all of the models in these regions may be unstable. The blue line marking the boundary of Region IV is the parabola ? = 1 + a^2, the locus of points for which O_e, the equatorial angular velocity, is equal to O_{cr}, the critical angular velocity. No equilibrium model exists in Region IV because the net force at the equator would be directed outward.



The dependence on the kinetic-energy parameter t of six basic physical properties for 3 $M_?$ models. Each variable is plotted in units of the value of the same variable for the corresponding nonrotating reference model. The solid curves are cubic-spline fits to data for models computed by Clement (1979) using a two-dimensional relaxation technique. The dashed lines are cubic-spline fits to data for SCF 3 $M_?$ models, with the filled circles indicating the actual data points for those models. Panel (a) displays the variation of the equatorial radius R_e and the polar radius R_p, Panel (b) the variation of the mean radius R_a and central temperature T_c, Panel (c) the variation of the central density $?_c$ and the luminosity L.

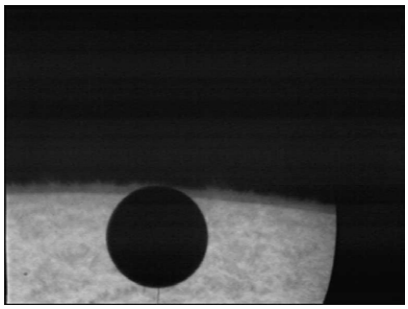
-Results in Stellar and Planetary Astrophysics- HAO's program in stellar and planetary astrophysics reached significant milestones in FY2003, driven by 3 noteworthy observations.

For the last 3 years, Tim Brown (HAO) has supervised operation of the STellar Astrophysics and Research on Exoplanets (STARE) telescope, now sited on the island of Tenerife, Spain. This work is carried out with extensive assistance from the Astrophysical Institute of the Canaries (IAC), including collaboration with J. Belmonte (IAC), and Brown's co-supervision of two graduate students (R. Alonso and O. Creevey, both of the IAC and the University of La Laguna). For about 18 months, STARE has observed in conjunction with two similar telescopes: one at Flagstaff, Arizona (operated by E. Dunham and G. Mandushev, both of Lowell Observatory), and the other at Mt. Palomar, California (operated by D. Charbonneau, Harvard University, and F. T. O'Donovan, CalTech). Together, these three telescopes make up the Transatlantic Exoplanet Survey (TrES) network. Recent improvements in analysis techniques, combined with the higher duty cycle possible with the 3-site network, have enabled a flurry of recent discoveries of interesting eclipsing objects.

In May 2004, during analysis of a data set obtained about a year earlier, R. Alonso noticed a star in the constellation Lyra that showed periodic eclipses that were consistent with a transiting planet. Extensive follow-up observations showed that this object is indeed a planet, now dubbed TrES-1, the first transiting planet detected by the TrES network. This was the fifth transiting planet known, and only the second that is near enough to the Sun that it can be thoroughly characterized using presently available telescopes. TrES-1 has a mass about 0.75 times that of Jupiter, a radius of about 1.04 Jupiter radii, and it circles its parent star (which is slightly smaller and cooler than the Sun) once every 3.02 days. At present, the most puzzling point concerning TrES-1 is that its mass and equilibrium surface temperature are quite similar to those of the planet HD 209458b (the first known transiting planet, also co-discovered by the STARE telescope), but its radius is 20% smaller (see the first accompanying Figure). Extensive studies of both planets to understand the origin of this difference are underway.

Graduate student O. Creevey investigated a newer TrES data set and found a relatively faint and unusually red eclipsing binary star that showed an apparent orbital period of 0.6 day. Further examination proved this to be a nearly-symmetrical pair of M dwarf stars, each with a mass only about 0.4 times the solar mass. Such binary systems present an opportunity for precise estimates of the radii and masses of both components; they are important because the theoretical mass/radius relation is ill-determined for stars with such cool temperatures, and because only 3 similar systems are known. In collaboration with F. Benedict and W. Cochran (both University of Texas), Creevey obtained radial velocity data confirming the characterization of the system, and giving mass and radius values accurate within a few percent. Future observations will refine these values further.

On June 8 2004, the planet Venus transited the Sun for the first time in more than 120 years (left). T. Brown and M. Knölker (HAO) traveled to Tenerife to observe the transit using the Vacuum Tower Telescope of the Kiepenheuer Institue for Solar Physics (KIS). Working with a team of German and Spanish scientists (including W. Schmidt and H. Schleicher from KIS, H. Rauer from the University of Berlin, and R. Alonso and M. Collados Vera from the IAC), they



observed the spectrum of sunlight that had traveled through the outer reaches of the Venusian atmosphere. By measuring the strengths and Doppler-shifted wavelengths of near-infrared lines of carbon dioxide, they aim to measure the composition, excitation temperature, and wind speed as a function of Venusian latitude and height above Venus's cloud deck. Initial analysis of the data shows promising results and more detailed study is in progress.

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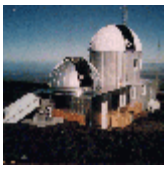

Facilities and Community Support

Support of Community Computational Models
Support of Integrated Community Programs
Observational Facilities and Data Services

Other HAO Sections TISO | SAH | SIV

Support of Community Computational Models

TIME-GCM / TIE-GCM / TING | WACCM | GSWM | AMIE | GLOW

TIME-GCM / TIE-GCM / TING

Ben Foster (HAO) completed rewrites of both the Thermosphere-Ionosphere-Electrodynamics General Circulation Model (TIE-GCM) and the Thermosphere-Ionosphere-Mesosphere-Electrodynamics General Circulation Model (TIME-GCM) to use a dynamic 2-D data decomposition with MPI for parallel execution and support for two spatial resolutions in both the horizontal and vertical coordinates. The code can run with either 5° latitude and longitude resolution with 2 grid points per scale height vertical resolution, or 2.5° latitude and longitude with 4 grid points per scale height. The code is flexible and can run with further increases in both horizontal or vertical resolution, as desired.

Ray Roble (HAO) updated and evaluated various aeronomic components in the TIME-GCM by direct comparison of model predictions with satellite and ground-based data. For example, he is comparing measurements of the atomic oxygen green line at 557.7 nm and the OH (8-3) band emission, obtained by the WINDII instrument on board the UARS satellite, with TIME-GCM simulations of the yearly variation of these emissions. The results of the comparison are being used to evaluate the importance of gravity wave transport and mixing in controlling the airglow structure of the MLT region. In addition, tidal measurements from ground-based stations are being used to evaluate the tidal propagation predictions in the TIME-GCM. The gravity-wave parameterization modules were also rewritten and improved.

The TIE-GCM's ability to predict the dynamics of the F-region electron density over the course of a year (2002) is being

evaluated by comparing foF2 and hmF2 with ionosonde observations over a global network of stations.

A satellite track processor has been developed to sample model data along any satellite track and analyze data in terms of ascending and descending orbit node differences. Simulations show that a significant aliasing can occur for various tidal components, e.g., migrating and nonmigrating diurnal and semidiurnal components into tidal fields with observed zonal wavenumbers greater or equal to zero. Using this code, the model can also present simulated results over any given ground-station, or process model output in various specialized modes for comparison with data.

Alan Burns, Wenbin Wang, and Michael Wiltberger (all of HAO) coupled the Thermosphere-Ionosphere-Nested-Grid (TING) version of the TIE-GCM with the magnetospheric Lyon-Fedder-Mobarry (LFM) model to form the Coupled Magnetosphere-Ionosphere-Thermosphere (CMIT) model. CMIT has been developed in several ways in the last year, both to enable its accessibility for the community and to continue to improve its representation of the magnetosphere, ionosphere and thermosphere. Users now have better access to its output as a result of the development of a Center for Integrated Space Weather Modeling Data eXplorer (CISM-DX) interface. This interface is an implementation of the open source data explorer language that has been explicitly developed for CISM. It is comprised of a number of three-dimensional graphics and data analysis modules that are accessible to users. An effort is also underway to improve the documentation of the CMIT model and to improve its accessibility for all users. It is anticipated that this action will be completed in the coming year , and that a version of the model, complete with documentation, will be delivered to Boston University for wider dissemination. Parallel efforts to improve the geophysical representations of the model have also been undertaken. The model is continually tested in a variety of different geophysical conditions in order to test and improve its descriptions of geospace. Among the specific improvements made in the last year are: including the feedback of neutral winds from the thermosphere/ionosphere system into the magnetosphere; initiating efforts to include a representation of the plasmasphere in the model; and, consideration of a more generalized potential solver.

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Whole Atmosphere Community Climate Model (WACCM)

Within the past year, the dynamics and chemistry components have been fully coupled in WACCM2, allowing self-consistent interactions to be examined throughout the troposphere, stratosphere, mesosphere and lower thermosphere. The dynamical model is based the Climate Systems Model at NCAR, but it has been extended to include molecular diffusion, a gravity wave spectrum parameterization, non-LTE radiation processes, and a finite volume dynamical core. The interactive chemical model also uses a finite volume core in the MOZART framework, but has been updated to include additional processes needed to represent the lower thermosphere, including ion-molecule reactions, auroral NO_x production and NO cooling. Other chemical and dynamic components needed for the upper mesosphere and lower thermosphere have been taken from the TIME-GCM. Much of the past year has been devoted to tuning the model by improving the gravity wave parameterization and comparing predictions of dynamics and chemical species, such as ozone, water vapor, methane, nitrogen dioxide and others that are currently being measured by satellites. In addition, a realistic magnetic field model has been included in WACCM2 to better predict the location and motion of auroral processes at high magnetic latitudes, and for a better prescription of ion drag throughout the ionosphere and thermosphere. A new code for handling solar radiation, based on satellite data, has been incorporated into WACCM2 giving detailed solar heating and photodissociation rates for a large number of chemical species. Metastable chemistry is also included. Modules are in development to resolve the major species diffusion in the thermosphere. The WACCM2 model is now being prepared to run over a complete solar cycle to examine the changes in atmospheric structure, dynamics and chemistry in response to realistic solar forcing. The results of these calculations will be compared with available satellite data.

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Global-Scale Wave Model (GSWM)

HAO continues to make GSWM results available to the community through the web site: http://www.hao.ucar.edu/public/research/tiso/gswm/gswm.html.

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Assimilative Mapping of Ionospheric Electrodynamics (AMIE)

Tomoko Matsuo, Art Richmond, and Gang Lu (all of HAO) demonstrated the feasibility of a new implementation of the AMIE procedure for the objective analysis of high-latitude ionospheric electrodynamic variables that utilizes Empirical Orthogonal Function (EOF) bases and the maximum likelihood method for on-line error covariance parameter estimation. This work is an important step in understanding how scale-dependent properties of electromagnetic energy

and momentum transfer processes affect the global thermospheric Joule heating estimation. They tested the new methodology for a magnetic cloud event that occurred on January 10-11, 1997.

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Global Airglow Model (GLOW)

Stan Solomon and Liying Qian (both of HAO) used the GLOW model to provide an updated parameterization of solar extreme-ultraviolet and X-ray ionization and thermospheric heating for implementation in the upper-atmospheric TIME-GCM/TIE-GCM/TING and WACCM models.

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Support of Integrated Community Programs

Space-Weather Program | CEDAR | GEM | Center for Integrated Space Weather Modeling | Virtual Solar-Terrestrial Observatory (VSTO)

Space-Weather Program

HAO maintains a vigorous, multi-faceted program of research on space weather, one embracing a variety of efforts aimed at attaining an improved understanding of the behavior of the Sun-Earth system. Among the many space weather-related topics receiving attention from HAO researchers are: the physical mechanisms underlying solar activity, particulary expulsions of mass and magnetic fields in the form of CMEs; the propgation of such disturbances through the interplanetary medium, their evolution and effects on the space environment from the Sun to the Earth; the interaction of ejecta from the Sun with the terrestrial magnetosphere, and the transmission of effects from this interaction into the ionosphere and upper atmosphere. HAO is an active participant in the Center for Integrated Space Weather Modeling (CISM), a Science and Technology Center funded by the National Science Foundation. In addition, two ongoing research efforts are currently supported by grants from the NSF Space Weather Program:

"The Quantification and Validation of Variable Electrodynamic Forcing of the Thermosphere," B. Emery (PI), A. Richmond, T. Matsuo, A. Maute, (Co-Is) (2002-2005);

"Inferring the Speeds of Earth-Directed Coronal Mass Ejections Using He I 1083 nm Velocity Observations," G. de Toma (PI), T. Holzer, H. Gilbert, J. Burkepile, T. Gombosi (University of Michigan) (Co-Is) (2002-2005).

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CEDAR

-CEDAR Web Site- HAO maintains a web page for the National Science Foundation (NSF) Coupling, Energetics and Dynamics of Atmospheric Regions (CEDAR) community that includes links to the CEDAR Science Steering Committee, contact information for CEDAR participants, Announcements of Opportunity, the CEDAR Post publication, and the annual CEDAR Workshop with an archive of Workshop tutorial lectures. Emery briefs the CEDAR community on topics of interest via a broadcast e-mail message every week or two. These briefings include announcements of job opportunities that are subsequently archived on the CEDAR web page. The CEDAR homepage at HAO can be accessed via the URL http://cedarweb.hao.ucar.edu. A new (linux) server with the new version 3.1 interface (based on ION IDL-On-the-Net) was released in June 2004. The CEDARWEB site supported CEDAR Science Steering Committee activities, including the CEDAR Prize Lecture nominations. The CEDAR POST continued to be made available on-line. The personnel that work with the CEDARWEB site and database at HAO are: Peter Fox (manager), Barbara Emery, Roy Barnes, Jose Garcia, and Patrick West.

-CEDAR Instruments and Database- The NASA TIMED satellite was launched December 7, 2001, with initial

acquisition of data from the 4 instruments (GUVI, SABER, SEE, TIDI) in late January, 2002. There are 8 ground-based instrument types in the CEDAR-TIMED program (HF radars, Mesosphere-Lower Thermosphere (MLT) radars (MLTRs), Incoherent Scatter Radars (ISRs), Fabry-Perot Spectrometers (FPSs), lidar, Michelson Interferometers (MIs) or CCD Spectrographs (CCDSs), 4-Channel Photometers, and [OH] or other imagers). The CEDAR Database at HAO is responsible for data access to the last 6 instrument types, and for the final archive of the MLTRs. The science emphasized by TIMED is in the MLT region. Data from 6 of the 8 instrument types were added to the CEDAR Database in FY 2004. Images from imager instrument data are still under construction, adding metadata to FITS files.

Updates to the CEDAR Database were made in 8 of the past 12 months for 22 ground instruments, 1 model (AMIE), 1 satellite, and 5 indices, of which all but 3 (AMIE, Arecibo, EISCAT) included recent (2003-2004) data sets. 4-day CEDAR-TIMED harmonic analyses came from 10 MF radars (Davis, Rothera, Adelaide, Rarotonga, Kauai, Yamagawa, Wakkanai, Saskatoon, Poker Flat, Tromsø) and 2 meteor radars (Ascension Island and Esrange). Additionally, some providers also gave the original 30-minute or hourly wind data (Davis, Adelaide, Yamagawa, Wakkanai, Poker Flat), where Davis, Yamagawa and Wakkanai were new MF radars in the CEDAR Database.

Another new instrument in FY2004 was the Davis spectrophotometer providing [OH] mesosphere temperatures during the night. The Wuppertal spectometer also provided new nightly [OH] temperatures. Other updates came from the Sondrestrom FPS, the South Pole MI, the CSU lidar, the USU imager at Maui, and 4 IS Radars (Jicamarca, Sondrestrom, EISCAT and Arecibo). A final new data set was the electron and ion precipitation data from the NOAA-15 satellite, which also provided part of the index of hemispheric power estimates.

New data sets and data sets in progress are listed on-line . The annual CEDAR Database Catalogue also describes the data in the CEDAR Database. A poster by Peter Fox and talk at the annual workshop was about a Virtual Solar-Terrestrial Observatory using the Virtual Solar Observatory concept (the "small box") as part of the architecture.

Community support continued for the CEDAR-TIMED Ground-Based Investigator data system support (http://cedarweb.hao.ucar.edu/timed/timed.html). The Applied Physics Laboratory (APL) is responsible for the TIMED satellite data support system (http://www.timed.jhuapl.edu/home.htm), and the CEDAR-TIMED data are also available from APL through the mechanism of Data Product Forms (DPFs).

Database use statistics are located at http://cedarweb.hao.ucar.edu/documents/statistics.html. The statistics show a jump in users starting in 2002, with increased interest in indices, empirical models, optical instruments below 150 km, MLT radars, red-line FPSs, lidars, and Jicamarca ISR data. Statistics show that most outside users get data via the web access.

-The 2004 CEDAR Workshop- The CEDAR Workshop for 2004 was held at the Eldorado Hotel in Santa Fe, New Mexico. The workshop webpage is at http://cedarweb.hao.ucar.edu (click on 'Workshop'). Barbara Emery and Louise Beierle of HAO were the local organizers, with support from HAO staff Kathryn Fisher, Barry Gamblin, Roy Barnes, Dan Gablehouse, and Liz Hoswell. A total of 317 persons from 71 institutions, 17 outside the United States and Puerto Rico, attended the 2004 CEDAR Workshop. This year, 121 students and recent grads came from 26 universities and 5 research labs, including Canada (4), Japan (4), the United Kingdom (1), France (1), Korea (1), Brazil (1) and Columbia (1). The total attendance was down from 356 in 2003, with 12 fewer students and 19 fewer Colorado locals.

The Student Workshop, organized by the new CEDAR student representative Stanley Briczinski of the Pennsylvania State University, looked at "Instrumentation - Gear for Your Thesis." There were 6 speakers, including Keynote Speaker Ron Woodman of the Jicamarca Radio Observatory in Peru, who gave a talk on "Incoherent and Coherent Scatter Radars: Jicamarca Examples" which was video-taped and is available on-line in .pdf form at: http://cedarweb.hao.ucar.edu/workshop/tutorials/2004/woodman04.pdf. Stan will continue as student representative for the next year, joined by Carlos Martinis of Boston University.

The CEDAR Prize Lecture was given by Maura Hagan of the National Center for Atmospheric Research. She gave an overview of "Tidal Coupling in the Earth's Atmosphere," available on-line as a .pdf file at: http://cedarweb.hao.ucar.edu/workshop/tutorials/2004/hagan04.pdf. The 4 tutorial speakers were Craig Heinselman of SRI International ("The AMISR/ISR Capabilities"), Chet Gardner of the University of Illinois ("Middle Atmosphere Wind and Temperature Lidars: Current Capabilities and Future Challenges"), Dave Hysell of Cornell University ("AMISR Contributions to Equatorial Aeronomy"), and Paul Bernhardt of the Naval Research Laboratory ("Chemical Release Applications, Observations, and Modeling"). All of these talks are available as .pdf files on the web at http://cedarweb.hao.ucar.edu/workshop/tutorials/2004/; they are also available on video tape and DVDs.

There were 25 workshops, which was the same number as last year, despite having 2 hours less of workshop time and combining several workshops together. The final workshop reports are on-line at:

http://cedarweb.hao.ucar.edu/workshop/pmworkshops.html with links to some of the individual talks, including a power point presentation by Emery for Fox on the Virtual Solar-Terrestrial Observatory in the LDS8 Workshop (Towards an Integrated Data Environment). Hanli Liu of HAO co-chaired the OL5 Workshop (Science Challenges for the CEDAR (Lidar) Observing Community). Alan Burns and Wenbin Wang of HAO were two of the chairs of the LDS4 Workshop (Storms and Superstorms: Observations, Analysis and Modeling of Large Geomagnetic Disturbances). There were 6 CEDAR and related post-doc reports given by Rebecca Bishop of Clemson, James Boulter of SRI, Aimee Merkel of ACD/NCAR, Weilin Pan of SRI, Alok Taori of USU, and Paul Withers of BU. There were also about 15 programmatic talks during the plenary sessions, including an update of the CEDAR Database given by Emery.

There were two late afternoon poster/reception sessions, during which all posters were up for the entire time. 83 posters were presented on Tuesday and 50 on Wednesday, for a total of 133. This is a record number of posters, exceeding the 118 presented in 2003. A total of 64 student posters were under competition, and 14 other student posters made for a record number of 78 student posters; the previous record was 64 student posters in 1994. There were two student winners in the poster competition, Ningyu Liu of the Pennsylvania State University and Melissa Meyer of the University of Washington. There were also three honorable mentions: Xiaohua Fang of the University of Michigan, Patrick Roddy of the University of Texas at Dallas, and Jing Tang of the University of Illinois. They all received prizes of books and achievement certificates.

There were many extra-curricular activities for the 2004 CEDAR Workshop. A 56-passenger bus was taken from Fort Collins, Colorado to Santa Fe with 12 passengers coming down from Colorado. The bus was then used to take students to the student bowling social at Silva Lanes on Sunday evening, and as transportation for the tours arranged by Santa Fe Destinations. Two tours were offered: one to the Bradbury Science Museum at Los Alamos and to the ancient Pueblo ruins at Bandelier National Monument, and the second to La Cieneguilla Petroglyphs. Santa Fe Destinations also designed a petroglyph CEDAR T-shirt to commemorate the meeting. Registration for the workshop and for shared nearby student suites was via web forms using Reg-on-Line. Meeting plans, the agenda, the poster booklet, lists of student and non-student participants, student biographies and other information is also at the Workshop website. The joint 2005 CEDAR-GEM Workshop will take place at the Eldorado and the La Fonda Hotels in Santa Fe, New Mexico June 26 - July 1.

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GEM

Gang Lu (HAO) continued as a member of the GEM Science Steering Committee and participated in the annual GEM workshop in Snowmass, CO, June 21-25, 2004, with two oral presentations, "Hemispheric Asymmetry of Ionospheric Convection and Field-aligned Current," and, "Overview of Ionospheric Conditioning During Selected Inner Magnetospheric Storm Events."

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Center for Integrated Space Weather Modeling

-CISM Organization and Science Goals- The Center for Integrated Space Weather Modeling (CISM) is a National Science Foundation Science and Technology Center initiated in 2002. The consortium is led by Principal Investigator Professor W. Jeffrey Hughes at Boston University. Its goal is to create an end-to-end model of the space environment

from the surface of the Sun to the bottom of the Earth's ionosphere. HAO is responsible for developing and testing the ionosphere/thermosphere models for CISM. Additional contributions to the magnetospheric and solar components are made by other HAO participants.

The ionosphere-thermosphere modeling segment of CISM is primarily housed at the National Center for Atmospheric Research, but includes affiliations with the Space Environment Center at NOAA, the University of Colorado, Southwest Research Institute, Utah State University, and Space Environment Technologies. Primary modeling tools include the NCAR Thermosphere General Circulation Models, auroral particle and photoelectron transport models, middle-atmosphere tidal and planetary wave models, and the Assimilative Mapping of Ionospheric Electrodynamics (AMIE) procedure for analyzing auroral region currents and conductances using a variety of measurement data. The particular model currently being used for CISM studies is a high-resolution version of the NCAR-TGCM known as the Thermosphere-Ionosphere Nested Grid (TING) model.

-Coupled Magnetosphere-Ionosphere Modeling- The ionosphere is created and maintained primarily by solar extreme-ultraviolet radiation. However, its variability on daily and shorter time scales is largely driven by processes controlled by the solar wind and magnetosphere and coupled to the ionosphere through the auroral regions. Many other small-scale forms of ionospheric variability, such as irregularities in the equatorial region and traveling disturbance waves, are also important, but are less accessible at this time to global-scale thermosphere-ionosphere models. Therefore, the initial goal of the CISM project for the geospace regions is to create a coupled model of the magnetosphere and ionosphere that includes upper atmosphere circulation, solar irradiance variation, and forcing by the lower atmosphere.

Two-way coupling between the Lyon-Fedder-Mobary (LFM) and TING models was originally implemented using an ad-hoc method accomplished through exchange of information via a series of interchange files. This method has now been updated to direct parameter exchange between seperate executables using the InterComm software package developed at the University of Maryland. This exchange of boundary conditions occurs once per TING time step of two minutes. During the intervening time the LFM uses the previous TING conductivities to calculate the ionospheric potential. Grid rotation and interpolation is also handled by the magnetosphere-ionosphere coupling module.

During the second year of the project, initial problems in the implementation of the two-way coupling methodology that produced unrealistically low ionospheric conductivities were resolved, and the model now performs well. Results for the CISM end-to-end run were described in a paper published in JASTP by Luhmann et al. Papers by Wiltberger et al. and by Wang et al., also published in JASTP, describe the details of the methodology and initial runs for parametric solar wind conditions. The coupled model has been installed on computers at NCAR and at Boston University, and an operational interface was developed to facilitate test runs. Validation studies to examine the intensity and morphology of auroral precipitation are in progress.

-Coronal Brightness and Polarization Brightness Images- Andrew Stanger (HAO) is currently working on a CISM project to transform the 3-dimensional MHD global model of coronal density developed by SAIC into 2-dimensional total brightness and polarization brightness images that can be used to compare the model output directly to coronal observations. The SAIC MHD model (MAS) density structure is produced from solar magnetograph-derived, averaged synoptic charts to specify the global scale photospheric magnetic field. The corresponding 2-dimensional images can then be directly compared with observational data, such as that provided by the MLSO Mark-IV K-coronameter and the two SOHO space-borne coronagraphs, LASCO C2 and C3. An assortment of software is currently being used to produce these results. Work is in progess to consolidate these capabilities into the OpenDX graphical programming environment. Additional effort will also be needed to develop some basic analysis software to enable comparisons between the model data and coronal observations to be performed.

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Virtual Solar-Terrestrial Observatory (VSTO)

The prototype Virtual Solar-Terrestrial Observatory (VSTO http://vsto.hao.ucar.edu) is a distributed, scalable education and research environment for searching, integrating, and analyzing observational, experimental, and model databases in the fields of solar, solar-terrestrial, and space physics. The VSTO project started in late 2004 with a grant from the National Science Foundation under the Shared Cyber infrastructure Initiative. In the coming year, the VSTO project plans to involve users from HAO and the community by establishing web and national meeting presence. This will guide the development of user and provider requirements using a Use-case methodology. Based on the findings, an initial VSTO design will be developed and reviewed with an advisory committee. VSTO will establish relations with other major VO projects for compatibility and long-term viability of VSTO as a community resource, identify initial data holdings

(data, models, educational materials) and evaluate, develop and install the initial technology for the first instance of the VSTO.

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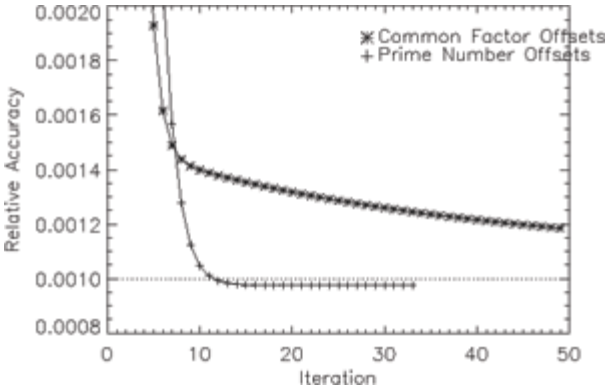
Observational Facilities and Data Services

PSPT | ECHO | CoMP | STARE | GONG | EPCO | MLSO

HAO operates many observational facilities at sites around the world. The scientific results obtained using these facilities are described elsewhere. This section describes rather the operational and organizational aspects of the facilities.

PSPT



The Precision Solar Photometric Telescope (PSPT) group at HAO has stabilized the telescope hardware and data processing algorithms. The new flat-field algorithm, with improved convergence using prime number offsets (see accompanying Figure), has been implemented as the default, and reprocessing of the full data set using it has begun. The past year has seen continued support of the SORCE mission and SFO collaboration with daily observations. Additionally, 117 data files have been delivered in response to specific requests; in one case, 10 GB of data was delivered in response to one user's request for a full month of observations. A MOU with the Rome observatory has been finalized, including a collaboration aimed at creating a common PSPT data base. Work has also begun to include PSPT data in the ACOS/MLSO data-search web-page.

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ECHO

HAO continues to operate a network of two velocity imaging instruments called the Experiment for Coordinated Helioseismic Observations (ECHO). One instrument is in the Canary Islands and is supported by the Astrophysics Institute of Canary Islands (IAC), and the other is located at HAO/NCAR's Mauna Loa Solar Observatory (MLSO). These instruments employ Magneto-Optical Filters and have sufficient spatial resolution to observe all globally coherent solar acoustic modes. The widely separated longitudes of the two sites allow up to twenty-two hours of continuous observations per day, resulting in improved measurement of the Sun's acoustic oscillations by reducing noise and confusion caused by nighttime interruption of the observations. HAO plans to continue to operate this network in order to search for changes of the internal solar rotation profile over the time scale of the 11 year solar cycle. Such changes are likely to occur in a region of high shear at the base of the convection zone where it is believed that a dynamo generates solar magnetic fields. Solar acoustic eigenfrequencies obtained from this dataset are available online at:
http://www.hao.ucar.edu/public/research/mlso/LowL/lowl.html

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CoMP

The Coronal Multi-channel Polarimeter (CoMP) is a filter-based polarimeter designed to measure magnetic fields in the solar corona and solar prominences. The instrument consists of an electro-optically tunable birefringent filter capable of observing the coronal emission lines of Fe XIII at 1074.7 and 1079.8 nm, and the prominence line of He I at 1083 nm, coupled with a polarimeter and a large format HgCdTe detector. The instrument creates simultaneous images of the

corona in two wavelengths corresponding to the emission line and continuum. The instrument was deployed to the 20-cm "One Shot" coronagraph at Sacramento Peak Observatory in January of 2004, and the first observations with the instrument were obtained during an observing run in March. Data continues to be collected in campaign mode with continuous operation expected to begin in 2005.

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STARE

The STellar Astrophysics and Research on Exoplanets (STARE) telescope is a small (10 cm aperture) CCD-based astrograph based in Tenerife, Spain. It is operated in conjunction with the Astrophysical Institute of the Canaries (IAC). Its principal objectives are to obtain extended time series of wide-field stellar photometry for use in studies of stellar oscillations, extrasolar planets, and stellar magnetic activity. In FY 2004, the STARE telescope became a part of the Transatlantic Exoplanet Survey (TrES) network, joining with other groups with telescopes at Lowell Observatory (Flagstaff, AZ) and Mt. Palomar, CA to provide more complete data sets for all of the STARE telescope's goals.

In FY 2004, the STARE telescope obtained observations on 75 nights through June 2004, and then encountered an extended series of technical problems involving the interconnection between its computers, erratic behavior of the telescope's mount, and a major failure of the system's power converter. These problems were resolved near the end of the fiscal year. In spite of the down time, STARE acquired extensive datasets for two fields (in the constellations Andromeda and Lynx), as well as a short observing run in support of the ESA COROT mission. STARE graduate student R. Alonso (IAC) implemented the vastly improved photometric pipeline developed by Lowell astronomer G. Mandushev, and at an organizational meeting at Lowell Observatory in July, much progress was made on coordinating the activities of the three components of the TrES network. Plans for the upcoming fiscal year include a major effort to re-analyze old data with the new photometric pipeline, and to install new hardware (a more robust telescope mount and a more efficient CCD camera) to improve the performance and reliability of the STARE telescope. Information about the STARE telescope and the TrES network may be found at http://www.hao.ucar.edu/public/research/stare/stare.html

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GONG

The Global Oscillation Network Group (GONG) is a community-based project, managed by the National Solar Observatory (NSO), to conduct a detailed study of solar internal structure and dynamics using helioseismology. GONG+ produces magnetograms and seismic images of the far side and interior of the Sun. Scientists use this capability to develop better tools to predict solar storms. Routine GONG+ observations are obtained from a network of solar telescopes located around the world. This year the Venus transit on 8 June 2004 (http://gong.nso.edu) was recorded from the Learmonth, Udaipur, and Teide GONG sites. This rare data set will be used to check the coalignment of the merged images. HAO's support at the MLSO GONG site includes preventive maintenance (PM) and first-response emergency maintenance. PM services are performed daily and include monitoring of the status of the instrument and shelter, removal and return of data storage media, and providing notification to the GONG project staff headquarters in Tucson, Arizona in the event of a problem.

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EPCO

A new Fabry-Perot interferometer was built and later deployed at the Early Polar Cap Observatory (EPCO) near Resolute, Canada (75 N), the future site of the National Science Foundation Advanced Modular Incoherent Scatter Radar (AMISR). The new instrument is designed to measure mesospheric and lower thermospheric tidal waves and the upper thermosphere polar cap convection pattern using OH, O 5577 Å and 6300 Å emissions. The wind errors for these emissions are 6 m/s (3 minute integration), 1 m/s (3 minute) and 2-6 m/s (5 minute), respectively. The instrument was tested in Boulder, Colorado, and measurement results were compared with nearby LIDAR mesospheric neutral wind measurements. The comparison showed good agreement between the two instruments. Neutral wind data obtained at Resolute also demonstrate that the instrument meets the design goal and is able to provide high quality data for future

studies of mesospheric and lower thermospheric dynamics as well as magnetospheric-ionospheric coupling, along with ion-neutral coupling in the upper atmosphere of the polar cap.

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MLSO

-Instruments- The Mauna Loa Solar Observatory (MLSO) resides in a lava field on the northwest flank of Mauna Loa (elevation 3353 m) on the island of Hawaii. This site provides some of the best solar observing conditions in the world. MLSO currently provides data for three observing programs: ACOS (Advanced Coronal Observing System), PSPT, and ECHO. ACOS includes the following instruments: Mark-IV (K-coronameter), the Polarimeter for Inner Coronal Studies (PICS) (Ha: 656.3 nm, disc and limb), and the Chromospheric He I Imaging Photometer (CHIP) (Helium-I: 1083 nm, disc).

-Operations- In 2002, MLSO was designated an NCAR facility, making it possible for a 3rd observer to be hired (January 2003), and to add 4 hours to the daily observing schedule. Mauna Loa instruments currently operate between 17:00 - 02:30 UT, weather permitting, and barring observer sick time. The number of coronal mass ejections (CMEs) observed with the Mark-IV white light coronameter has nearly doubled between 2002 and 2003, despite the slight decline in solar activity. Mark-IV white light observations of the low corona are unique, and the increased number of observed CMEs can greatly improve the physical understanding of the initiation of these events and their interaction with the surrounding solar atmosphere. The number of observing days during which MLSO acquired data in the past two years was:

Instrument	2002 [2 observers]	2003 [3 observers]
CHIP:	310 days (85%)	347 days (95%)
PICS:	284 days (78%)	345 days (95%)
Mark-IV:	246 days (67%)	307 days (84%)

A significant increase in daily 'duty cycle' for each instrument is evident since MLSO extended its observing schedule. Furthermore, in 2003, there were 211 days when observations were taken beyond 00:00 GMT. For most of those days, the observations ran to 02:00 UT or beyond. Prior to 2003, MLSO observations typically ended between 22:00 and 23:00 UT. This means that MLSO now provides a significant number of days with observations that overlap Australia, Japan and China for 3-5 hours.

-Datasets- Since acquiring a DVD "juke-box" storage system in 2002, MLSO is now able to provide easy access (via the MLSO web site) to all recent ACOS data (2001 - 2004). Despite a reduction in MLSO data processing support staff this year, and the large increase in observations (due to extended observing hours), HAO is continuing to provide the community with fully-processed data in a timely manner. In addition, HAO is slowly continuing to add older ACOS data (prior to year 2001) to its DVD storage system. On-demand access to the entire ACOS dataset collection via the MLSO web site will eventually be provided. The data archiving scheme has allowed MLSO to become one of the first beta test cases for the Virtual Solar Observatory project, a joint effort (Stanford University, National Solar Observatory, Montana State University, and the Solar Data Analysis Center) initiated via a proposal in November, 2002.

-Additional Coronal Data from the MLSO Website - Solar Maximum Mission- The MLSO image catalog database (MySQL) now provides data searches which are quick and complex. It also makes it relatively easy to add new observational datasets. HAO is currently making preparations to store Mark-III K-coronameter (1980 - 1989) and Solar Maximum Mission Coronagraph (1980, 1984-1989) data on the DVD archive. HAO recently received a NASA grant (LWS03-0161-0051) to provide all Solar Maximum Mission (SMM) coronagraph observations to the community, utilizing the MLSO web site resources. The SMM coronagraph operated during 1980 and from 1984 through 1989, recording over 240,000 images of the white-light corona, and more than 1,300 CMEs over most of a solar cycle. The complete SMM coronagraph dataset will be available to the scientific community by the spring of 2005.

-Instrument Upgrades-

Two instrument upgrades are in progress:

a. A sky brightness monitor from the University of Hawaii is soon to be installed at MLSO as an aid in calibrating the MLSO sky transmission telescope. High quality sky transmission readings are needed to help ensure the quality of the MK4 calibration. MLSO and HAO staffs are currently creating the infrastructure needed to support the new monitor. This effort has been delayed until the completion of the ATST site survey.

b. MK4 01 guider electronics are being completely redesigned by MLSO observer Allen Stueben and the HAO

instrumentation group. Fabrication has begun and the new hardware will be installed soon. This should significantly improve the MK4 pointing which is currently the largest source of error in the Mark-IV calibration.

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For further information, visit the following web sites:

MLSO: http://mlso.hao.ucar.edu

ACOS: http://mlso.hao.ucar.edu/cgi-bin/mlso_acoshome.cgi

PSPT: http://rise.hao.ucar.edu/pspt/instrument.html

ECHO: http://www.hao.ucar.edu/public/research/mlso/LowL/lowl.html

GONG: http://gong.nso.edu http://www.gong.noao.edu/sites/sites.html

VSO: http://virtualsolar.org

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Education and Outreach

HAO operates a four-part visitor program, hosting post-doctoral fellows, graduate research fellows, summer undergraduate visitors, and short-to-long-term scientific visitors. This year HAO hosted a total of eight postdoctoral fellows, four supported through its own NSF base funding or supplemental grant funding, one jointly with the Scientific Computing Division (SCD), and three by NCAR's Advanced Study Program (ASP). HAO supported a total of six graduate research fellows, one jointly with the University of Rome. HAO's summer undergraduate student visitor program hosted five students for terms of two to three months, one supported by HAO's NSF base funding, two jointly with Evergreen College by supplemental grant funding, and two through the SOARS (Significant Opportunities in Atmospheric Research and Science) program. Partial support was provided to 25 short-long-term scientific visitors from numerous separate home institutions worldwide.

A continuing educational outreach activity with a long tradition at HAO is the base funded production of educational materials distributed to K-12, undergraduate, and graduate school educators. HAO maintains three distinct slide sets in stock: The Sun: A pictorial introduction, Southwest archeoastronomy, and Coronal physics. The first two of these, other educational materials, and other more advanced lectures are available online through HAO's homepage http://www.hao.ucar.edu. Additionally, this year several HAO Scientists (including Holzer, Hagan, Solomon, and Wiltberger) teamed up with staff members (including Owens and Kiessling) from UCAR's Cooperative Program for Operational Meteorology, Education and Training (COMET) to create a learning module focused on the Earth's aurora. Created for the undergraduate science students with physics and calculus experience, the material is presented using high-quality graphics, interactive visualizations, and hands-on applications. The module is divided into four sections: Mystery of the Aurora, Magnetosphere, Thermosphere/Ionosphere, and Aurora. In each of the last three sections, an overview is followed by a more detailed discussion supplemented with a number of in-depth topics. The module has been designed for multiple uses, including support material and tools for lecturing instructors, homework assignments, and independent study projects. It can be found at the website http://www.meted.ucar.edu/hao/aurora.

For the second year of a three-year grant cycle HAO scientists Richmond and Lu served as PI's on NASA-funded Education and Public Outreach (EPO) collaborations with scientists and educators from UCAR's Office of Education and Outreach (EO). A Teachers-in-Residence program led by Richmond engaged high school teachers Gayle Bintner and Chris Conery for four weeks this summer in drafting new classroom lessons and content about Earth's atmospheric structure and space weather. The teachers chose to adapt an undergraduate level Space Weather module developed in 2003 by HAO and the COMET program for use in high school physics, astronomy, and earth science classes, identifying which sections of the module could be used in their current form, which should be omitted, and which should be revised for their high school students. Their recommendations were discussed in meetings with HAO scientists Richmond and Maute and Dolores Knipp from the US Air Force Academy. Also participating were educators Kiessling from the COMET Program and Foster and Russell from EO. This work continues into 2005 with high school module development, testing. and revision, with the goal of installing the module on EO's Windows to the Universe web site (http://www.windows.ucar.edu) and disseminating it through presentations at local and national professional meetings

reaching scientists and K-12 teachers. HAO scientist Metcalfe also contributed new content to the Windows to the Universe web outreach project with interactive materials on the "Fate of the Sun" and "Pulsating Stars".

Lu's grant enabled the prototyping of educational resources which scientists can use and adapt to their particular areas of interest when preparing K-12 classroom visits. These resources include:

1. background information, tips, and guidelines for making successful presentations to elementary, middle, and high school students,
2. hands-on inquiry activities designed to augment standards-based classroom learning about magnetism (Earth's magnetic fields) and technology (interpretation of images recorded by various solar-observing technologies), and
3. a PowerPoint presentation on Sun-Earth connection science concepts.

They were developed by contracted teacher, Doug Haller, and reviewed by HAO scientists Rast, Gibson, Burkepile, and Wiltberger; University of Wisconsin scientist Susan Nossal; and EO educators Foster, Eastburn, and Barnes. Technology support was also provided by HAO's Starr and Mauriello. Inquiry activities were tested with middle school students visiting the Mesa Lab tour program and in two local schools. The focus in the final year will be on further classroom testing, revising, and formatting the resources for dissemination via website and short EO workshops.

Visits and talks were made by HAO scientists (Gablehouse, Lecinski, Lites, Maute) to local elementary, middle and high school students as well as local club (Girl Scout and Rotary) members on Solar physics, Atmospheric science and Solar/Terrestrial interactions. HAO scientist Solomon delivered guest lectures at the University of Colorado (CU), the Global Change teacher education workshop (NCAR), and the Space Weather Summer School (Boston University). HAO scientist Gibson presented at the math, science and technology career conference, Expanding Your Horizons, held at CU for middle school girls, their parents and teachers. She also participated in three separate Solar Week (http://www.solarweek.org) events to provide web based activities and real time scientific interaction to elementary school classrooms. HAO scientist Norton served as guest scientist on the National Public Radio Show "Pulse of the Planet" episode devoted to sunspots.

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Community Service

Editorships

- **Alan Burns**, Associate Editor, Journal of Atmospheric and Solar Terrestrial Physics, 2000-present
- **Barbara Emery**, Editor, Coupling, Energetics and Dynamics of Atmospheric Regions (CEDAR) E-mail Community Announcements, 1990-present
- **Peter Fox**, Associate Editor, Fundamentals of Cosmic Physics
- **Maura Hagan**, Guest Editor, Journal of Atmospheric and Solar-Terrestrial Physics, Planetary Scale Mesopause Observing System (PSMOS) Special Issue, 2003-present
- **Timothy Killeen**, Editor-in-Chief, Journal of Atmospheric and Solar-Terrestrial Physics, 1999-present
- **Arthur Richmond**, Editor, Journal of Geophysical Research, Space Physics, 2002-2005

Scientific, Policy, or Educational Committees and Advisory Panel/Boards

Mausumi Dikpati

- Member, HAO Visitor Committee (since September 2003)
- Member, CAWSES Working Group Theme 4 (since March 2004)
- Member, SOC of 22nd NSO Workshop

Yuhong Fan

- Member, NASA LWS proposal review panel (February 2004)

Peter Fox

- Member, SunRISE Scientific Steering Committee, 1994-present
- Member, Distributed Oceanographic Data System (OPeNDAP) Technical Advisory Committee, 1997-present
- Member, Steering Committee for NSF Cyber Infrastructure Initiative (Workshop and Report), 2002-present
- Member, International Solar Cycle Studies (Scientific Committee on Solar Terrestrial Physics), Working Group 1, Subgroups 1 and 3, 1997-present, and co-leader of Subgroup 1, 1999-present
- Member, SOC, 2004 COSPAR Symposium on Solar Variability and Climate Change (C2.1/D2.3/E3.3)
- Program/Session Chair, COSPAR2004 Symposium
- Member and USA co-chair of SOC for The Sun and Earth's Climate Symposium to be held in Rome, Italy, June 2005
- Member, Climate and Weather of the Sun Earth System (CAWSES), Theme 4, Working Group 1

Scientific Coordinator, CAWSES, Theme 4, Work Group 1, Space Climatology

Peter Gilman

- Member, AURA Board of Directors
- Member, Solar Observatory Council, AURA (Chair through June 2003)
- Member, NSO GONG Scientific Advisory Committee
- Member, HAO/NSO Solar Magnetism Initiative Steering Committee
- Member, NSO SOLIS Advisory Committee

Matthias Rempel

- Member, NASA's SRT review panel (May 2004)

Mark Rast

- Member, NASA's Solar and Heliospheric Physics Peer Review Panel (August 2004)

Barbara Emery

- Ex Officio Member, Coupling, Energetics and Dynamics of Atmospheric Regions (CEDAR) Science Steering Committee, 1987-present

R. Daniel Gablehouse

- Member, Data System Working Group, NASA Thermosphere Ionosphere Mesosphere Energetics and Dynamics (TIMED) Mission, 1993-present
- Member, Science Working Group, NASA Thermosphere Ionosphere Mesosphere Energetics and Dynamics (TIMED) Mission, 1993-present

Maura Hagan

- Scientific Discipline Representative, Scientific Committee on Solar-Terrestrial Physics (SCOSTEP) International Council of Scientific Unions, 1999-present
- Member, NASA Geospace Sciences Management Operations Working Group (GMOWG), 2003-present
- NSF ATM Upper Atmosphere Facilities Review Panel, Oct. 2003-Jan. 2004

Timothy Killeen

- Member, American Geophysical Union (AGU) Global Climate Change Panel, 1998-present
- Member, International Arctic Research Center Oversight Council (IARC OC), 2000-present
- Member, Community Climate Systems Model (CCSM) Advisory Board (CAB), 2000-present
- Member, Thermosphere Ionosphere Mesosphere Energetics and Dynamics Scientific Working Group (TIMED SWG), 2000-present
- Member, National Academy of Sciences (NAS) Solar and Space Physics Survey Panel on Magnetosphere-Ionosphere-Atmosphere (MIA), 2001-present
- Co-chair, Interagency Working Group, US Weather Research Program, 2002-present
- Member, American Association for the Advancement of Science (AAAS) Scientific Program Committee, 2003-present
- Member, American Geophysical Union (AGU) Space Physics and Aeronomy Section Nominating Committee, 2003-present
- Member, Screening Panel for Experimental Program to Stimulate Competitive Research (EPSCoR) Director Search, 2003-present
- Member, NASA Earth Systems Science and Applications (ESSAAC) Advisory Committee, 2003-present
- Member, Committee on Facilitating Interdisciplinary Research, The National Academies, 2003-present
- Member, Weather Research Forecasting (WRF) Executive Committee, 2003-present

Hanli Liu

- Member, NCAR Early Career Scientists Assembly Steering Committee, 2002-present
- Member, HAO Visitor Committee, 2003-present

Gang Lu

- Associate, University of Colorado Center for Integrated Plasma Studies, 1996-present
- Scientific Discipline Representative, Scientific Committee on Solar-Terrestrial Physics (SCOSTEP), 1999-present

- Member, Geospace Environment Modeling (GEM) Science Steering Committee, 2002-present
- Member, National Research Council Committee on Solar and Space Physics, 2003-present
- Secretary for Aeronomy, AGU-SPA, 2004-2006
- Co-leader, Working Group 3.3 of Theme 3 on Atmospheric Coupling Processes, Solar-Terrestrial Physics Climate and Weather of the Sun-Earth System (SCOSTEP-CAWSES), 2004-present

Arthur Richmond

- Member, Coupling, Energetics and Dynamics of Atmospheric Regions (CEDAR) Science Steering Committee, 2000-2003
- Member, Scientific Committee on Solar-Terrestrial Physics (SCOSTEP) Climate and Weather of the Sun-Earth System (CAWSES) Steering Committee, 2002-2005
- Member, American Geophysical Union (AGU) Space Physics and Astronomy Section Executive Committee, 2002-2005
- Member, Science and Technology Definition Team for the NASA Global Electrical Connections Mission, 1998-present

Raymond Roble

- Member, Advisory Board, Geophysical Institute, University of Alaska, 1985-present

Stanley Solomon

- Member, NASA Thermosphere Ionosphere Mesosphere Energetics and Dynamics (TIMED) Mission Science Working Group, 1993-present
- Member, Steering Committee, Thermosphere-Geosphere Research, 1998-present
- Secretary for Aeronomy, Space Physics and Astronomy Section, American Geophysical Union (AGU), 2002-2004

Michael Wiltberger

- Member, NSF Space Weather Proposal Review Panel, 2003
- Member, NSF Geospace Environment Modeling (GEM) General Geospace Circulation Model Coordinating Committee (GGCMCC), 2003-present
- Co-chair, HAO Colloquium Committee, 2003-present

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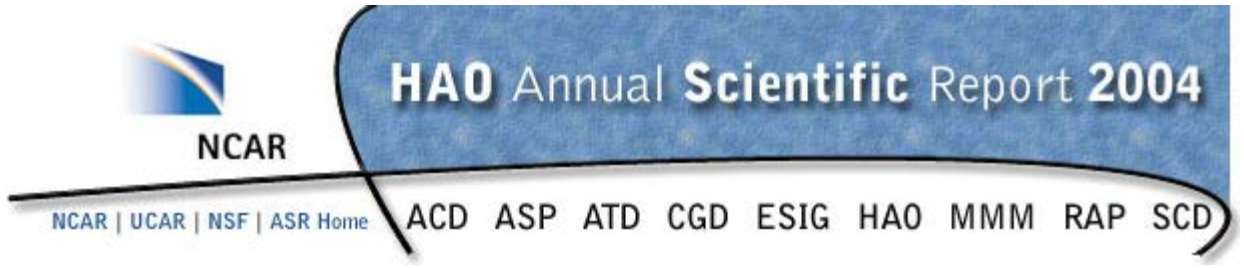

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Awards

Maura Hagan

CEDAR Prize Lecturer, June 2004

Timothy Killeen

Elected Councilor, American Meteorological Society, 2003-2006
President-Elect, American Geophysical Union, 2004-2006

Mark Rast

UCAR Outstanding Publication Award

Raymond Roble

Highly Cited Researcher in Space Sciences by ISIHighlyCited.com

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HAO Publications for 2004

A B C D E F G H I J K L M N O P Q R S T U V W X Y Z

NOTE: **Bold** denotes University collaborators and * denotes non-NCAR or other collaborators

A

Alonso, R., T.M. Brown, G. Torres*, D.W. Latham*, A. Sozzetti*, G. Mandushev*, J.A. Belmonte*, D. Charbonneau*, H.J. Deeg*, E.W. Dunham*, F.T. O'Donovan*, and R. Stefanik* 2004: TrES-1: The transiting planet of a bright K0 V star, *ApJ Letters*,**613(2)**, L153-L156

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Bogdan, T., S. W. McIntosh*, R. F. Stein*, M. Carlsson* 2004: Waves in the magnetized solar atmosphere II: Waves from localized sources in magnetic flux concentrations, *ApJ*, **599(1)**, 626-660

Brun, A.*, M. Miesch, **J. Toomre** 2004: Global-scale turbulent convection and magnetic dynamo action in the solar envelope, *ApJ*, Accepted

Burkepile, J., A. J. Hundhausen, A. Stanger, **O. C. St. Cyr**, J. A. Seiden 2004: The role of projection effects on solar coronal mass ejection properties. Paper I. A study of CMEs associated with limb activity., *JGR*, **109**,DOI 10.1029/2003JA010149

C

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Casini, R., A. López Ariste*, S. Tomczyk, B. Lites 2004: Magnetic Maps of prominences from full Stokes analysis of the

He I D3 Line, *ApJ Letters*, **598**, L67-L70

D

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de Toma, G., O.R. White, **G. A. Chapman**, **S. R. Walton**, **D. G. Preminger**, and **A. M. Cookson**, 2004: Solar Cycle 23: An Anomalous Cycle?, *ApJ*, **609(2)**, 1140-1152

de Toma, G., O.R. White, **G. A. Chapman**, and **S. R. Walton** 2004: Solar irradiance variability: progress in measurements and empirical analysis, Advances in Space Research, **34**, 237-242

Dikpati, M., G. de Toma, P. Gilman, N. Arge*, O.R.< White 2004: Diagnostics of polar field reversal in solar cycle 23 using a flux-transport dynamo model, *ApJ*, **601(2)**, 1136-1151

Dikpati, M., P. Gilman, M. Rempel 2003: Stability analysis of tachocline latitudinal differential rotation and coexisting toroidal band using a shallow-water model, *ApJ*, **596(1)**, 680-697

Dikpati, M., P. Gilman, **P. Cally** 2004: Linear analysis and non-linear evolution of 2D global MHD instabilities in a diffusive tachocline, *ApJ*, **610**, 597-615

F

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Fan, Y., S. Gibson 2004: Numerical simulations of three-dimensional coronal magnetic field resulting from the emergence of twisted flux tubes, *ApJ*, **609**, 1123-1133

G

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Gibson, S. , Y. Fan, **C.H. Mandrini**, **P. Demoulin**, **G. Fisher** 2004: Observational consequences of a magnetic flux rope emerging into the corona, *ApJ*, Accepted

Gibson, S. , D. A. Foster, **O. C. St. Cyr**, M. Guhathakurta*, T. Holzer 2003: Three dimensional cororal density structure: Paper 1 model, *JGR - Space Physics*, **108(A12)**, DOI: 10.1029/2003JA009994

Gilbert, H, R. MacQueen, T. Holzer 2004: A new technique for deriving prominence mass from SOHO/EIT FE XII (19.5 nm) absorption features, *ApJ*, Accepted

Gilbert, H, T. Holzer, B. Thompson*, J. Burkepile 2004: A comparison of CME-associated atmospheric waves observed in coronal and chromospheric lines, *ApJ*, **607(1)**, 540-553

Gilbert, H, T. Holzer 2004: Chromospheric waves observed in the HeI spectral line (?= 10830 Å): A closer look, *ApJ*, **610**, 572-587

Gilman, P. 2004: Limits to penetration of meridional circulation below the solar convection zone, *ApJ Letters*, , Accepted

J

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Jackson, S., K. MacGregor, A. Skumanich 2004: Models for the rapidly rotating Be star Achernar, *ApJ*, **606**, 1195-1199

Judge, P., Understanding the time-dependence of atomic level populations in evolving plasmas, Journal of Quantitative Spectroscopy and Radiative Transfer, Accepted

Judge, P., **M. Carlsson**, R.F. Stein* 2004: On the origin of the Basal emission from stellar atmospheres: Analysis of

solar C II lines, *ApJ*, **597(2)**, 1158-1177

Judge, P., A. Pietarila 2004: On the formation of Extreme-Ultraviolet helium lines in the sun: Analysis of SOHO data, *ApJ*, **606(2)**, 1258-1275

Judge, P., T. Rimmele*, C. U. Keller*, B. Lites, D. Elmore 2004: Evaluation of seeing-induced cross talk in tip-tilt-corrected solar polarimetry, *Applied Optics*, **43**, 3817-3828

Judge, P., M. Carlsson, **T. Ayres**, S. Saar* 2004: A comparison of the outer atmosphere of the flat activity star t Ceti (G8V) with the Sun (G2V) and a Cen A (G2 V), *ApJ*, **609(1)**, 392-406

K

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Kavanagh, A., **F. Honary**, **A. Senior**, **S. R. Marple**, E. Woodfield-Kavanaugh, I. McCrea*, **M. J. Kosch** 2004: The statistical dependence of auroral absorption on geomagnetic and solar wind parameters., *Annales Geophysicae*, **22(3)**, 877-887

Kavanagh, A., **A. Senior**, **S. R. Marple**, **F. Honary**, I. McCrea* 2004: On solar protons and polar cap absorption: constraints on an empirical relationship., *Annales Geophysicae*, **22(4)**, 1133-1147

Kazil, J., E. R. Lovejoy* 2004: Tropospheric ionization and aerosol production: A model study, *JGR - Atmospheres*, Accepted

Korth, H., M. Wiltberger, **B.J. Anderson**, **J.G. Lyon** 2004: Intercomparison of ionospheric electrodynamics from the Iridium® constellation with global MHD simulations, *JGR*, **109**, DOI: 10.1029/2004JA010428

Kosch, M.J., **M. T. Rietveld**, **A. Senior**, I. McCrea*, A. Kavanagh, I. Isham*, **F. Honary** 2004: Novel artificial optical annular structures in the high latitude ionosphere over EISCAT, *Geophysical Research Letters*, **31**, L12805, DOI:10.1029/2004GL019713

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Lisle, J.P., M. P. Rast, **J. Toomre** 2004: Persistent north-south alignment of the solar supergranulation, *ApJ*, **608(2)**, 1167-1174

Lites, B., H. Navarro 2004: Characterization of magnetic flux in the quiet Sun.II.The internetwork fields at high angular resolution, *ApJ*, **613(1)**, 600-609

Lites, B., G. B. Scharmer*, T. E. Berger*, **A. M. Title** 2004: Three-dimensional structure of the active region photosphere as revealed by high angular resolution, *Solar Physics*, **221**, 65-84

Liu, H., D.M. Riggin*, R. S. Lieberman*, **E. R. Talaat**, R. Roble 2004: 6.5 day wave and it's seasonal variability in the middle and upper atmosphere, *JGR - Atmospheres*, Accepted

Liu, H., **J. W. Meriwether** 2004: Analysis of a temperature inversion event in the lower mesosphere, *JGR*, **109(D2)**, DOI: 10.1029/2002JD003026

Liu, H., R. Roble, J. Mason 2004: Dynamical processes related to the atomic oxygen equinox transition, *Journal of Atmospheric Solar-Terrestrial Physics*, **66**, 769-779

Lopez, R.E., S. Hernandez, J. G. Lyon*, M. Wiltberger 2004: Solar wind density control of energy transfer to the magnetosphere, *Geophysical Research Letters*, **31**, L08804, DOI: 10.1029/2003GL018780

Low, B.C., M. Zhang 2004: Magnetostatic structures of the solar corona. III. Normal and inverse quiescent prominences, *ApJ*, **609(2)**, 1098-111

Low, B.C., M. Zhang 2004: Global magnetic-field reversal in the corona, *Geophysical Monograph*, **141**, 51-64

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Navarro, H., M. Sobotka*, M. Vazquez*, V. M. Pillet* 2004: The thermal and magnetic structure of umbral dots from the inversion of high-resolution full Stokes observations, *ApJ*, **614(1)**, 448-457

Navarro, H., J. T. Bueno*, **E. L. Degl'Innocenti** 2004: Signatures of incomplete Paschen-Back splitting in the polarization profiles of 10830, *ApJ*, Accepted

Navarro, H., Multi-Line Stokes analysis for the study of small-scale solar magnetic fields, *ApJ*, **613(1)**,610-614

Navarro, H., A simple procedure for optimizing the height resolution in spectral line inversions, *ApJ*, 614(1), 457-463

Navarro, H., H. Uitenbroek* 2004: On the diagnostic potential of H-alpha for chromospheric magnetism, *ApJ Letters*,**603(2)**, L129–L132

Navarro, H., V. M. Pillet*, B. Lites 2004: Magnetic properties of the solar internetwork, *ApJ*, **611(2)**, 1139-1148

Norton, A., P. Gilman 2004: Magnetic field - minimum intensity correlation in sunspots: A tool for solar dynamo diagnostics, *ApJ*, **603**, 348-354

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Oberheide, J., M. Hagan, R. Roble, **Gusev** 2004: A global view of tidal temperature perturbations above the mesopause; Preliminary model K observation intercomparison, *Advanced Space Research*, **644**, 857-862

P

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Pietarila, A., P. Judge 2004: On the formation of the resonance lines of Helium in the Sun, *ApJ*, **606(2)**, 1239-1257

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Ramos, A.*, J. T. Bueno*, M. Bianda*, R. M. Sainz, H. Uitenbroek* 2004: Observational confirmation of molecular Zeeman effect in the G band via sunspot spectropolarimetry, *ApJ Letters*, **611**, L61-L64

Rast, M.P., The scales of granulation, mesogranulation, and supergranulation, *ApJ*, **597(2)**, 1200-1210

Rast, M.P., **J. Lisle**, **J. Toomre** 2004: The spectrum of the solar supergranulation: multiple nonwave components, *ApJ*, **608(2)**, 1156-1166

Rempel, M., Overshoot at the base of the solar convection zone - a semi-analytical approach, *ApJ*, **607(2)**, 1046-1064

S

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Sainz, R.M., **E. L. Degl'Innocenti**, J.T. Bueno* 2004: Concerning the existence of a turbulent magnetic field in the quiet Sun, *ApJ Letters*, Accepted

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Wiltberger, M., C. C. Goodrich*, J. G. Lyon* 2004: Results from the Lyon-Fedder-Mobarry global magnetospheric model for the electrojet challenge., *Journal of Atmospheric Solar-Terrestrial Physics*, **65(11)**, 1213-1222

Z

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Zhang, M., B. C. Low 2004: Magnetic energy storage in the two hydromagnetic types of solar prominences, *ApJ*, **600(2)**, 1043-1051

Zhang, M., **L. Golub** 2004: The dynamical morphologies of flares associated with the two types of solar coronal mass ejections, *ApJ*, **595(2)**, 1251-1258

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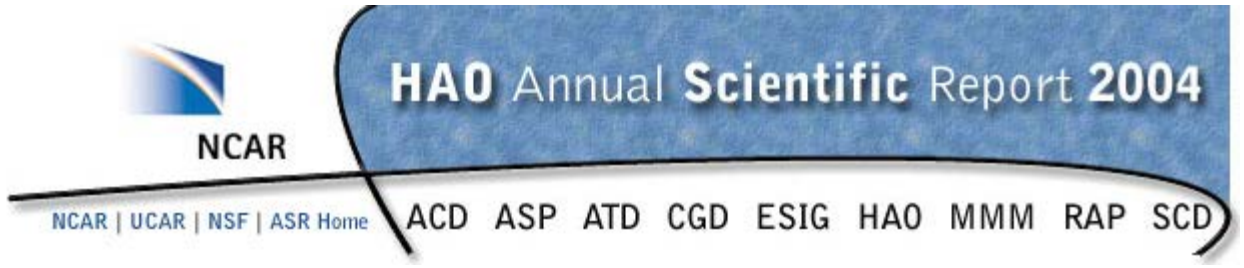

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The People of HAO

Staff | Visitors | Collaborators

STAFF

MICHAEL KNÖLKER - Director
KEITH MACGREGOR - Deputy Director
KATY CONROY - Assistant

TIM BROWN - Associate Director for Instrumentation
HANNE MAURIELLO - Division Administrator
LIZ HOSWELL - Budget/Finance Administrator
ELIZABETH CHAPIN - Visitor Program/Admin

TSO

M.Hagan
L.Beierle
A.Knack - AGU Admin

R.Barnes
A.Burns
B.Emery
B.Foster
D.Gablehouse
C.Hack
R.Johnson
A.Kavanagh
E.Woodfield-Kavanagh
J.Kazil
T.Killeen
C.Lin
H.Liu
G.Lu
N.Maruyama
A.Maute
L.Qian
A.Richmond
R.Roble
A.Semenov
S.Solomon
W.Wang
M.Wiltberger
Q.Wu
W.Xu

SAH

B.C.Low
G.Starr

T.Bogdan
J.Burkepile
R.Casini
T.Darnell
G.deToma
S.Gibson
H.Gilbert
T.Holzer
A.Hundhausen
P.Judge
B.Lites
R.MacQueen
A.Pietarila
P.Seagraves
H.Socas-Navarro
A.Skumanich
A.Stanger
S.Tomczyk

SIVS

P.Gilman
B.Abdallah

T.Brown
M.Dikpati
Y.Fan
T.Fielder
P. Fox
J.Garcia
D.Kolinski
K.MacGregor
E.McDonald
R.Meisner
M.Miesch
A.Norton
G.Petrie
M.Rast
M.Rempel
J.Wang
S.Wasinger
P.West
O.White

IG

K.Streander
B.Abdallah

G.Card
C.Chambellan
D.Elmore
D.Koon
T.Leach
A.Lecinski
R.Lull
A.Stueben
E.Yasukawa

CS

B.Gamblin
B.Pfau
E.Chapin

E.Gilbert
V.Tisone

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Visitors

Post Doctoral Fellows | Long Term Visitors | Affiliate Scientists | Graduate Students | Short Term Visitors | Summer Undergraduate Visitors | Student Assistants (non-science)

Post Doctoral Fellows

Andrew Kavanagh
Lancaster University, United Kingdom
observations of energetic precipitation from imagers

Emma Woodfield- Kavanagh
Lancaster University, United Kingdom
Magnetosphere-ionosphere coupling

11/18/02-11/17/04

Jan Kazil
University of Bern, Switzerland
ionosphere
11/1/02-10/31/03

Naomi Maryuama
Tohoku University, Japan
space weather modeling
6/2/2003-6/01/05

Matthias Rempel
Max-Planck-Institut Für Aeronomie, Germany
Magneto hydrodynamics
10/1/03-1/1/04

1/18/02-11/17/04

Gordon Petrie
University of Athens, Greece
Modeling of coronal magnetic structures
10/27/03-10/12/04

Joanne Mason
University of Leeds, United Kingdom
Solar Dynamo
3/26/04-3/25/06

David Salabert
University of Nice, France
Helioseismology
4/1/04-3/31/06

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Long Term Visitors

Graham Barnes
Colorado Research Associates, Boulder, CO
Emergence of twisted magnetic flux into the solar corona
12/16/02-12/15/03

Jadwiga Beres
University of Washington at Seattle, Seattle, WA
WACCM
10/1/02-4/7/03

Bob MacQueen
Unaffiliated, Boulder, CO
Acceleration of coronal mass ejections
3/3/03-3/2/04

George Millward
Imperial College, London

Dusan Ostrcil
NOAA, Boulder, CO
CISM
1/22/04-1/21/05

Leslie Mayer
NOAA, Boulder, CO
CISM
1/22/04-1/21/05

Egil Leer
University of Oslo, Norway
Fluid Description of Ionized Gas
06/15/04-12/15/04

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Affiliate Scientists

Dr. Stephen Bougher
University of Michigan
3/1/03-2/28/06

Dr. Paul Cally
Monash University, Australia
4/1/98-4/30/04

Dr. Martin Mlynczak
NASA/Ames, Virginia
3/1/00-2/28/06

Dr. David Rees
CSIRO Telecommunications and Industrial Physics
3/1/03-2/28/06

Dr. Jørgen Christensen-Dalsgaard
University of Aarhus, Denmark
5/1/98-3/31/04

Prof. Egil Leer
Institute for Theoretical Astrophysics, Norway
4/1/98-4/30/04

Dr. Haosheng Lin
Institute for Astronomy, Hawaii
3/1/03-2/28/06

Prof. Michael Thompson
The Blackett Laboratory, U.K.
3/1/03-2/28/06

Dr. Mei Zhang
Chinese Academy of Sciences
03/01/04-02/28/07

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Graduate Students

David Foster
University of Colorado, Boulder
Understanding Coronal Cavities and other reliable precursors of CMEs
11/1/02-10/31/02

Charles Lin
National Central University, Taiwan
Thermosphere Ionosphere Electrodynamic General Circulation Model (TIEGCM)
9/27/01-9/26/03

Anna Pietarila
University of Oslo, Norway
He I A line in the solar spectrum
11/11/02-11/10/03

Alexey Semenov
St. Petersburg State University, Russia
Global Mean Temperature Profile in the Planetary Atmosphere
10/21/02-10/20/03

Serena Criscouli
University of Rome, Italy
Photometrical Properties of Photospheric Magnetic Structures
3/8/04-3/7/05

Orlagh Creevey
University of La Laguna, Spain
Asteroseismology
1/5/04-1/4/05

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Short Term Visitors

Cassandra Fesen
Dartmouth College, Hanover, New Hampshire
thermosphere ionosphere electrodynamic circulation model (TIEGCM)
11/10/03-11/21/03

Ase Marit Janse
University of Oslo, Norway
A new set of transport equations for ionized gas
10/22/03-11/06/03

Young-Sil Kwak
Kyungpook National University, Korea

Chris Dove
Evergreen State University, Seattle, Washington
wave propagation
07/02/04-07/30/04

E.J. Zita
Evergreen State University, Seattle, Washington
wave propagation
07/02/04-07/30/04

Øystein Lie-Svendsen
University of Oslo, Norway
minor ion composition and outflow from the sun

thermosphere ionosphere electrodynamic circulation model (TIEGCM)
12/8/03-2/25/04 and 6/15/04-8/26/04

Dirk Lummerzheim
University of Alaska, Fairbanks
auroral proton precipitation
10/13/03-10/17/03

Lars Heggland
University of Oslo, Norway
wave propagation in magnetized atmospheres
10/13/03-10/26/03

Øystein Lie-Svendsen
Norwegian Defense Research Establishment, Norway
minor ion composition and outflow from the sun
10/17/03-11/08/03

Mari Anne Killie
University of Oslo, Norway
a new set of transport equations for ionized gas
10/22/03-11/06/03

Robert Greenkorn
Purdue University, West Lafayette, Indiana
precision solar photmetric telescope (PSPT)
11/16/03-11/22/03

Travis Metclafe
Center for Astrophysics Harvard/Smithsonian, Boston, MA
computational asteroseismology
11/18/2003-11/20/03

David Mozzoni
Florida State University, Tallahassee
TIE-GCM
12/1/03-6/30/04

Richard Collins
University of Alaska, Fairbanks
CEDAR/TIME-GCM/GSWM
1/20/04-5/20/04

Roi Alonso Sobrino
IAC Tenerife, Spain
STARE Planet Finding
1/12/04-2/3/04

Thomas Rimmele
NSO Sunspot, NM
ATST site survey instrument calibration
1/5/04-1/9/04

Mark Komsa
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ATST site survey instrument calibration
1/5/04-1/9/04

Peter Wilson
University of Sydney, Australia
solar polar fields
2/17/04-2/20/04

8/11/04-12/18/04

Satonori Nozawa
Nagoya University, Taiwan
TIME-GCM
07/02/04-07/20/04

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Theorectical Astrophysics Center and Astronomical Observatory, Denmark
high resolution imaging as a constraint for numerical models of strong-field magnetoconvection
07/19/04-07/23/04

Eirik Endeve
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multi-fluid models of the solar corona to describe coronal Helium abundances
07/07/04-07/27/04

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Sunrise
08/02/04-08/20/04

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LOWL/ECHO data
08/02/04-08/13/04

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University of Wuppertal, Germany
TIMED
08/13/04-9/05/04

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simulation of waves in middle atmosphere
09/20/04-11/20/04

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CISM
08/04/04-08/25/04

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National Central University, Taiwan
empirical electric field modeling based upon ROCSAT-1
09/08/04-09/10/04

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computational MHD modeling of the solar corona
09/20/04-09/24/04

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CISM
09/18/04-10/13/04

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plasmaspheric modeling

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photospheric MHD
12/3/03-12/19/03

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TIME-GCM
1/26/04-2/3/04

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1/26/04-2/3/04

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upper atmosphere
1/6/04-1/9/04

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3D dynamo project
3/1/04-3/6/04

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analysis of HE1 10830 spectro-polarimetric observations in active regions
3/1/04-3/26/04

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macroscopic description of plasmas
3/25/04-4/15/04

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University of St. Petersburg, Russia
TIME-GCM and WACCM
3/21/04-5/20/04

Minna Palmroth
Finnish Meteorological Institute, Finland
GUMICS and LFM - idealized solar wind conditions
4/18/04-7/3/04

Monica Rodriguez Guillen
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3D modelling of photoionization in the interestellar medium (ISM)
04/04/04-04/25/04

Alexandros Alexis
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Bounds on Space Averaged Quantities in Turbulent MHD Flows
04/12/04-04/14/04

Jiannan Tu
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simulating high latitude ion outflow using a coupled CMIT
09/13/04-09/15/04

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comparing solar wind model results to transition region
09/06/04-09/24/04

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09/23/04-09/24/04

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solar dynamo
07/02/04-07/30/04

LIDAR Retreat
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Empirical Model of High-Latitude Magnetosphere-Ionosphere Energy Transfer based on Satellite Data
05/24/04-08/24/04

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Timothy Guild, Magnetospheric model
George Siscoe, Space weather modeling
Harlan Spence, Magnetic model validation

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Steve Walton, Precision Solar Photometric Telescope and Solar Variability

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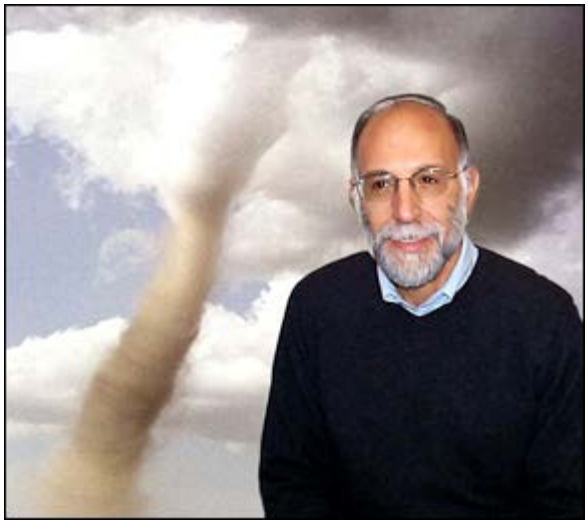
MMM Director's Message



Rich Rotunno, MMM Interim Director

This past year has been one of scientific achievement and management change for the Mesoscale and Microscale Meteorology (MMM) Division. As an extension to my responsibilities as Assistant Director, I assumed leadership of the division as Interim Director following Bob Gall's appointment to Director of the Development Testbed Center (DTC). I am pleased to share with you the scientific accomplishments achieved throughout the division during FY2004. Selective highlights are summarized in the Executive Summary of this report, and further accomplishments are detailed under MMM Achievements.

The mission of MMM is to advance understanding of the mesoscale and microscale aspects of weather and climate, and to apply this knowledge to benefit society. Our research is organized within two principle thematic programs. The first, Prediction of Precipitating Weather Systems (PPWS), is focused on reducing forecast errors toward predictability limits. The second, Cloud and Surface Processes and Parameterizations (CaSPP), is focused on quantifying the collective effects of small-scale processes.

Our research integrates modeling, observations, and theoretical understanding. By focusing our efforts and establishing effective collaborations with universities and other research agencies, we have successfully accelerated progress towards achieving the goals of the MMM Science Plan, which directly supports the NCAR Strategic Plan. For example, the Weather Research and Forecasting (WRF) model is a highly successful collaborative endeavor that benefits not only the research community but also the operational community. MMM contributions to the Data Assimilation and Water Cycle Across Scales Initiatives are other examples where collaboration and focused effort are integral to success.

As will be evident as you read through our ASR report, MMM fosters both external and internal collaborations. In addition, this past year MMM recruited three new Scientist Is, two of which hold joint appointments. Arlene Laing holds a joint appointment with COMET while Paul Field holds a joint appointment with RAP. George Bryan, currently an ASP post doc, will join MMM's scientific ranks in January 2005. These three early career scientists add scientific talent and acumen to our research program and will strengthen our program in the areas of warm season climatology of precipitating systems, quantitative precipitation forecasts, ice-related

microphysical processes in clouds, and model simulations of moist convective processes.

MMM continued its strong commitment to community service and educational activities throughout FY2005. For example, division staff participated in a number of field campaigns that covered a broad spectrum of science. MMM scientists, in collaboration with Woods Hole and Penn State, conducted the Ocean Horizontal Array Turbulence Study (OHATS) in Martha's Vineyard in an effort to investigate wind-wave interactions and improve our ability to assess the impacts on weather forecasts and climate variability. MMM researchers also played a major role in the North American Monsoon Experiment (NAME), an internationally coordinated, joint CLIVAR-GEWEX study aimed at determining the sources and limits of predictability of warm season precipitation.

MMM, as part of a national center, fosters collaborations with national and international universities and other research institutions as a means of advancing the understanding of weather and climate for the benefit of society. In FY2004, MMM hosted 463 visitors, representing 72 different universities and 27 foreign countries. These and other statistics in this report are evidence of the broad contributions that divisional staff makes to the atmospheric community.

Looking forward, the new year will bring more change and opportunity. NCAR will reorganize to be more responsive to the changing world of atmospheric sciences. MMM will move forward within the reorganization under the leadership of a new director, Greg Holland. The integration of the science divisions within the Earth and Sun Systems Laboratory (ESSL) will provide new opportunities for multidisciplinary interactions and successful implementation of our strategic plan. I invite you to peruse our FY2004 Annual Scientific Report and encourage you to return next year for more exciting accomplishments.

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MMM Executive Summary

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Overview

The mission of the Mesoscale and Microscale Meteorology (MMM) Division is to advance the understanding of the mesoscale and microscale aspects of weather and climate and to apply this knowledge to benefit society. MMM establishes its priorities through an evaluation of its program against the priorities of its five-year Science Plan (http://www.mmm.ucar.edu/products/stratplan.html) and the NCAR Strategic Plan (http://www.ncar.ucar.edu/stratplan/plan.pdf), as well as against those of national and international research programs such as the USWRP and the USGCRP.

Approximately half of the MMM science program is USWRP-related and is focused on the goal of improving the ability to forecast weather events. This part of the program is organized under the theme Prediction of Precipitating Weather Systems (PPWS). The other half is focused on problems related to understanding the physics of mesoscale and microscale processes, the way these processes interact with larger scales, and how the processes can be represented in models where they are not resolved. This part of the MMM program is organized under the theme Cloud and Surface Processes and Parameterizations (CaSPP).

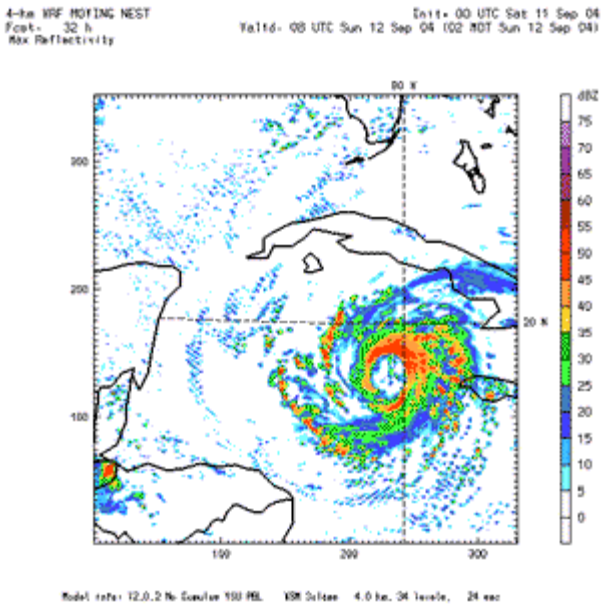
Research

Prediction of Precipitating Weather Systems (top)

The main goal of the PPWS, one of the division's two overarching scientific themes, is to advance the understanding and prediction of significant precipitation events in order to substantially reduce forecast errors toward the limits of predictability. Within the PPWS theme there are four separate programs as described below.

Weather Research and Forecasting Model

The goal of this program is to develop an advanced mesoscale forecast and assimilation system, and to accelerate research advances into operations. The WRF model is being developed as a collaborative effort with NOAA/NCEP, NOAA/FSL, AFWA, NRL, CAP at U of OK, and the FAA. The work carried out in FY2004 included further collaborations with the UK Met Office, U of Munich (Germany), Yonsei U (Seoul,



Click image for a larger animation.

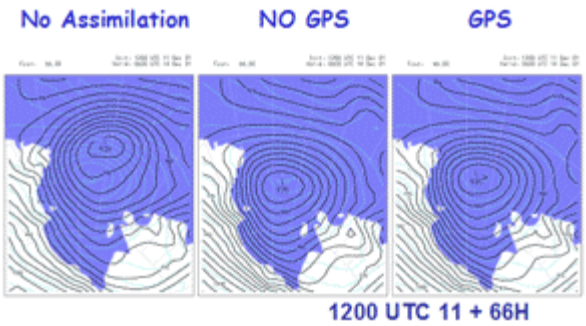
WRF researchers implemented moving two-way interacting nests in WRF and demonstrated the capability with a Hurricane Ivan case from 11-13 September, 2004. The animation above shows simulated radar reflectivity for Hurricane Ivan in output from a moving 4 km nest on 80 processors of the NCAR IBM bluesky computer.

Korea), U of CA at Davis, Hebrew U of Jerusalem (Israel), Pacific Northwest National Laboratory, Iowa State U, San Francisco State U, U of WA, and Ohio State U. Interdivisional collaborations included ASP, RAP and CGD.

Highlight:

Recent results show that WRF forecasts exhibit realistic structure and intensity from coarse initial data without bogusing; hurricane track forecasts have accuracy similar to or better than the current operational models; and, moving nested grids yield high-resolution forecasts with greatly enhanced efficiency (smaller fine-grid domains).

Mesoscale Data Assimilation



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The 66-h forecasts of mean sea level pressure initialized at 1200 UTC 11 and valid at 0600 UTC 14 December 2001. Dashed contours represent mean seal level pressure from ECMWF analysis and solid lines represent the forecast from a) the cold start run initialized with NCEP/AVN analysis, b) No GPS experiment, and c) GPS experiment.

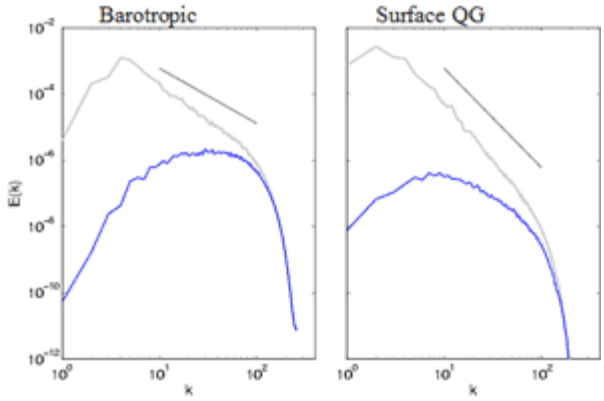
The goal of this program is to determine optimal use of mesoscale observations for accurate precipitation forecasts. The WRF data assimilation research has many applications within NCAR and has been advanced through collaborations with the Danish Meteorological Institute, the Taiwan Civil Aeronautics Administration and Central Weather Bureau, the India National Center for Medium-Range Weather Forecasts, Seoul National U, the Shanghai Meteorological Bureau, Ohio State U, A.M. Boukhov Institute of Atmospheric Physics (Moscow), Texas A&M, CIMMs/U of OK, NOAA/NSSL, U of WA, and U of CO. Cross divisional collaboration included CGD, ESIG, RAP, and COSMIC.

Highlight:

Recent highlights were the assimilation of GPS RO data from CHAMP and SAC-C mission for a case of intense cyclone over the Ross Sea; and, the assimilation of ~50 GPS RO soundings over a two-day period with MM5 4DVAR which produced significant impact on the prediction of the cyclone.

Prediction and Predictability

The goal of this program is to estimate the duration of useful skill in mesoscale precipitation forecasts and



Click image for a larger version.

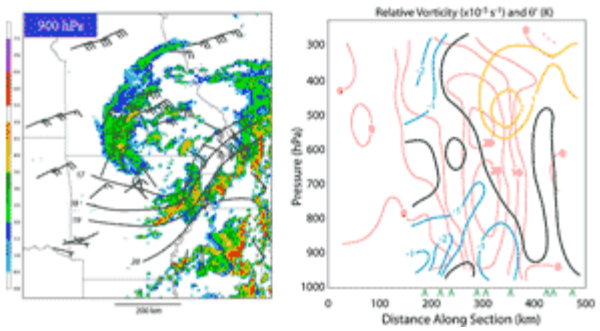
In the case of flows with many scales, small-scale errors may grow rapidly and contaminate larger scales in finite time.

identify key skill-limiting physical processes. Collaborations in support of this program involve researchers at Nanjing U (China), Texas A&M, and U of WA. These FY2004 activities included collaboration with TAMU, Nanjing U/China, NOAA, RAP, and ASP.

Highlight:

Recent progress has been made in understanding flows with many scales. In the case of flows with many scales, small-scale errors may grow rapidly and contaminate larger scales in finite time. Such systems may have intrinsic, finite limits of predictability (i.e., at some point, improved initial conditions provide little or no benefit to forecasts). Scaling suggests finite predictability when E(k) is less steep than k-3, and recent progress has confirmed relation of predictability to E(k) for 2D turbulence.

Life Cycles of Precipitating Weather Systems



Click image for a larger version.

BAMEX results point to the importance of MCVs for focusing heavy rainfall, and offer hope for improved 0-48-h prediction.

The goal of this program is to understand life cycles of precipitation events, and to assess implications for predictability, data-assimilation and model physics. Collaborations included U of NE (Lincoln), U of KS, CRN (Italy), NOAA/ETL, Yale, SUNY, U of S. Florida, and Simon Fraser U (Canada) as well as interdivisional collaboration with RAP and ASP.

Highlight:

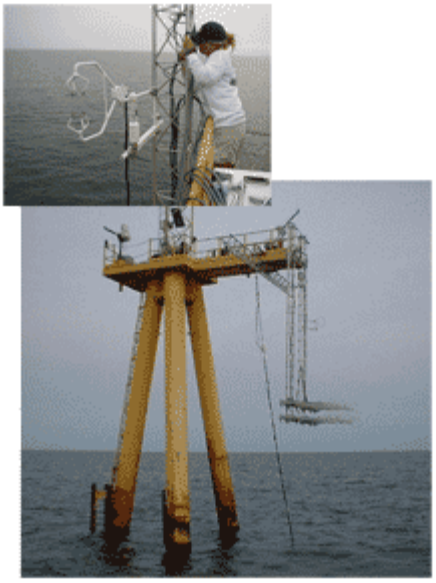
The main findings of recent research are that mini baroclinic waves grow from convection and have a strong effect on rainfall organization; surface penetration has implications for T.C.'s; and, varied environments exist, including strong shear.

Cloud and Surface Processes and Parameterizations (top)

The main goal of CaSPP, the second of MMM's two overarching scientific themes, is to quantify the large-scale effect of mesoscale and microscale processes and to develop physically based methods to account for these effects in large-scale models. Within the CaSPP theme are five separate programs as described below. A research highlight for each program of research is included.

Surface-Atmosphere Interactions

The goal of this program is to understand the influences of surface heterogeneity and surface-atmosphere interactions. Collaborations in support of this program include CU, USGS, U of MT, Penn State, Woods Hole, TAMU, CNdR/Italy, Trento U/Italy, U of IL, Iowa State, NASA, U of Miami, OSU, ACD, RAP, and ATD. Each year MMM scientists are involved in large-scale field campaigns



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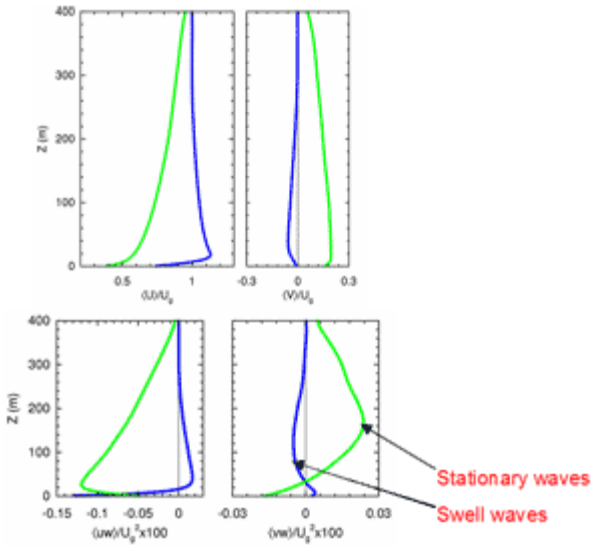
Sonic anemometers and laser altimeters have constructed subfilter-scale (LES) fluxes in the marine surface layer.

that further the program objectives. For example, in FY2004 scientists played a leading role in the Ocean Horizontal Array Turbulence Study (OHATS) that took place off the coast of Martha's Vineyard (www.mmm.ucar.edu/research/surface/hats.html#ohats).

Highlight:

Collaboration between NCAR, Woods Hole Oceanographic Institute and Penn. State University has led to the collection of 2000 hours of turbulence and wave data from 18 sonic anemometers and 3 laser altimeters and to the construction of subfilter-scale (LES) fluxes in the marine surface layer. The investigators examined the couplings between atmospheric turbulence and surface gravity waves, using the OHATS and HATS databases to build new subgrid scale parameterizations for LES (large-eddy simulations).

Planetary Boundary Layer



Click image for a larger version.

Sea state can modulate magnitude and orientation of mean wind and momentum flux, according to a recent joint research study between MMM, Woods Hole Oceanographic Inst. and the University of California.

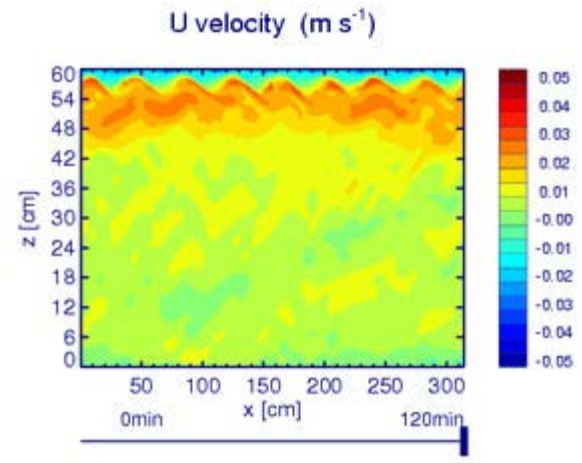
The goal of this program is to determine how boundary-layer clouds affect climate. Collaborations that furthered this program's goals include UCLA, Utrecht U/Netherlands, U of WY, U of OK, Drexel U, CU, LANL, USCA, Seoul U/Korea, ACD, ATD, ASP, and RAP.

Highlight:

A recent research highlight includes a joint study involving MMM, Woods Hole Oceanographic Institute and University of California, Los Angeles. Finding were that sea state can modulate magnitude and orientation of mean wind and momentum flux. LES results were obtained for a neutral PBL with swell (phase speed c = 12.5 m/s) moving parallel to geostrophic wind Ug = 5 m/s; the surface layer wind component normal to geostrophic wind is negative instead of positive; surface layer wind component along geostrophic wind has low-level jet at 20m height; and, weak shear results in loss of turbulence energy in the PBL.

Multiscale Convective Cloud Systems and Waves

The goal of this program is to determine cloud effects on atmospheric and ocean circulations. Numerous collaborations took place in FY2004 in support of this



Click image for a larger animation.

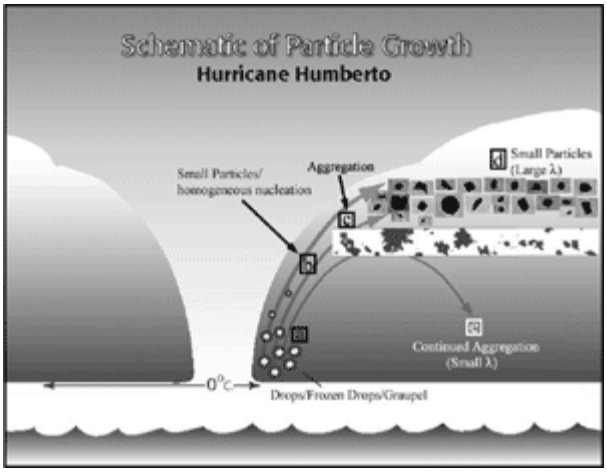
Direct numerical simulation of the laboratory analogue of QBO.

program including those with Iowa State U, ECMWF, LANL, Cranfield U in UK, Institute of Earth Envionment at Chinese Academy of Sciences, Osaka U (Japan), U of Florida, NCMRWF in New Delhi (India), NASA/Langley, UK Met Office, CSU, Nasa/Goddard, Japan Agency for Marine-Earth Science and Technology, Institute of Meteorology and Water Management (Poland), and interdivisionally with SCD, ASP, RAP, and CGD.

Highlight:

QBO, the dominant variability of the equatorial stratosphere, has so far eluded complete understanding. Plumb & McEwan's (1978) laboratory analogue demonstrated the basic mechanism of a mean-flow development, but its relevance to the atmospheric QBO has been criticized. Direct numerical simulation shows the lab experiment is relevant but needs reinterpretation in terms of wave-wave-mean flow interaction, critical layer formation and subsequent wave breaking.

Cloud-Microphysics and Small-Scale Processes



Click image for a larger version.

The schematic shows the current understanding of the process of ice formation at the microphysical level in clouds.

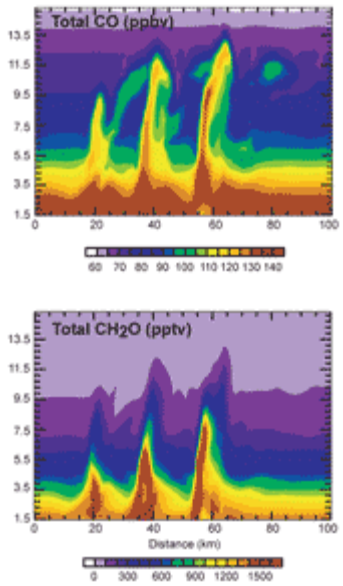
The goals of this research are to understand ice phase latent heating in hurricanes, to develop parameterizations of ice microphysics for use in hurricane weather forecast models, and to develop algorithms for deriving ice microphysical properties from multi-wavelength radars. Collaborations include the NOAA Hurricane Research Labs, University of Maryland, and NASA JPL.

Highlight:

During the past year, a group of cloud physicists met frequently to design a series of field programs, laboratory experiments and modeling activities to make progress in the area of ice initiation. An internationally-represented steering committee was formed, and the first "Ice Initiation Workshop" with 64 participants from 32 institutions and 5 countries was conducted over two days in June. An outline for an NSF Scientific Overview Document (SOD) was also developed.

Chemistry, Aerosols, and Dynamics Interactions Research

The goal of this program is to understand interactions between atmospheric dynamics, aerosols, and chemistry at meso- and cloud scales. Work in this program includes collaborations with NOAA FSL, MIT, Penn State, Seoul U/Korea, ACD, ASP, and CGD.



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Effect of boundary layer processes on chemical species distributions showed that cloud chemistry enhances the segregation of reacting species.

Highlight:

Recent studies on the effect of boundary layer processes on chemical species distributions showed cloud chemistry enhances the segregation of reacting species. These results were compared with Dutch LES (large-eddy simulations), and turbulent dispersion of scalars was examined. Another recent research study focused on the WRF-AqChem, a coupled meteorology and multi-phase chemistry model. This study led to the implementation of aqueous chemistry into the WRF model, and an intercomparison of convective cloud chemistry models.

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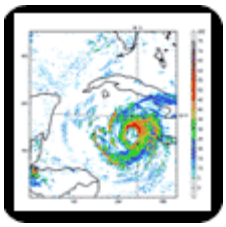
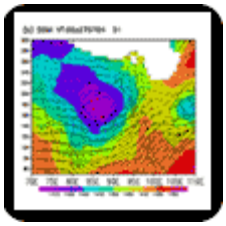
Research Areas in the Mesoscale & Microscale Meteorology Division

PPWS

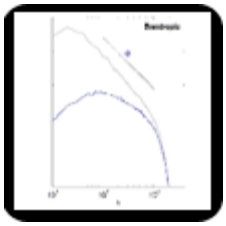
Prediction of Precipitating Weather Systems



WRF - Weather Research & Forecasting Model



Mesoscale Data Assimilation

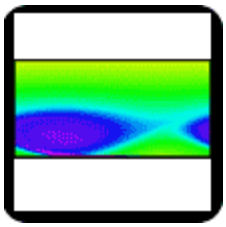


Prediction & Predictability

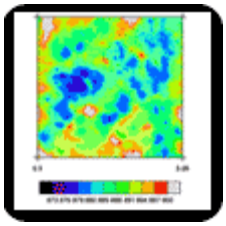
Life Cycles of Precipitating Weather Systems

CaSPP

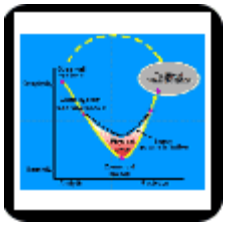
Cloud and Surface Processes & Parameterizations



Surace-Atmosphere Interactions

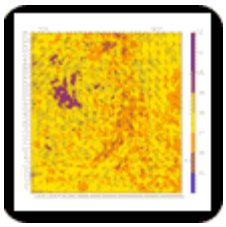


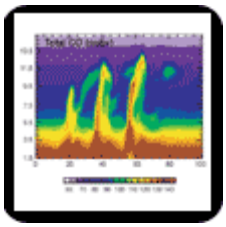
Planetary Boundary Layer



Multiscale Convective Cloud Systems and Waves

Cloud-Microphysics and Small-Scale Processes





Chemistry, Aerosols, and Dynamics Interactions

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WRF: Weather Research and Forecast Model Development

The overall goal of the WRF Model project is to develop a next-generation mesoscale forecast model and data assimilation system that will advance both the understanding and prediction of mesoscale weather, and will accelerate the transfer of research advances into operations. The model is being developed as a collaborative effort among the NCAR MMM Division, NOAA's National Centers for Environmental Prediction (NCEP) and Forecast System Laboratory (FSL), the Department of Defense's Air Force Weather Agency (AFWA) and Naval Research Laboratory (NRL), the Center for the Analysis and Prediction of Storms (CAPS) at the University of Oklahoma, and the Federal Aviation Administration (FAA), along with the participation of a number of university scientists. With this model, researchers seek to improve the forecast accuracy of significant weather features across scales ranging from cloud to synoptic, with priority emphasis on horizontal grids of 1–10 kilometers.

The WRF model is state-of-the-art, transportable, and efficient in a massively parallel computing environment. It is designed to be modular, and a single source code will be maintained that can be configured for both research and operations. It offers numerous physics options, thus tapping into the experience of the broad modeling community. Advanced data assimilation systems are being developed and tested in tandem with the model. WRF is maintained and supported as a community mesoscale model to facilitate wide use in research, particularly in the university community. Research advances will have a direct path to operations. With these hallmarks, the WRF model is unique in the history of numerical weather prediction in the U.S.

Significant development and testing for WRF continued during the past year, leading up to the release of the research-quality version (V2.0) in May. The basic 3DVAR package has been undergoing testing, and has been integrated with the model into the V2.0 release to insure compatibility in code supported for community use. The first operational implementation of WRF began at NCEP in September, running an ensemble configuration in their six High Resolution Domains. The following sections highlight the recent progress in the various areas of WRF development.

WRF Model numerics and dynamic cores

The WRF model framework presently hosts two dynamical cores: a split-explicit Eulerian model, based on mass vertical coordinate, called the Advanced Research WRF (ARW) core that was developed at NCAR, and the NMM (Nonhydrostatic Mesoscale Model) model, developed by Zavisa Janjic (NOAA/NCEP) from the operational hydrostatic ETA model. Additionally, a semi-implicit semi-Lagrangian

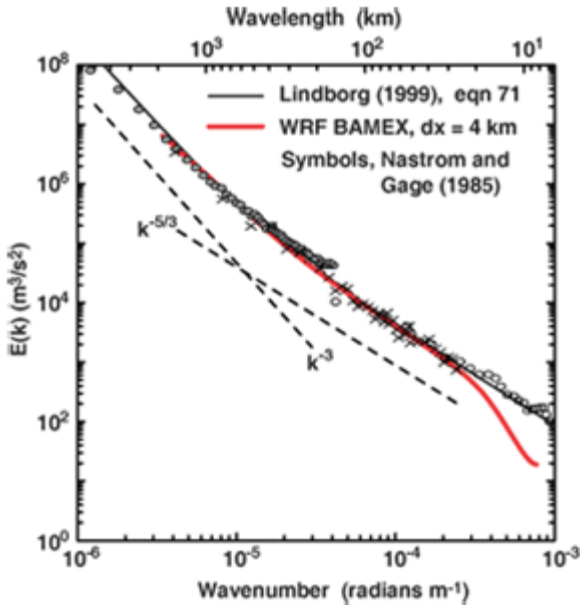

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Figure 1. *Comparison of simulated and observed temperature and precipitation for 1990/10 – 1991/3.*

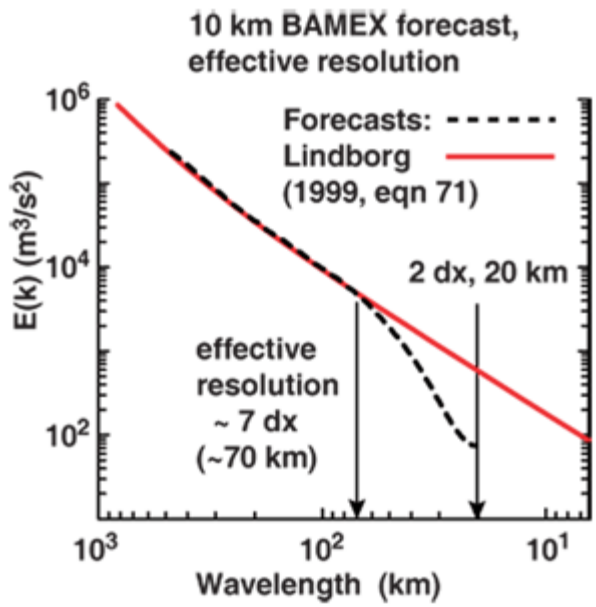

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Figure 2. *Text*

prototype is being developed in an effort led by Jim Purser (NOAA/National Centers for Environmental Prediction). The WRF framework is being used to comparatively evaluate the relative accuracy and efficiency of their numerical techniques used in the cores, in a controlled computational environment, in retrospective forecasts by the DTC, in convective resolving forecasts in the 2004 warm season, and in ongoing idealized testing.

William Skamarock has characterized the resolution capabilities of the ARW core using kinetic energy spectra computed from the 2003 BAMEX real-time forecasts run at both 10 and 4 km horizontal resolution. **Figure 1** shows spectra computed from observations and from ARW model forecasts for the full forecast period during the BAMEX field program (5 May 2003 through 14 July 2003).

The ARW model reproduces the observed spectra very well, and spectra also show that the dissipation (damping) mechanisms in the model start becoming noticeable at around 6-8 dx as indicated in Figure (Skamarock_figure_2.ai). Examination of Spectra from other models, including the NCEP NMM, MM5, and COAMPS, indicates that the ARW model has significantly greater resolution capabilities than the other models based on their current configurations. Additionally, the differences in the spectra from the models can be traced to differences in the dissipation mechanisms used in the models.

In a complementary analysis, W. Skamarock has also computed structure functions from the WRF forecasts. The flatness factor for the WRF BAMEX forecasts is shown in **Figure 2**. It indicates that the strong intermittency observed in the mesoscale and cloudscale is reproduced in the WRF model forecasts, lending further evidence to the correctness of the WRF spectra at convective-resolving scales. In an effort related to WRF model dynamics and core development, W. Skamarock, Jim Doyle (ONR/NRL) and Peter Clark (UK Met Office), have begun developing a standard test set for nonhydrostatic dynamical cores of NWP models. Historically, a number of tests cases have been used to examine the efficiency and accuracy of discrete solvers for the

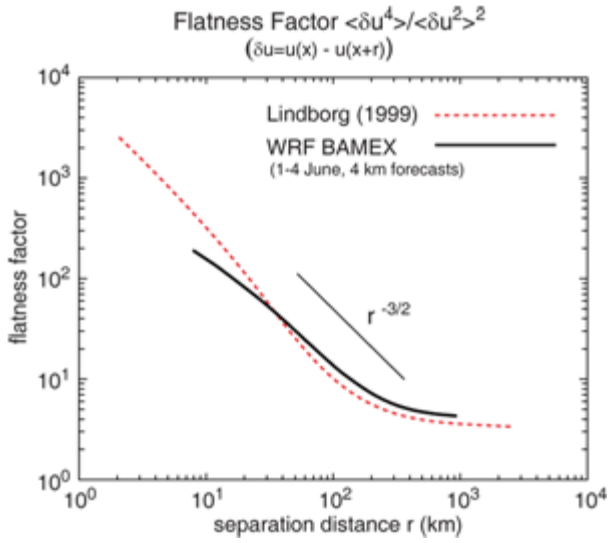

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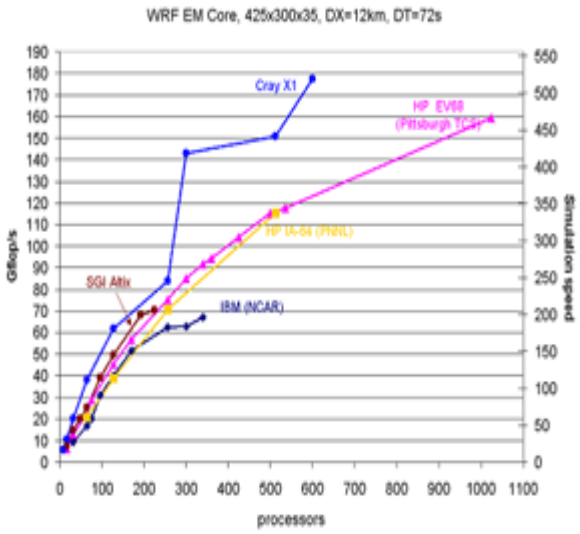
Figure 3. *Text*

nonhydrostatic Navier Stokes equations used in high-resolution NWP models. These test cases, including 2D and 3D mountain waves, gravity currents, thermals, and moist convection, are generally not well documented in the literature. W. Skamarock and his collaborators have put together a set of test cases that probe the robustness of the solvers with respect to nonhydrostatic motions. The need for a nonhydrostatic model test suite, and an initial set of test cases, was endorsed by over 80 scientists, representing both operations and research, at the Short Range Numerical Weather Prediction (SRNWP) workshop in Bad Orb, Germany in October 2003. The initial test suite is briefly described on the web at http://www.mmm.ucar.edu/individual/skamarock/test_cases/test_cases.html

Guenther Zaengl (University of Munich, Germany) visited in Spring 2004, and collaborated with Jimy Dudhia on WRF diffusion, damping, and a new vertical coordinate. G. Zaengl's diffusion changes are potential improvements for WRF applications in complex terrain, while the change to the upper damping layer will soon be added to WRF to allow its use with real-data simulations. G. Zaengl also provided a new vertical coordinate code for WRF that improves structures over mountains by having coordinate surfaces that have terrain slope effects confined to lower levels of the model atmosphere. In collaboration with J. Dudhia and Joseph Klemp, he has continued to further adapt this to a generalized time-dependent coordinate.

WRF computational framework

WRF in High-performance Computing



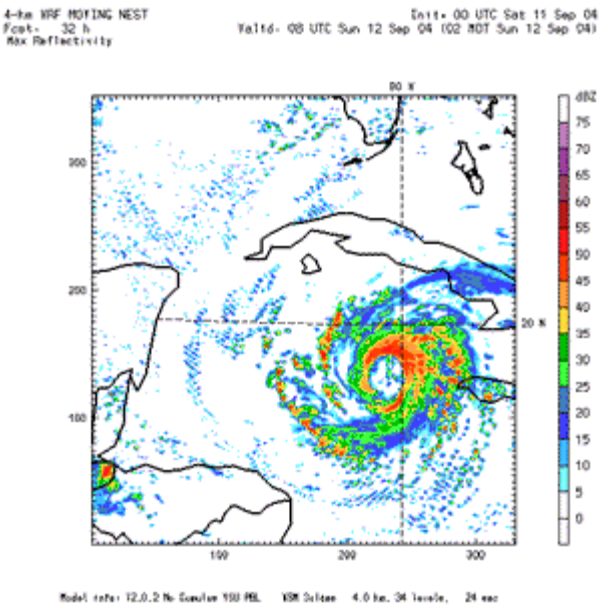
A major element of the WRF software design is to provide good performance over a wide range of computing platforms. Through efforts led by John Michalakes, WRF is now ported to and running routinely on many of the fastest high performance computers in the world, as listed by the Top 500 Super Computing Sites organization (as of June 2004, see www.top500.org), including systems at NCAR, NOAA/NCEP and FSL, the Pittsburgh Supercomputing Center, Pacific Northwest National Laboratory, NCSA (University of Illinois), and the Navy Oceanographic Office. Through the efforts of Tom Henderson, working with the vendor, WRF has also been ported to the Cray X-1, the first scalable-parallel vector computing system. Recent WRF performance benchmarks in terms of sustained performance demonstrate good scaling across a

Click image for larger version.

Figure 4. *Text*

large number of processors, as shown in **Figure 4**, below. In addition to parallelization of the WRF model, many of the WRF pre-processing and off-line nesting utilities have been parallelized by David Gill, avoiding bottlenecks for running large to very-large domains with the WRF system.

Grid Nesting Schemes



Click image to view a larger animation.

Figure 5. *Text*

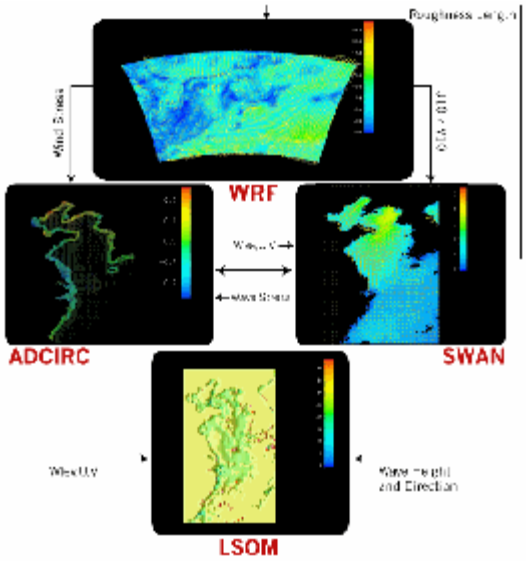
The capabilities of the horizontal mesh refinement infrastructure have been expanded this year by J. Michalakes and D. Gill, with extensive testing conducted by J. Dudhia, W. Wang, and James Bresch during the 2004 hurricane season. The WRF model now performs both two-way (lateral forcing of the fine grid by the coarse grid, and feedback of the fine grid to the coarse domain) and one-way (no feedback from the fine grid to the coarse grid) horizontal grid nesting. Grid nesting was part of the research release of the WRF model (V2.0) made available to the user community last spring. The one-way nesting forecasts may be handled inside WRF as a single forecast where feedback is disabled, or through multiple sequential WRF forecasts (the technique that is preferable for real-time runs and used by operational centers). The two-way nesting options allow the model to generate an initial condition for the fine grid, or to alternatively ingest a fine grid domain's higher resolution orographic information. Both the one-way and two-way nesting options permit any integer ratio for the mesh refinement, as illustrated in the animation [nesting_compare.avi] showing fine-grid nesting ratios of 2, 3, 4, and 5. All portions of the WRF nesting code were developed from the ground up to be parallel, scalable, and low overhead. Preliminary tests show that the computational overhead for two-way nesting is around 8%, well below the original target of no more than 15% additional overhead for nesting.

J. Michalakes has implemented moving two-way interacting nests in WRF and demonstrated the capability with a Hurricane Ivan case from 11-13 September, 2004. The animation in **Figure 5** shows simulated radar reflectivity for Hurricane Ivan in output from a moving 4 km nest on 80 processors of the NCAR IBM bluesky computer.

Without moving nests a researcher must create a nested domain large enough to contain the hurricane as it moves for the duration of the simulation. A smaller nest that can move with the storm requires only a fraction of the grid points of a non-moving domain, providing proportional savings in computational cost. The additional overhead for moving the nest within a running simulation is under 2 percent of total run time.

WRF as a component in coupled modeling systems

As part of a project funded by the U.S. Department of Defense Program Environment and Training (PET) program, J. Michalakes used WRF to demonstrate a flexible, efficient software infrastructure for operational forecasting of regional environments. The WRF I/O



Click image for a larger animation.

Figure 6. *Text*

API was extended with the Model Coupling Environment Library (MCEL) developed by Matthew Bettencourt of Air Force Research Laboratory to handle coupled interactions between four environmental models into a coupled system for operational theater scale forecasting. The WRF atmospheric model, the ADCIRC ocean circulation model, the SWAN wave model, and the LSOM sediment optics model have been coupled together using the MCEL implementation of the WRF I/O and Model Coupling API to simulate a 24 hour forecast over the Yellow Sea. **Figure 6** shows the coupling of the models, with output from the 24-hour forecast for November 25, 1999, the date of a high-wind induced ferryboat accident in that domain (note this image is clickable and viewable as an animation on-line).

WRF Model physics

The release of Version 2 of WRF in May 2004 included many new physics packages that were the culmination of several collaborative projects in recent years:

- Fei Chen and Mukul Tewari (both RAP) worked with J. Dudhia on putting the unified Noah land-surface model into WRF V2. They also added some improvements to the urban representation and the emissivity treatment of the LSM this year.
- Tanya Smirnova (NOAA/FSL) collaborated with W. Wang on adding the RUC LSM to WRF Version 2. This land-surface model is the one used operationally by FSL in the Rapid Update Cycle (RUC) model.
- Georg Grell and Deszo Devenyi (both NOAA/FSL) provided their new Grell-Devenyi ensemble cumulus parameterization scheme, which was implemented by W. Wang and J. Dudhia into WRF. It is also part of the new RUC physics.
- Song-You Hong and Jeong-Ock Lim (both Yonsei University, Seoul, Korea) worked on updated versions of the old NCEP 3-class and 5-class microphysics, and also provided a new 6-class scheme, including graupel. These new schemes known as WSM3, WSM5 and WSM6 are now part of WRF Version 2, and represent a collaborative effort with J. Dudhia and Shuhua Chen (U California, Davis).
- S.-Y. Hong and J. Dudhia also finalized the Yonsei University planetary boundary layer scheme (YSU PBL), and added it to Version 2. This is an updated form of the MRF PBL that takes a new approach in representing the PBL top entrainment layer explicitly, and has been used as the preferred choice in WRF forecasts this year including hurricane and the 4 km central US forecasts.
- Barry Lynn and Alex Khain (both Hebrew University of Jerusalem, Israel) visited for a week in summer 2004, and initiated work with Jimy Dudhia on adding a spectral bin microphysics parameterization to WRF. This is suitable for the fine-scale modeling of cloud processes with grid sizes well below 1 km.

Tom Black (NOAA/NCEP/EMC) and J. Dudhia added NCEP's updated physics packages to Version 2. This brings into WRF the version of the physics used operationally by NCEP, where notable changes have been made since the previous set of schemes brought into WRF Version 1 a few years ago. The updated packages included the Mellor-Yamada-Janjic PBL, the Betts-Miller-Janjic cumulus parameterization, the Ferrier Eta microphysics, and the GFDL radiation scheme. These physics packages can also be run by NCEP with their NMM core, making possible direct comparisons and swapped physics tests between dynamical cores as was done for the Developmental Testbed Center's retrospective forecast project.

WRF idealized and case-study testing

George Bryan (MMM/ASP) and Jason Knievel (RAP) evaluated squall line structures produced by the WRF Model in an idealized framework. They extended the research of an earlier study to include the newly released ARW core, and they explored a wider range of shear environments. They found that a previously documented spurious updraft pattern does not occur in strong shear conditions, even when a low-diffusion setting is used in the model. Additionally, they demonstrated that squall lines in weak shear are much more sensitive to implicit model diffusion than are squall lines in strong shear. Based on this work, they summarized their recommendations to WRF Model users in a paper at the WRF Users Workshop.

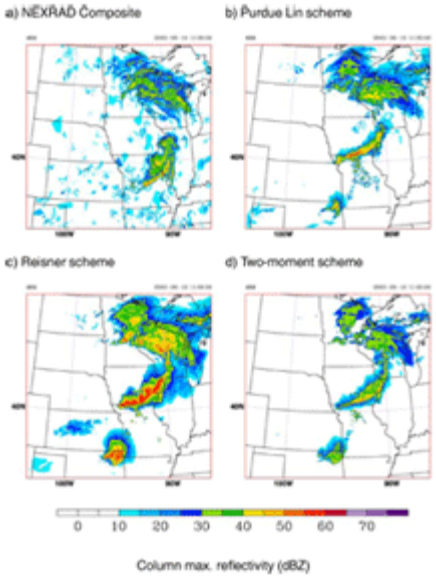


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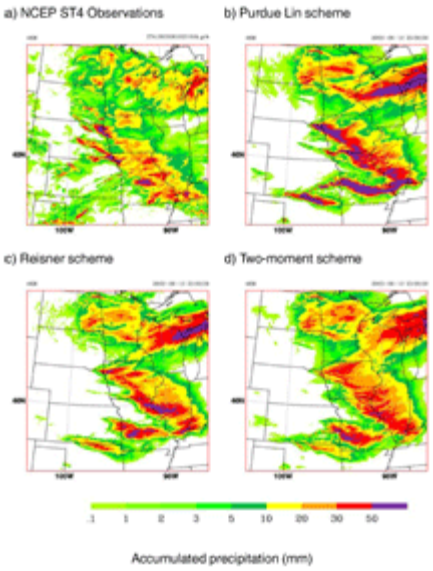
Figure 7. *Text*



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Axel Seifert (ASP), in collaboration with Morris Weisman, investigated the effects of cloud microphysics on WRF forecasts with explicit convection. Four cases from the BAMEX field phase were simulated with a four-km WRF using different microphysical schemes, including a sophisticated two-moment five-class scheme. All simulations revealed a very weak effect of the microphysical schemes on the mesoscale organization of the convection, for example in the June 10th case the formation and propagation speed of the squall line itself (**Figure 7**), although the schemes produce significantly different microscale cloud structures. The two-moment scheme is able to distinguish between the high reflectivity at the leading edge of the convection and a trailing stratiform region with lower reflectivity. The Lin scheme shows a lack of stratiform regions, while the Reisner scheme, which was mainly developed for stratiform clouds, overestimates the reflectivity in general. The surface precipitation (**Figure 8**) shows that the Lin scheme tends to overestimate the amount of precipitation in convective regions, while the other schemes give slightly better results. The two-moment scheme is available for the WRF community and, although it increases the WRF runtime by about 30%, may be attractive for research and special applications.

WRF experimental real-time forecasting

WRF real-time forecasts were continued this year in support of a variety of scientific goals. These interests include testing the robustness of the newly developed nesting capability, the convection-resolving forecasts over sub-continental US domain, and hurricane track and intensity forecasting.

In support of nesting development and WRF Version 2 release, a two-domain nested configuration at 36 and 12 km was set up in April to test and evaluate the new capability's correctness and robustness. Real-time runs and others since April have shown that the nesting is stable and robust.

Convective weather remains a significant challenge for

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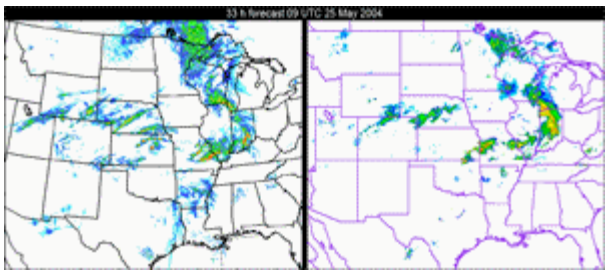
***Figure 9**. Text*



Click image to view a larger animation.

***Figure 10.** Text*

numerical weather prediction systems, and is recognized as a major contributor to poor warm season quantitative precipitation forecasting (QPF). Based on the preliminary findings of BAMEX real-time, 4 km simulations from 2003, a twice-as-large 4 km domain was configured by Wang and Weisman to continue the explicit convection forecasts for the spring and summer of 2004. The extended domain included more mountainous regions to the west, and it was designed to test model's ability to simulate diurnally varying convection. These 4 km forecasts were then compared to equivalent 10 km WRF forecasts as well as to other operational models, which all employed convective parameterization.

The animation illustrates the model forecast for convection beginning on 24 May 2004 in comparison to the observed radar reflectivity. These simulations show much promise for improving convective forecasting out to 36 h, especially with respect to forecasting convective system mode and propagation, but also highlight existing challenges, related especially to the systematic over prediction of rainfall. The early findings from these enlarged domain forecasts showed that the model has indeed improved in capturing the diurnal variability of the convection. The overall success of these forecasts was also largely due to the use of explicit convective resolution over a very large domain, thus avoiding issues of mismatched convective representations across domain boundaries (e.g., explicit versus parameterized). Further sensitivity testing of these cases to changes in microphysics, boundary layer physics, resolution, etc., is ongoing in an attempt to improve known problem areas. The apparent improvements in convective forecast guidance at 4 km resolutions were found to be extremely useful for operations planning during the recent BAMEX field program, and were also highly praised by NWS and SPC forecasters, who used the WRF output for their daily severe weather outlooks. During the spring and summer of 2003, 2004, approximately 150 36 h real-time forecasts were conducted with the NCAR version 1.3 and 2.0 of WRF-ARW.

To examine the ability of the updated WRF Version 2.0, which includes the nesting capability (released in May 2004), to predict the tracking and intensity of tropical cyclones, W. Wang, J. Bresch, and D. Gill conducted a series of real-time forecasts of hurricanes during the 2004 season, with the support of SCD. A number of powerful storms made landfall in the U.S. in September, and W. Wang, J. Bresch, and D. Gill ran WRF for hurricanes Charley, Frances, Ivan, and Jeanne. Nested WRF runs were performed with inner nests as fine as 4 km, within 12-km larger-area domains for 48-hour forecasts. A separate single domain, 12 km configuration was also run for 5-day track forecasts. While the high-resolution runs were designed to test the model's ability to simulate the realism of the storm intensity and structure, the low-

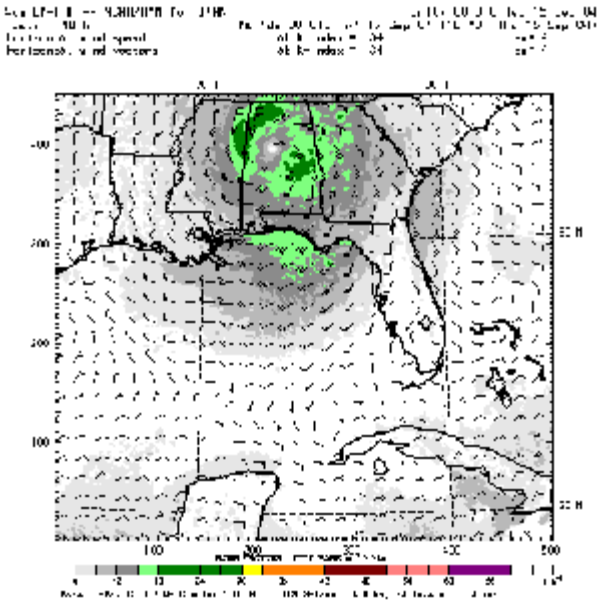


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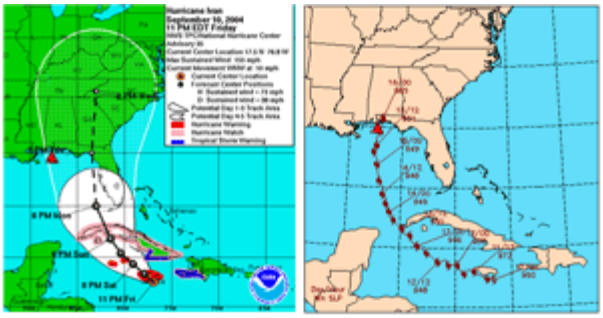
Figure 11. *Text*



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resolution configuration was performed to examine the model's ability to predict tracks for up to 5 days. These experiments demonstrated that WRFV2 with its new two-way nesting capability has the potential to predict the intensity of the storms. During the period when Ivan was a category 4 and 5 storm, the nested WRF simulated surface winds in exceeding 60 m/s . The five-day, 12 km track forecasts showed that the model can predict the tracking of these systems with the accuracy similar or better than the current operational models in real-time mode. The figure below shows the comparison of the five-day track forecast from 0000 UTC, September 11 initialized WRF and that issued from National Hurricane Center at 0300 UTC on the same day. WRF's track was very accurate and predicted the landfall near Mobile Bay, Alabama, with a timing error of about 9 hours.

WRF model data assimilation

An upgraded version of the WRF 3D-Var (V2.0) data assimilation system was released to the research community in May 2004. The code, documentation and online tutorial are available from the WRF web-site http://www.wrf-model.org/wg4. New capabilities available to the community in V2.0 include a vertical velocity analysis, radar radial velocity assimilation, preconditioned conjugate gradient minimization (to improve convergence), and an improved assimilation of surface observations via the use of boundary layer parameterizations in the interpolation from model to observation locations. The development and testing work for the WRF 3DVAR is discussed in the section on Mesoscale Data Assimilation.

WRF Atmospheric Chemistry Modeling (WRF-Chem)

W. Skamarock has developed a new advection scheme for WRF-ARW chemistry (WRF-Chem) applications, applicable more generally to scalar transport in WRF-ARW applications. The advection scheme is based on a timesplit implementation of Lin and Rood's unlimited-timestep advection algorithm, and it is implemented

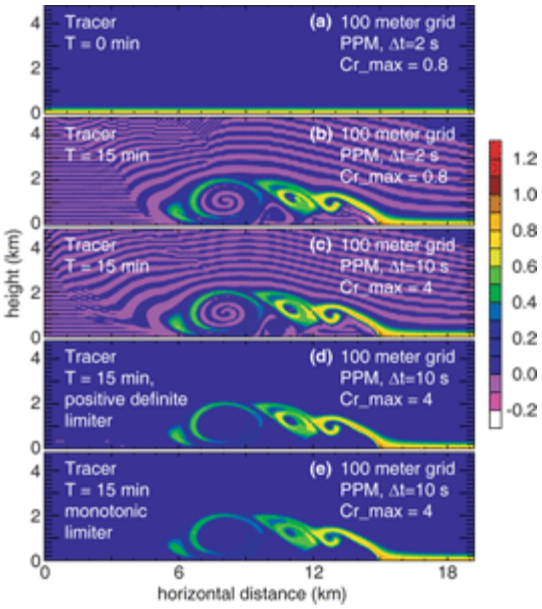

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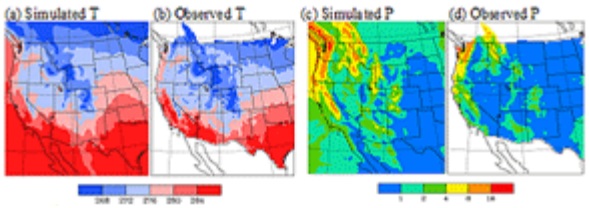
Figure 13. *Text*

using a Piecewise-Parabolic Method (PPM) flux evaluation. The full scheme has both positive definite and monotonic options, is conservative and consistent with the discrete continuity equation in the WRF-ARW Runge-Kutta time integration. The large timestep capability of the new advection scheme will allow the use of timesteps for scalar transport that are much larger than those used in the WRF-ARW dynamics. In WRF-Chem applications, tens to hundreds of scalars are transported, and this transport dominates the processor time in a WRF-Chem application. The new transport scheme will reduce this the transport processor time by the ratio of the transport timestep to the dynamics timestep, resulting in major cost savings in addition to providing positive definite or monotonic behavior. Preliminary tests of the new scheme in the WRF model is shown in **Figure 13**, where transport within a highly nonlinear gravity current is reproduced by the new advection scheme at timesteps a factor of five larger than the stable timestep for the dynamical solver, with no discernable loss of accuracy.

WRF Regional Climate Modeling



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(a) Simulated T (b) Observed T (c) Simulated P (d) Observed P

Figure 14. *Comparison of simulated and observed temperature and precipitation for 1990/10 – 1991/3.*

A regional climate model (RCM) provides high-resolution climate scenarios important for impact assessment and resource management. The Weather Research and Forecasting (WRF) model was designed specifically for high-resolution applications and has provided a base for the development of a new RCM for simulations using 1-30 km grid spacing. The development of a regional climate capability for WRF is being carried out through an NCAR Opportunity Fund project led by B. Kuo and J. Dudhia. Ruby Leung (visitor from Pacific Northwest National Lab), and J. Dudhia are incorporating physics packages from the Community Climate System Model (CCSM) into WRF. First, the CAM3 radiation package was implemented and tested, and the work is now continuing with coupling the Community Land Model (collaborating with Gordon Bonan and Mariana Vertenstein, CGD). With James Done, several changes have been implemented to the model, including modification to the treatment of lateral boundary conditions, updating of sea surface temperature and vegetation parameters, and a consistent treatment of fractional cloud cover and cloud liquid/ice water path in the cloud and radiation parameterizations for cloud-radiation feedback.

J. Done, R. Leung, C. Davis, and B. Kuo have evaluated WRF for four-month simulations and compared results with observations and with MM5. They conducted a cold-season simulation of the western U.S. at 30 km spatial resolution for the period October 1990 to March 1991 and compared the model

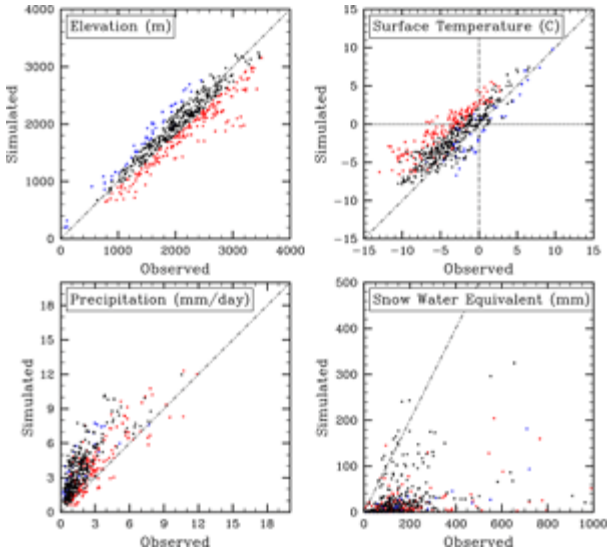

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Figure 15. *Scatter plots showing simulated versus observed elevation, surface temperature, precipitation, and snow water equivalent at the snow telemetry stations in the western U.S.*

results with observed temperature, precipitation, and snow data. **Figure 15** compares the observed and simulated cold-season mean temperature and precipitation and shows a model warm bias of up to 3oC and an overprediction of precipitation, and compares the observed and simulated temperature, precipitation, and snow water equivalent at the snow telemetry stations that are typically located at high elevation. Snowpack is grossly underpredicted by the model. Although our results are similar to results from regional climate simulations using MM5 at 40-km grid spacing, it is thought the benefits of WRF will become apparent for higher resolution simulations.

WRF Forecast Verification

J. Knievel, D. Ahijevych, and K. Manning demonstrated that the realism of numerical weather prediction models can be evaluated by examining the temporal modes of the simulated rainfall. Because of its growing prominence in the operational and scientific communities, the Weather Research and Forecasting (WRF) Model was chosen for the study. Its simulated rainfall frequency was compared to rainfall frequency diagnosed from the WSR-88D network. Simulations and observations were similar overall in the normalized amplitudes of their diurnal and semidiurnal modes. The modes' phases were different, though, and in the WRF Model the simulated rain fell too early, and light rain was too frequent. The model also did not produce the distinct, nocturnal maximum in rainfall frequency so integral to the hydrologic cycle of the Great Plains.

C. Davis has collaborated with Barbara Brown, Randy Bullock and Daran Rife, all from RAP, to develop and apply new verification approaches to assess the skill of high-resolution forecasts of rainfall and surface winds. Traditional scores are problematic for verifying flows approaching the limits of predictability because they reward forecasts having unrealistically low spatial and temporal variability, and are mute regarding the causes of forecast error. With B. Brown and R. Bullock, C. Davis has developed and applied an algorithm to define coherent areas of precipitation, emphasizing mesoscale convection, and compared properties of these areas with observations obtained from NCEP Stage IV precipitation analyses (gauge and radar combined). Both simulations on a 22-km grid and 4-km grid, the latter with no cumulus parameterization, have been evaluated (for different time periods). In general, the WRF model produced too many large rain areas in both cases, large being defined as 20 grid lengths or more. The intensity distributions differed substantially, however. The WRF with parameterized convection had rainfall too narrowly distributed about the mean, especially in the later afternoon when the cumulus parameterization was most active. The intensity distribution among rain systems in the 4-km forecasts was generally too broad, especially in the late afternoon. Both sets of forecasts exhibited considerable regional variation in statistics. The 22-km WRF failed to produce the nocturnal MCS maximum in the Great Plains and underestimated the diurnal cycle of convection near the Gulf of Mexico, in agreement with Davis et al. (2003). The 4-km WRF exhibited the largest positive size and intensity bias associated with systems over the Midwest and Mississippi Valley regions, but little size bias over the High Plains, Ohio Valley and Southeast. Overall, the skill scores produced by the algorithm agreed with those obtained from manual inspection by Done et al.(2004).

C. Davis and D. Rife compared forecast skill of MM5 for 30-km and 3.3-km-grid forecasts over the White Sands

Missile Range in Central and Southern New Mexico. They compared forecast time series at surface stations with observations by devising and applying non-traditional verification scores. In particular, they defined objects as two-hour temporal changes greater than one standard deviation in magnitude and verified whether forecasts produced observed changes, allowing for temporal error of the forecast changes. Whereas root-mean-square error statistics showed little benefit of the higher-resolution, the object-based technique revealed notably greater skill of finer-scale forecasts immediately over and within roughly 10-20 km of complex terrain features. However, there was only modest benefit over flat areas greater than 10-20 km from terrain features. In addition, higher skill was evident for the cross-barrier wind component than the along-barrier wind component. Other verification metrics, such as temporal anomaly correlation and time series variance were examined and pointed to similar benefits of higher-resolution.

WRF Workshops, Tutorials and Community Support

International WRF Workshops and scientific visits

In an effort to introduce the WRF modeling system to the international atmospheric science community, B. Kuo and J. Klemp organized two major international WRF workshops in FY04; one at the Seoul National University in December 2003, and the other at Taiwan's Central Weather Bureau in September 2004. J. Klemp, B. Kuo, B. Skamarock, J. Dudhia, D. Barker, J. Knievel, and Georg Grell (NOAA/FSL) gave lectures that cover the various aspects of the WRF modeling system, from dynamics, numerics, data assimilation, chemistry modeling, to real-time forecast applications and Development Testbed Center (DTC). These workshops were all very well attended, with more than 100 participants in the audience, showing strong interest from the international community in the WRF modeling system. J. Klemp and B. Kuo also visited the New Zealand Weather Service and the Chinese National Meteorological Center to discuss the use of WRF for forecast applications over the Southern hemisphere and China. These international workshops and scientific visits are very useful in helping the international atmospheric science community to transition from MM5 to WRF for research and operational applications.

WRF community support

The number of WRF users continued to increase in the last year. Another 800 people (in addition to the previous 1400) have visited WRF site and downloaded the code. Over 960 users have subscribed to the WRF news list, compared to 600 people reported last year. In May 2004, the WRF ARW, SI, and 3DVAR Version 2.0 was released in which the nesting capability was included. Two minor version releases were followed in late May and early June. The WRF User page has been redesigned and made its debut with the WRF Version 2 release in May. The number of user emails continues to increase. During FY04, W. Wang and other MMM staff answered 1130 user emails, which is a 66% increase over the previous year.

W. Wang, J. Klemp, J. Dudhia and J. Powers organized the Fifth WRF and Fourteenth MM5 Users' Workshop, which took place 22-25 June. One hundred papers were received for the workshops, and among them, sixty-five were WRF-related. About 170 people from 90 institutions and 20 countries participated.

Following the Users' Workshop, a four-day WRF tutorial was offered on 28 June - 1 July. The WRF model, WRF Standard Initialization and WRF 3DVAR were taught at the tutorial. This was the first WRF tutorial where practice sessions were offered. It was no small task to accommodate 115 people (from 75 institutions and 15 countries) at the tutorial. A new User's Guide was developed and distributed at the tutorial. Cindy Bruyere, Shu-hua Chen (University of California, Davis), J. Dudhia, D. Gill, Yong-Run Guo, W. Huang, J. Michalakes, and Wang, along with John Smart, and Paula McCaslin (NOAA/FSL), lectured at this WRF tutorial.

Developmental Testbed Center and testing for WRF operational implementation

This year was the initial spin-up for the Center. Louisa Nance was hired during the final quarter of FY03, and Bob Gall became director about the same time. One additional employee was hired during FY04 (Meral Demirtas) who will be starting early in FY05. Strong links were forged between the NCAR and FSL components of the Central DTC located in Boulder. A Terms of Reference has been drafted describing a distributed DTC with components at several locations, including the central DTC in Boulder, consisting of components at FSL

and NCAR, and initially one distributed component at NRL in Monterey, CA.

Completion of WRF System Test

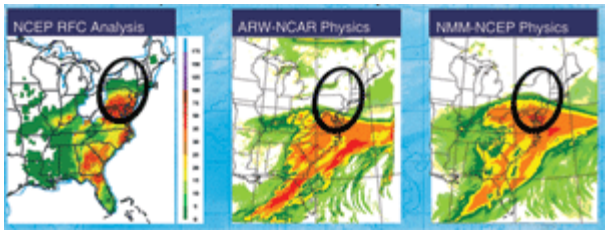

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Figure 16. *One such event is the strong storm that impacted a significant portion of the East Coast between 15-17 February 2003 shown in the attached figures.*

During FY03 and FY04, an extensive series of tests were performed on the two WRF Cores (NMM and ARW) and their attendant physics packages to determine readiness of the WRF system for it's initial operational implementation at NCEP, October 1, 2004. This pre-implementation testing of WRF was a collaborative effort by scientists from NCAR, FSL, NCEP, AFWA, and Northup Grumman. The testing involved eight configurations, four for each core (baseline physics, swapped physics and perturbed initial/boundary conditions) applied to four regions around the US for four different seasons. This testing included over 2000 separate runs of the WRF system. Standard verification statistics were computed for each deterministic forecast, as well as ensemble statistics for various combinations of the eight configurations, using NCEP software. A select subset of individual events are also being analyzed for the purpose of gaining a physical understanding of the differences between the two WRF Cores and their attendant physics packages. One such event is the strong storm that impacted a significant portion of the East Coast between 15-17 February 2003 shown in **Figure 16**. Initial indications are the results for the cores themselves were similar with considerable differences related to the physics packages. The tests have led to operational implementation.

Initial WRF Visitor Program

A major goal of the DTC will be to tap the extensive expertise in the NWP research community for much of the testing that will be done in the DTC. This year we began a modest visitor program with four visitors; Bill Gallus and Isidora Jankov (Iowa State University), Dave Dempsey (San Francisco State University), and Ying Lin (NCEP). The visitors worked on grid structure for the ARW core (Dempsey), physics options within the cores (Gallus and Jankov), minimum requirements for a cloud resolving resolution—grid spacing, physics options, number of levels (Gallus and Jankov), and verification techniques (Lin).

High Resolution Summer Experiment

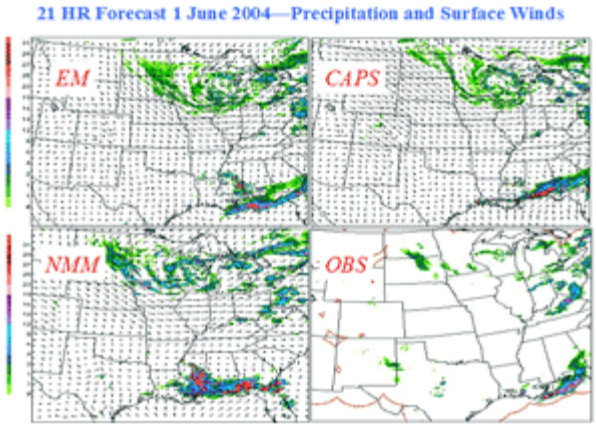

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Figure 17. *Text*

The DTC participated, with several other groups (NCEP, CAPS, NSSL, NWS Central Region); in a follow on experiment to the previous year's of a high resolution (4km) forecast experiment over the Midwest. The purpose of these experiments was to examine whether forecasters found useful information in the high- resolution forecasts beyond that available in the lower resolution operational models in the 36-hour timeframe. The answer was "yes". **Figure 17** shows 1-h forecasts from the NMM and ARW cores using a cold start and a third forecast using the University of Oklahoma (CAPS) data assimilation system for a hot start with the ARW. At this time range, the hot start (which it was initialized with radar information) produced the best forecast. **Figure 17** shows the same forecast cycle after 12 hours. At this longer time range the initial precipitation fields resulting from the assimilation system used in the hot-start forecast have died out and now the cold start forecasts look much better. At longer time ranges (not shown), all three models produce similar forecasts. This

result was found consistently throughout the experiment.

MM5 Development and community support

Final MM5 Enhancements: Preparation for MM5's final release in FY05 are continuing. Many changes are being incorporated for the release (MM5 Version 3.7). Two of the major new components come from Guenther Zaengl (University of Munich, Germany) who has provided an improved sub-grid parameterization scheme for mountainous terrain, and a solar radiation modification to allow for terrain slope and shadow effects. Zaengl worked with C. Bruyere and J. Dudhia during his visit in Spring 2004 to finalize this code for Version 3.7. He has also provided separate code with a new vertical coordinate for MM5 that represents flow over complex terrain better, and an improved upper radiative boundary condition for nested domains. These codes will be made available to users separately from Version 3.7.

C. Bruyere and J. Dudhia are also adding a new version of the microphysics scheme by Paul Schultz (NOAA/FSL), modifying the Grell cumulus parameterization as suggested by Georg Grell (NOAA/FSL), making improvements to the MRF PBL scheme based on work by Yubao Liu and Fei Chen (RAP), and have changed the cloud ice representation in the CCM2 radiation in response to tests carried out by Cliff Mass and co-workers at the University of Washington.

MM5 Experimental Real-Time Mesoscale Modeling: To support flight forecasting and research activities over Antarctica, J. Powers, K. Manning, Michael Duda, and Syed Rizvi have continued to develop the Antarctic Mesoscale Prediction System (AMPS). NCAR has been collaborating in this project with David Bromwich of The Ohio State University's Byrd Polar Research Center. AMPS is an experimental real-time mesoscale modeling system generating twice-daily MM5 forecasts at resolutions as high as 3.3 km in support of the United States Antarctic Program. AMPS also serves a broad range of international activities, such as the Global Ocean Ecosystem Dynamics Program and the Antarctic operations of Italy, the UK, Australia, Chile, Germany, and South Africa.

Over the past year AMPS has also provided support for emergency medical evacuations. In September 2003 a medevac from Amundsen-Scott South Pole Station was necessitated by a worker suffering from a failing gall bladder before flight operations to the Pole had started for the summer season. AMPS was used in the fight forecasting for the Twin Otter rescue aircraft. Similarly, in April 2004, another critical medical situation required the airlift of three workers from McMurdo Station, this time after flight operations had ceased for the year, and AMPS was there to help. Over the past year AMPS began using 3-dimensional variational data assimilation (3DVAR). Analyses found this to be superior to the previous objective reanalysis package. This is significant not only for the immediate gain in forecast accuracy, but more importantly for the long-term positioning of AMPS to take advantage of indirect satellite atmospheric measurements, notably the COSMIC (Constellation Observing System for Meteorology, Ionosphere, and Climate) observations. The latter should greatly enhance the initialization of models targeting the polar regions. Future work in AMPS will revolve around implementation and testing of the WRF model over Antarctica. This application is expected to offer a unique testbed for this next-generation modeling system.

Next Topic: **Mesoscale Data Assimilation**

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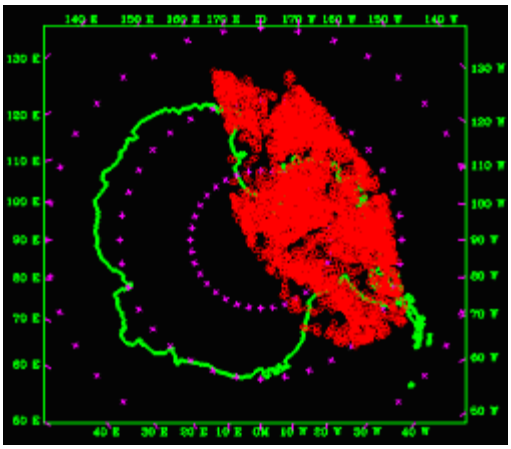
Mesoscale Data Assimilation

Advanced data assimilation systems for community use

Application of WRF 3D-Var in polar, tropical and global domains

The WRF three-dimensional variational (3D-Var) data assimilation system is an integral part of many MMM projects. In FY04, scientists at MMM applied the WRF 3D-Var system for data assimilation efforts over polar, tropical and global domains. Dale Barker, Wei Huang and Syed Rivzi recently upgraded the data assimilation component of the MM5-based Antarctic Mesoscale Prediction System (AMPS), which was jointly develop by the MMM Division and Byrd Polar Research Center of the Ohio State University, to WRF 3D-Var for real-time forecasting over high southern-latitudes. The WRF 3D-Var system was enhanced to assimilate several types of satellite remote sensing observations. Rizvi implemented the capability of WRF 3D-Var to assimilate ATOVS retrieved temperature and moisture profiles from the NOAA satellites. Barker has begun assimilating retrieved motion vectors from the MODerate resolution Imaging Spectrometer (MODIS) instrument aboard NASA's Aqua satellite. (**Figure 18**) shows a typical observation distribution of retrieved MODIS atmospheric motion vectors over a 2-h period. This data-source was provided by the University of Wisconsin's Space Science Engineering Center. Given the dearth of conventional polar wind observations, the assimilation of MODIS winds is expected to lead to significant improvements in the forecasting of key polar processes (e.g. katabatic winds, polar cyclogenesis) as well as for medium-range mid-latitude NWP.



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The performance of variational data assimilation techniques in the tropics is a challenging area of research. Balance constraints (e.g. geostrophic) used in mid-latitudes do not apply at low latitudes. Also, the proper representation of nonlinear processes (e.g. convection) is key to successful tropical NWP. In variational systems, these issues translate to

1. Alternative, flow-dependent background error covariance models, and
2. The development of 4D-Var. Barker, Qingnong Xiao, and Hans Huang (long-term visitor from Danish Meteorological Institute) has begun working on both the flow-dependent error covariance models as well as the WRF 4D-Var in FY2004. The inclusion of nonlinear processes has been achieved in WRF 3/4D-Var via an "outer-loop" which effectively iterates towards the converged nonlinear

Figure 18. *Observation coverage of atmospheric motion vectors retrieved from the MODIS instrument aboard NASA's Aqua polar-orbiting spacecraft. Presented data is valid within 2 hours of 12 UTC December 1 2002 and has been quality controlled prior to assimilation in WRF 3D-Var.*

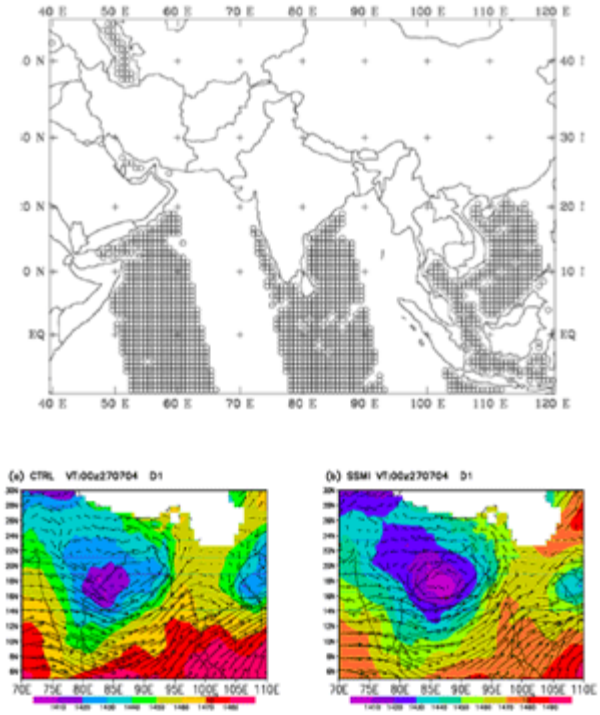

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Figure 19. *Above - Coverage of SSM/I data over the Indian MM5 domain valid at 12 UTC 28 July 2004. 24hr MM5 850hPa height forecast from 3D-Var initial conditions without (below left), and with (below right) SSM/I data assimilated in MM5/WRF 3D-Var (Courtesy Munmun Gupta, NCMRWF).*

solution.

Tropical variational data assimilation work is supported by international collaborations with both Taiwan (Civil Aeronautics Administration, and Central Weather Bureau) and India (National Center for Medium-Range Weather Forecasts). The MM5-based MMM/NCMRWF collaborative work to date has concentrated on the specification of forecast error statistics for the Indian domain (**Figure 19**), and the impact of particular observations on Indian NWP. For example, differences between **Figures 19a** and **19b** illlustrate the impact of Special Sensor Microwave/Imager (SSM/I) data on 24hr 850hPa geopotential height forecasts. The improved definition of the tropical cyclone when using the SSM/I surface wind speed data is clearly shown,

The WRF 4D-Var capability of WRF-VAR (the merged WRF 3/4D-Var system - see elsewhere) will be applied as it becomes available to worldwide applications of WRF. The impact of improved forecast error covariances, and additional observations (e.g. radiances) in WRF-VAR will be also assessed. High-resolution applications of WRF 3/4D-Var over IHOP cases over continental U.S. are ongoing.

Doppler Radar data assimilation using WRF 3D-Var system

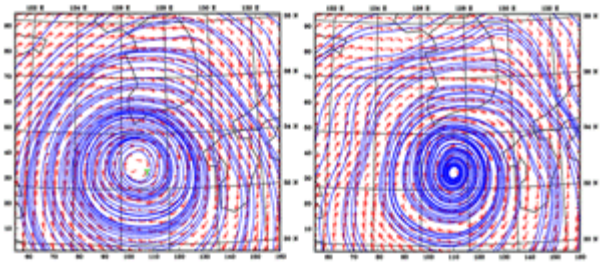

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Figure 20. *Typhoon Rusa (2002) 850-hPa streamlines and wind barbs at 00 UTC 31 August 2002, (a) without, and (b) with radar data assimilation*

In collaboration with Seoul National University and Korea Meteorological Administration, Q. Xiao, Jianfeng Gu (long-term visitor from Shanghai Meteorological Bureau), D. Barker, Wei Haung, and Ying-Hwa (Bill) Kuo worked on the Dopper radar data assimilation using WRF 3D-Var system for the Northwestern Pacific Typhoon Rusa (2002). **Figure 20** compares the 850-hPa wind distributions with and without the assimilation of Doppler radar data. The typhoon initialization with Doppler radial velocities is much more compact. The wind around the typhoon is increased, and the radius of the maximum wind is decreased. As Doppler radar observations have very high resolution, assimilation of these data can adjust the typhoon vortex to the right position with improved vortex structure. As a result, the typhoon forecasts using the initialization enhanced by radar data are also improved.

Tropical cyclone initialization

Q. Xiao, B. Kuo, Ying Zhang (RAP) and D. Barker developed a typhoon bogus data assimilation algorithm and implemented in the MM5 3D-Var system. Numerical experiments on Typhoon Rusa (2002) case showed that the scheme works well and can improve the prediction of typhoon track and intensity. With MM5 3D-Var bogus data assimilation scheme, the initial typhoon vortex is dynamically balanced, and possesses a well-defined warm core structure. Compared with traditional bogussing in the 3D-Var background fields, MM5 3D-Var bogus data assimilation scheme has the advantage of much reduced problem in precipitation spin-down/up in the subsequent typhoon forecast. Sensitivity experiments show that assimilation of only the bogus sea-level pressure data produces too strong typhoon intensity, while assimilation of the bogus wind data alone produces a storm that is much weaker than the observations. Assimilation of both bogus sea-level pressure and wind data obtains the best hurricane initialization and subsequent forecast for this case. The landfall location, time and intensity all compare favorably with the observation.

Comparison of Variational and Ensemble Data Assimilation at High-Latitudes

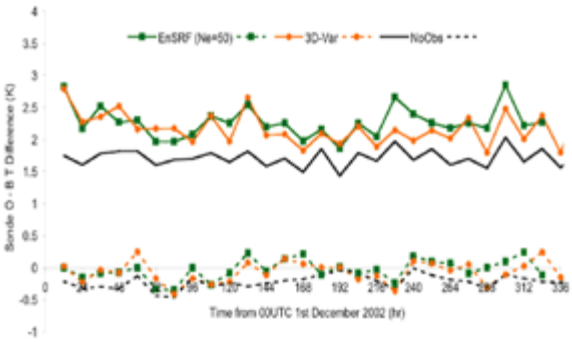

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Figure 21. *12hr MM5 forecast upper-air temperature errors (verified against all radiosondes) for EnSRF (50 member ensemble), MM5/WRF 3D-Var, and "NoObs"experiments. Period shown is 1st half of December 2002. Experiment spin-up period in late November is not shown. Same observation are used for both EnSRF and 3D-Var.*

Data assimilation at high latitudes is particularly challenging given the relative sparcity of conventional observations and unique physics present in these regions. Given this, and the fact that most modern data assimilation systems are designed with an emphasis on mid-latitudes, Antarctic mesoscale data assimilation is a demanding test of current assimilation strategies. In FY04, D. Barker performed an assessment of the relative performance and costs of MM5 3D-Var and ensemble square-root filter (EnSRF) algorithms in AMPS. His preliminary results indicate comparable performance of 3D-Var/EnSRF during a one month trial period in December 2002. For example, **Figure 21** shows 12hr temperature forecast verification for EnSRF, 3D-Var and "NoObs" forecasts run from interpolated GFS data (the latter's superiority is due at least in part to the lack of radiance assimilation in the MM5 EnSRF and 3D-Var algorithms). In a paper submitted to the *Monthly Weather Review*, D. Barker highlights the detrimental impact of EnSRF ensemble sampling error on subtle multivariate forecast error covariances. D. Barker also studies the use of randomized samples of 3D-Var covariances to provide initial and lateral boundary condition perturbations for the EnSRF.

MM5/WRF Research Community Variational Data Assimilation System

With the team effort by D. Barker, W. Huang, Yong-Run Guo, Q. Xiao, and S. Rizvi, an upgraded version of the WRF 3D-Var (V2.0) data assimilation system was released to the research community in May 2004. The code, documentation and online tutorial are available from the WRF web site http://www.wrf-model.org/wg4. New capabilities available to the community in V2.0 include a vertical velocity analysis, radar radial velocity assimilation, preconditioned conjugate gradient minimization (to improve convergence), and an improved assimilation of surface observations via the use of boundary layer parameterizations in the interpolation from model to observation locations.

Assimilation of GPS radio occultation data

Assimilation of GPS RO Data for an Intense Antarctic Storm

Recently, Tae-Kwon Wee (COSMIC), B. Kuo and David Bromwich (Ohio State University) collaborated on a study to assimilate the GPS radio occultation (RO) data from CHAMP and SAC-C missions using an updated version of MM5 4D-Var assimilation system, and assessed their impact on short-range prediction of an intense cyclone that took place in December 2001 over the Ross Sea. The intensity of the December 2001 storm

(which has a minimum pressure of 936 hpa) had not occurred near McMurdo Station over the 46 years of record keeping. Wee et al. performed parallel data assimilation experiments with and without the use of GPS RO data over an 8-day period for this storm. Continuous assimilations with a window size of 12-h were carried out over 48 hours (e.g., 4 cycles). For this case, various types of observations were collected and processed.

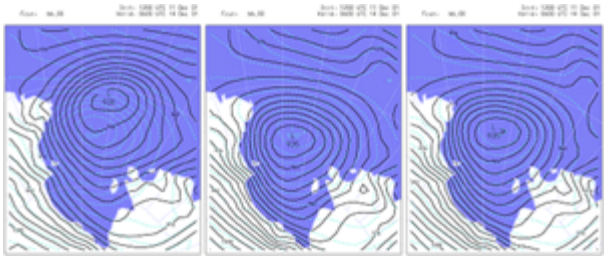

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Figure 22. *The 66-h forecasts of mean sea level pressure initialized at 1200 UTC 11 and valid at 0600 UTC 14 December 2001. Dashed contours represent mean seal level pressure from ECMWF analysis and solid lines represent the forecast from a) the cold start run initialized with NCEP/AVN analysis, b) No GPS experiment, and c) GPS experiment.*

The CHAMP and SAC-C GPS RO data were obtained from the COSMIC Data Analysis and Archive Center (CDAAC) at UCAR. Other observations collected include TEMP (rawinsonde and pibal), SYNOP (surface, ship, drifting buoy, and PAOB), aircraft observations (AIREP, PIREP, and AIRCAR), ATOVS retrieved soundings from NESDIS (NOAA 15 and 16), MODIS/Terra retrieved soundings, satellite motion vectors, SSM/I retrievals (rainfall rate, total liquid water, precipitable water vapor, and surface wind speed) from DMSP 13-15, and QuikSCAT surface wind vector.

A significant positive impact of GPS RO data on short-range forecasts was found for experiments with 48 hours of continuous assimilation (**Figure 22**). The assimilation of GPS RO data over an extended period (e.g., 48 h) improved all parameters in all forecast ranges. Moreover, the amount of positive impact as a result of GPS RO data assimilation increased proportionally to the lengthened analysis period. With continuous cycling assimilation, the analysis errors were kept to a degree comparable to those of the NCEP operational analysis. A significant error reduction was noted over the interior of the Antarctic continent when the forecasts were verified against observed GPS RO data. This study demonstrates the importance of GPS RO data for weather prediction over the Antarctic.

Development of nonlocal observation operator for GPS radio occultation

The radio occultation (RO) sounding technique that uses signals transmitted by the Global Positioning System (GPS) has evolved as an important global observing technology. The Constellation Observing System for Meteorology and Climate (COSMIC) will launch six microsatellites in late 2005, and will provide approximately 2,500 GPS radio occultation (RO) soundings per day, distributed uniformly around the globe. The COSMIC GPS RO data have the potential to make a significant contribution to operational numerical weather prediction. However, the GPS RO soundings are non-traditional measurements. Effective and efficient assimilation of GPS RO data into operational models remains a challenge. In FY04, B. Kuo and Wei Wang collaborated with Sergey Sokolovskiy on the development of a new observation operator, known as the “nonlocal excess phase” operator. This new observation operator takes into account the effects of horizontal inhomegeneity of atmospheric refractivity. It is considerably more accurate than the “local refractivity” operator (which does not account for horizontal inhomegeneity), and much more computationally efficient than the sophisticated bending observation operator (which is nearly two order of magnitudes more expensive). This observation operator was evaluated in observing system simulation experiments using WRF 4-km simulation of Hurricane Isabel, as well as against actual CHAMP GPS RO observation. It was proven to be an accurate and effective observation operator. The results were presented in two papers submitted to the Mon. Wea. Rev. The development of this observation operator greatly facilitates the use of COSMIC data in operational forecasting.

Research with ensemble Kalman filters

Assimilation of Doppler radar observations using ensemble Kalman filters

Mesoscale data assimilation is hampered by two facts. First, observations which are plentiful (e.g. Doppler radar measurements of wind and reflectivity) involve only a subset of atmospheric variables, while observing platforms such as radiosondes that measure all relevant variables are sparse and resolve mesoscale motions

poorly. Second, the balances between variables, such as geostrophy, that pertain at large scales in the atmosphere are questionable at the mesoscale; these balances are an important component of more traditional assimilation schemes such as 3DVar. To overcome these difficulties, there has been substantial effort within MMM and the Data Assimilation Initiative to explore the potential of the ensemble Kalman filter (EnKF) for mesoscale assimilation. Following the results of Snyder and Zhang (2003), who showed using simulated observations from a single radar that the EnKF could produce accurate analyses of convective storms, Fuqing Zhang (Texas A&M), C. Snyder and Juanzhen Sun have explored how the assimilation is influenced by changes in the available observations or in the quality of the initial estimate of the storm (Zhang et al. 2004). Alain Caya (MMM and Data Assimilation Initiative [DAI]), C. Snyder and J. Sun have also compared the EnKF to a four-dimensional variational assimilation scheme (again in the context of simulated observations) and find that the EnKF performs somewhat better given several radar scans but somewhat worse than the variational scheme when only 2--3 scans are available.

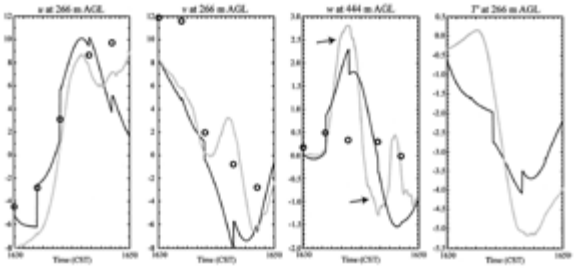

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Figure 23. *Observations from the instrumented tower (5-min running averages, shown in gray) and corresponding traces of model-state variables in the control EnKF assimilation experiment at the tower location (black) between 1630 and 1650 CST for the 1981 Arcadia, Oklahoma supercell. Samples from the dual-Doppler analysis are also shown (open circles). The analyzed fields, from left to right, are the westerly ground-relative wind component (u) at 266 m AGL (m/s), the southerly ground-relative wind component (v) at 266 m AGL (m/s), the vertical velocity (w) at 444 m AGL (m/s), and the perturbations temperature (T') at 266 m AGL (K). The arrows indicate the main updraft-downdraft couplet.*

In addition, a team led by David Dowell (presently Cooperative Institute for Mesoscale Meteorology at Oklahoma University, formerly ASP and MMM postdoc), and including F. Zhang, C. Snyder, A. Crook and Louis Wicker (NOAA/NSSL), has explored the assimilation of real Doppler-radar observations of the 1981 Arcadia, Oklahoma with the EnKF. They find that the EnKF, using observations from a single radar, performs at least comparably to traditional dual-Doppler retrieval techniques. Together, these results are the first for the EnKF outside of global atmospheric models and hold substantial promise for the application of the EnKF to meso- and convective scales.

The foregoing experiments with the EnKF all assume that the larger-scale environment in which the storm develops is known perfectly. In the context of a simulated squall line, William Skamarock and C. Snyder have examined the effects of uncertainty in the environmental sounding. They show that the EnKF errors are significantly degraded for errors that are comparable to likely uncertainty in soundings (several m/s), and they have begun exploring the possibility of estimating the environmental sounding based on the radar observations.

Development and application of EnKF system based on WRF

This past year progress was made in developing an EnKF system for mesoscale data assimilation based on WRF. This is a leading-edge effort with few counterparts, and which complements other research with the EnKF at global scales. Lateral boundary conditions are an important source of uncertainty in limited-area forecasts and this uncertainty must be accounted for in the EnKF. To this end, Ryan Torn, Greg Hakim (both University of Washington), and C. Snyder have begun exploring various treatments of the lateral boundary conditions for short-range limited-area ensemble forecasts. They have demonstrated that the preferred treatment of the lateral boundaries, in which an EnKF on a larger domain provides an ensemble of boundary conditions, often yields only marginal benefits over various simple, ad hoc treatments, such as drawing boundary perturbations from a climatological time series or generating them using the background covariance model from the WRF three-dimensional variational assimilation scheme.

In addition, A. Caya, together with Jeffrey Anderson (CGD), Joshua Hacker (RAP) and C. Snyder, has continued the development of an EnKF system for WRF based on the Data Assimilation Research Testbed (DART, developed by DAI). Observation operators for surface fields, radar reflectivity and radial velocity have been implemented, along with the capability to use the EnKF on multiple nested domains, which will be

required for assimilations that span the meso- and convective scales. This is one of the first assimilation systems that handles nested domains together rather than performing analyses separately for each domain. A. Caya and C. Snyder have continued their assimilation work using the WRF/DART system. In simulated-observation experiments, they have found that the EnKF is an effective scheme on a continental-U.S. domain. They have begun initial tests of the system with real observations, including radiosondes, aircraft observations and a subset of satellite winds.

Design of optimal global observing system

Developing optimal observing strategies requires evaluating the costs and benefits of different observations. Although the meteorological community has discussed the question of optimal investment in observations for more than three decades, it still lacks a practical, systematic framework for analyzing the issue. In FY04, R. Morss, Kathleen Miller (ESIG), and Maxine Vasil (graduate student, University of Colorado) developed an economic approach to analyzing the optimal observing system. In a publication currently in press in Monthly Weather Review, they present the approach, then combine meteorological, cost, and benefit information to demonstrate the approach for a simplified version of the real observing and prediction system. They also identify gaps in existing knowledge that must be addressed before the framework can be implemented to analyze the real observing system.

Choices about implementation of publicly funded observing systems require understanding meteorological aspects of observing systems, but are made in the public policy arena. To help meteorological knowledge and meteorologists contribute more effectively to public policy decisions on observing systems, R. Morss analyzed meteorological observing system design from a public policy perspective. The results are presented in a manuscript, in press in BAMS, which illustrates the importance of careful problem definition and builds towards an appropriate multidisciplinary problem definition for observing system design.
e. Cloud-scale data assimilation

Microphysical parameter retrieval and improvement of warm rain microphysical parameterization scheme

Juanzhen Sun, Ed Brandes (RAP), and Guifu Zhang (RAP) conducted a study on Microphysical parameter retrieval and improvement of warm rain microphysical parameterization scheme. This project was supported by the NCAR opportunity fund. They used a four-dimensional variational scheme, a simple cloud model, and single Doppler radar observations to optimally determine both the initial conditions of the numerical model and some of the warm rain microphysical parameters. Experiments were performed using both simulated data and real data. Effort was also made to implement a new microphysical scheme that was based on constrained Gamma drop size distribution. This new scheme was compared with the existing Marshal-Palmer scheme. They have found that both the optimal determination of the microphysical parameters and the constrained Gamma microphysical scheme showed potential improvement in the prediction of thunderstorms.

Assimilation of multiple Doppler radar observations to improve 0-12 hour QPF

J. Sun, Q. Xiao, A. Crook, C. Snyder, J. Miller, D. Barker, and B. Kuo conducted the research on the assimilation of multiple Doppler radar observations into mesoscale models. They worked on a squall line case observed during IHOP. Data from 12 NEXRAD radars for a period of 6 hours were quality-controlled and preprocessed. Simulations using WRF initialized without radar observations showed the model was unable to predict the initiation and evolution of the squall line. OSSE experiments are being performed using the WRF 3D-Var to answer the question whether a 3D-Var system is able to retrieve the unobserved wind component through continuous cycling. Real data experiments using WRF 3D-Var, EnKF, and a 4D-Var system have just begun.

Assimilation of Doppler radar for an Oklahoma supercell

A. Crook and David Dowell (CIMMS/University of Oklahoma) have continued their data assimilation studies of the Arcadia Oklahoma supercell. The focus in FY04 has been on the retrieval of unobserved parameters and fields. Using the microphysical retrieval code of Sun and Zhang discussed above it is shown that making the

precipitation fallspeed a control parameter (rather than a constant) allows for a much better fit to the observed radar data. It is shown that the primary mechanism that determines the fallspeed is the improvement in the fit to the temporal evolution of the reflectivity data. It is also shown that the optimal fallspeed is less than the default value which is probably due to the lack of ice physics in the underlying cloud model. In related work, a simple cloud model (without dynamics) and its adjoint have been developed to examine how the total water field is adjusted in regions of precipitation. Given observations of the rainwater field at two different times, it is possible to retrieve the total water field via the adjoint of the microphysical processes.

Next Topic: Prediction and Predictability

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Prediction and Predictability

Predictability

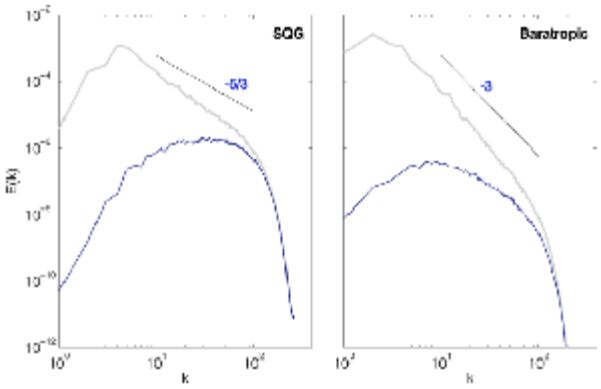

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***Figure 24**. Energy spectra of the full flow (grey) and of differences between two solutions (blue) as a function of horizontal wavenumber for two-dimensional doubly periodic turbulence forced at wavenumber 8. The panel at left shows spectra for surface quasigeostrophic (sQG) turbulence, while the right panel shows barotropic turbulence. In each case, the initial differences are concentrated near $k = 20$; in the sQG case, differences grow most rapidly at the smallest scales outside the dissipation range, while for the barotropic case diferences grow at larger scales (comparable to that of the forcing for the full flow). The arguments of Lorenz (1969) suggest that the sQG flow has finite intrinsic predictability. The thin solid line segments show the theoretical power laws for the full flow of $k^{-5/3}$ and k^{-3} in the sQG and barotropic cases, respectively.*

The skill of today's weather forecast is clearly limited by the accuracy of the forecast model and its initial conditions. It has long been hypothesized, however, that forecast skill in certain flows will still have an intrinsic, finite limit even given arbitrary improvements in the quality of both the forecast model and initial conditions. The validity of this hypothesis, and quantitative estimates of the intrinsic limit of predictability for different scales and phenomena, are important issues as numerical weather prediction begins to focus on quantitative precipitation forecasts (QPF) and other forecast problems with small spatial scales and short time scales.

Zhe-Min Tan (Nanjing University, China) and Fuqing Zhang (Texas A&M University), together with Chris Snyder and Richard Rotunno, have explored the limits of predictability for precipitation within the context of an idealized, moist baroclinic wave developing in a channel (Tan et al. 2004). As in previous studies by F. Zhang, C. Snyder and R. Rotunno, they find rapid growth of forecast differences in regions of (parameterized) moist convection, which then contaminate larger scales. It is clear that this growth from small to large scales places an upper bound on the skill of QPF forecasts.

As an intermediate step between studying atmospheric predictability with simple models and with complex models such as the Weather Research and Forecast Model (WRF), Rebecca Morss, C. Snyder and R. Rotunno investigated the predictability of various quasigeostrophic (QG) flows, including a three-dimensional jet in a beta-plane channel and forced two-dimensional turbulence under both barotropic and surface-QG dynamics. Using the tangent linear and full non-linear versions of the model, they examined error growth rates, the power law of the energy spectrum, and the evolution of the error spectrum during error growth. They are

focusing on understanding interactions among errors in different scales and the effects on predictability, and on evaluating the long-standing hypothesis that there is a critical exponent for the energy spectrum (thought to be -3) above which flows have finite intrinsic predictability.

Error growth behavior

In the coming year, R. Morss, C. Snyder, and R. Rotunno will continue their investigation of QG predictability. They will focus on understanding the error growth behavior in the model, and on developing improved techniques for diagnosing predictability behavior that can be applied in more complex models, especially when error growth is strongly intermittent in space and time. They will then apply the results to more realistic flows to help delineate the mechanisms by which errors at the convective scale spread across the mesoscale to synoptic scales.

While the work of Zhang et al. has focused on the intrinsic limits of predictability, the practical predictability of synoptic-scale flows, given realistic observing systems, is also of interest. Analysis error statistics and their influence on forecast-error growth are crucial factors in determining practical predictability, and are poorly understood at present.

C. Snyder and Gregory Hakim (University of Washington) examine how various assumptions about analysis error statistics influence singular-vector (SV) calculations in the quasigeostrophic Eady model (Snyder and Hakim 2004). They propose an empirical covariance norm for SVs based on the assumption that potential-vorticity variance of analysis errors is small in the interior of the troposphere relative to the surface and tropopause. Their results show that a common conclusion from SV studies, namely that forecast errors arise principally from highly tilted structures in the mid- and lower troposphere, depends strongly on the assumption that the total energy norm approximates analysis-error statistics.

Next Topic: **Life Cycles of Precipitating Weather Systems**

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Lifecycles of Precipitating Weather Systems

Convection Initiation

The initiation of deep moist convection involves many time and space scales, including boundary-layer turbulence, interaction between the land surface and the atmosphere and moisture transport and lifting in the free troposphere. The studies herein are aimed at enhancing our knowledge of how convection begins and are closely linked with efforts in numerical prediction, statistical prediction (RAP), and data assimilation to better predict initiation in short-range (< 12 h) numerical forecasts. Observations from recent field campaigns such as the International H2O Project (IHOP) and the Bow-Echo and MCV Experiment (BAMEX) are keys to understanding convection initiation.

Dynamical Approaches

Stanley Trier completed a study with Fei Chen (RAP) and Kevin Manning that diagnosed simulations of convection initiation using a coupled land-surface mesoscale atmospheric model (MM5). This study isolated the importance of multiple scales of motion in the development of afternoon deep convection in the vicinity of a southern Great Plains dryline. Convection was initiated by fine-scale (1-10 km) circulations confined to ~100-km wide zone of enhanced early afternoon planetary boundary layer (PBL) depth, which itself resulted from horizontal differences on surface sensible heat flux and was reinforced by the ensuing mesoscale solenoidal circulation occurring over the sloped terrain with horizontal contrasts in soil moisture. This study illustrated that an improved forecast of convection initiation using a more detailed and accurate initialization of soil moisture resulted from subtle differences in lower-tropospheric thermodynamic structure even when the overall structure of the dryline moisture gradient remained relatively unaffected.

S. Trier and Christopher Davis have examined the kinematic and thermodynamic structure of mesoscale convective vortices (MCVs) generated by diabatic heating during the Bow-Echo and MCV Experiment (BAMEX) of 2003. MCVs have recently become of interest in convective research since model-produced convective forecasts have exhibited strong sensitivity to details of MCV location and structure. Composite analyses created using BAMEX field observations including dropsonde and mobile soundings combined with in-situ National Weather Service Profiler data constitute the most detailed look at mature MCV structure to date. A dipole pattern of lower tropospheric vertical motion with downshear (upshear) ascent (descent) was diagnosed in 3 of the 5 cases. The pattern of vertical motion was, however, more complicated for strong vortices occurring in weak vertical shear. Both the vertical motion pattern and vortex-induced horizontal advections resulted in large-differences in vertical shear and thermodynamic stability across the MCVs, which, in turn influenced the location of convective redevelopment. It appears that MCVs may act alone or with additional forcing mechanisms (e.g., frontal convergence) to focus convective redevelopment, with

regeneration of deep convection requiring a precursor large-scale thermodynamically unstable environment.

Statistical Approaches

S. Trier and David Ahijevych continued collaboration with Cindy Mueller, Dan Megenhardt and Nancy Rehak (each of RAP) on using mesoscale information on thermodynamic stability and convective precipitation forecasts to influence 0-3 h nowcasts of deep convection. A combined interest field based on parameters derived from RUC output was implemented into the RAP auto-nowcaster algorithm to influence areal growth of deep convection. Results from a test period during the 2004 convective season are currently being analyzed. Examination of several convectively active periods from 2004 has established both the utility of 20-km RUC analyses in estimating the lower-tropospheric vertical shear and the strong relationship between the shear and convective behavior in subsequent 0-3 h periods.

Matt Parker (University of Nebraska, Lincoln) and Jason Knievel explored spatial patterns in thunderstorm frequency to probe the widespread belief that population centers (especially those with large populations of meteorologists) are weather “holes”, local minima in frequency of convection. Statistical analyses of data from the WSR-88D network demonstrated that many places thought to be weather holes generally are not. The analyses also revealed other basic characteristics about the shape, timing, and motion of groups of thunderstorms. M. Parker and J. Knievel recommend that their techniques and datasets be used to formulate probabilistic rainfall guidance for parts of the United States where radar coverage is good. A forecaster might then use such guidance to adjust deterministic predictions from numerical models.

Convection Evolution

Once initiated, convection tends to organize to larger scales and may become a mesoscale convective system (MCS). The study of MCS dynamics is a cornerstone of mesoscale meteorology. New areas of emphasis involve use of newly acquired datasets to validate numerical and theoretical models of MCSs, and to probe the complexity of organized convection structures and the affect of these structures on mesoscale and synoptic-scale motions.

Validation of RKW Theory

According to RKW theory (Rotunno et al., 1988) the evolution of a convective line is shaped by the relative values of horizontal vorticity contained in the environmental wind profile versus the cold pool. RKW theory was originally based on numerical simulations of idealized squall lines by the classic Klemp-Wilhelmson (K-W) Model. George Bryan (ASP), Matt Parker (University of Nebraska, Lincoln), and Jason Knievel tested how well simulations by other models bear out the theory. It turns out that RKW theory is not specific to the K-W Model. Indeed, the theory's primary points are consistent with simulations by all three models that were tested: the Advanced Regional Prediction System (ARPS), the Weather Research and Forecasting (WRF) Model, and the Bryan-Fritsch (BF).

G. Bryan, along with David Ahijevych, Christopher Davis, and Morris Weisman, sought observational confirmation of RKW theory by calculating the intensity of convectively generated cold pools within mesoscale convective systems (MCSs) using dropsonde data from the Bow Echo and MCV Experiment (BAMEX). The results support the notion that cold pool intensity plays an important role in MCS structure. In addition, the analyses from this study show that many idealized modeling studies have insufficiently deep and strong cold pools, owing to the neglect of ice processes. Because cold pool intensity is difficult to estimate in real-time, the calculations from the BAMEX dataset are being used to develop a method to determine cold pool intensity from only surface observations.

The North American Monsoon Experiment (NAME)

NAME was designed to study multiscale aspects of the North American monsoon. This international field project employed surface, airborne, and ship-based observations to document the continental-scale circulation that transports vast amounts of tropical moisture into western Mexico and the Southwest United States during the summer months. These instruments captured several phases of the monsoon, including its onset, peak, and termination. D. Ahijevych and James Done served as S-Pol radar scientists and implemented the most

appropriate scanning strategy based on current scientific objectives and local conditions near Mazatlan, Mexico. This activity was also a valuable cross-divisional collaboration with ATD scientists, technicians and RAP software engineers.

Orographic Effects

The presence of orography induces numerous local enhancements and reductions of rainfall, and these effects are generally less predictable than thought, especially when the atmosphere is unstable to deep, moist convection. In addition orography induces numerous downstream effects on rainfall that must be quantified and properly represented in models.

Warm Season Orographic Influences

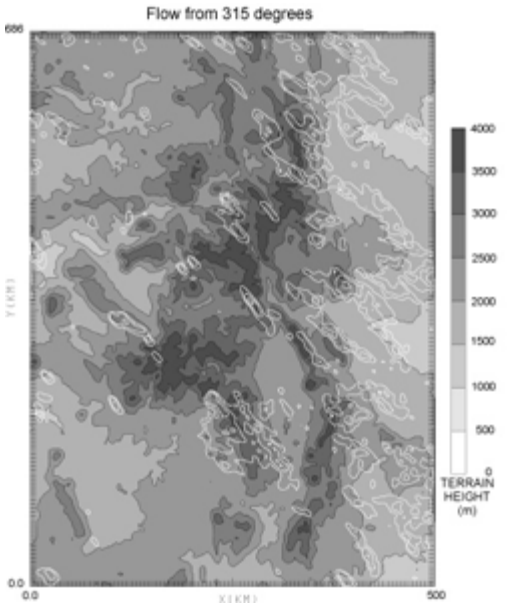

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Figure 25. *12 hour accumulated precipitation (contours) for northwest flow over the Rocky Mountains (grayscale). Contours are at 2, 4, 8, 16 and 32 mm.*

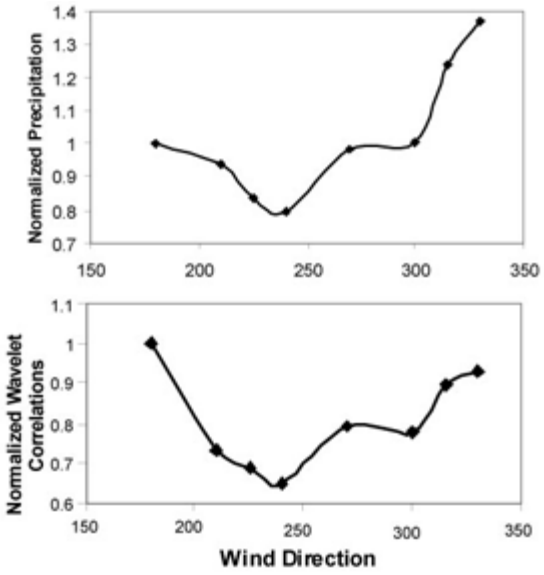

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Figure 26. *(top) Precipitation accumulation versus wind direction. (bottom) Wavelet correlations of terrain elevation versus wind direction.*

Andrew Crook and Donna Tucker (University of Kansas) have completed a study of the flow over heated terrain. In Part I of this study, an analytical model was developed of the dry response to flow over heated topography. The individual responses to orographic and thermal forcing are first considered and then combined response is examined. It is shown that if the terrain is stretched preferentially in one direction, then the leeside lifting will be maximized if the large scale flow is along that direction. In Part II of this study, these results are applied to the complex topography of the Rocky Mountains. From **Figures 25** and **26**, it is evident that the precipitation accumulation is maximized for flow from the northwest and minimized for flow from the southwest. A wavelet analysis (**Figure 25**) applied to the terrain of the Rocky Mountains shows more topographic features that are stretched preferentially in the NW/SE direction than in the SW/NE direction. These results are important for understanding statistics of orographic rainfall and are potentially useful for validation of weather and climate prediction models.

Taking a larger-scale perspective on orographic, warm season rainfall, D. Ahijevych analyzed warm-season rainfall with spatally-averaged diurnal composites of precipitation frequency. The sharp coherence of propagating rainfall extending from the Central Massif of the Rockies through the Midwest was documented in Carbone et al. (2002). At first, the 2002 warm season coherence of rainfall looked very different from the previous six years, but after accounting for the east-west position of the Rocky Mountains, the characteristic timing and location of the diurnal precipitation peak reappeared. This illustrated the remote effect of orography on precipitation frequency hundreds of kilometers downstream. Plus, it highlighted two-dimensional aspects of

the Rocky Mountain-Great Plains atmospheric circulation.

Cool Season Orographic Influences

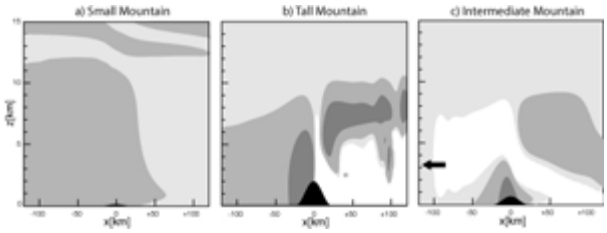

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Figure 27. *Cloud water mixing ratio q_c where white indicates regions of q_c < 0.01 g/Kg, light grey, 0.01g/Kg <q_c<0.1g/Kg, medium gray, 0.1g/Kg<q_c< 0.5g/Kg, and dark gray, q_c>0.5g/Kg. Environmental flow is from left to right with initial q_c = 0.05 g/Kg. Panel a) shows that if the mountain height is small enough, a saturated flow can be maintained everywhere given sufficient initial cloud water. Panel b) shows that for tall mountains the atmosphere upwind of the mountain is maintained in a saturated state and transitions to an unsaturated downslope flow on the lee side (which has characteristics associated with downslope windstorms.) Panel c) shows that for mountains of intermediate height, the solutions have the unexpected feature of an upwind-propagating disturbance which has the effect of desaturating the atmosphere above the mountain..*

Although a fairly common atmospheric condition in orographic-rain scenarios, there is relatively little known about moist neutral flows over a ridge from theory and modelling. To shed light on this important flow regime, M. Miglietta (Il Consiglio Nazionale delle Ricerche (CNR), Italy) and R. Rotunno have conducted numerical simulations of the orographic-flow modification occurring for a two-dimensional moist nearly neutral flow over a ridge. If an initially saturated moist neutral flow were to remain everywhere saturated as it flows over an obstacle (**Figure 27a**), then the expected solution would be the linear solution because then the condition for linearity (hill height less than the ambient wind velocity/static stability) is always met. However for tall mountains (**Figures 27b** and **27c**), the numerical solutions indicate the development of areas of unsaturated air, with correspondingly larger values of local static stability. This internal switching from small to large values of static stability is an inherent nonlinearity which has far-reaching consequences for understanding the orographic-flow modification in this regime. M. Miglietta and R. Rotunno find that the numerical solutions fall into three basic categories as summarized in the figure.

M. Ralph (NOAA/ETL), P. Neiman (NOAA/ETL) and R. Rotunno used dropsonde observations to document the mean vertical profiles of kinematic and thermodynamic conditions in the pre-cold frontal low-level jet (LLJ) region of extratropical cyclones over the Eastern Pacific Ocean. This LLJ region is responsible not only for the majority of heavy rainfall induced by orography when such storms strike the coast (**Figure 28a**), but also for almost all meridional water vapor transport at midlatitudes. The data were collected from NOAA's P-3 aircraft in ten storms during the CALJET experiment of 1998 (during El Niño) and in seven storms during the PACJET experiment of 2001 (during La Niña). Although the composite winds, temperatures and water vapor mixing ratios in 2001 differed markedly from 1998, Ralph, Neiman and Rotunno found that the moist static stability remained near zero from the surface up to 2.8-3.0 km altitude for both seasons (**Figure 28b**). Hence, they concluded that orographic precipitation enhancement is favored in this sector of the storm, regardless of the phase of ENSO. Although the total meridional water vapor transport in 1998 was about twice that in 2001, the vertical structure of the transport was nearly invariant.

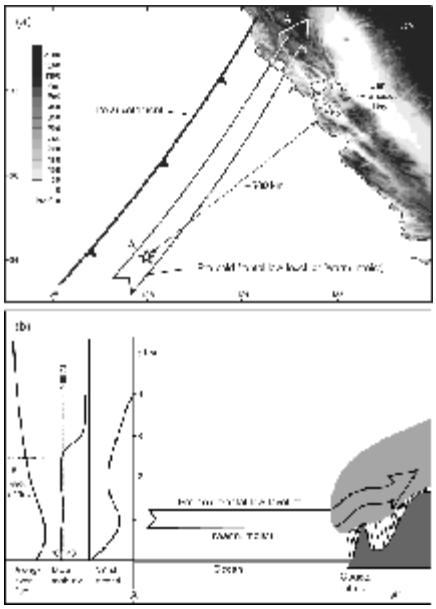

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Figure 28. *Conceptual representation focusing on conditions in the pre-cold-frontal low-level jet (LLJ) region of a land-falling extratropical cyclone over the northeastern Pacific Ocean. (a) Plan-view schematic showing the relative positions of a LLJ and trailing polar cold front. The average position of the 17 dropsondes used in this study is shown with a star (~500 km offshore of San Francisco), and the Cazadero microphysics site is marked with a bold white dot. The points A and A' along the LLJ provide the approximate endpoints for the cross section in panel b. (b) Cross-section schematic along the pre-cold-frontal LLJ (i.e., along AA' in panel a) highlighting the offshore vertical structure of wind speed, moist static stability, and along-river moisture flux at the location of the altitude scale. Schematic orographic clouds and precipitation are shown, with the spacing between the rain streaks proportional to rain intensity.*

Basic Measures of Orographic Precipitation

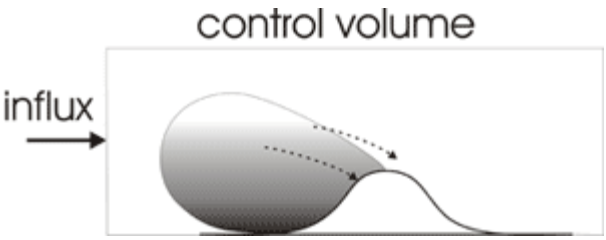

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Figure 29. *Setup for idealized orographic precipitation studies.*

Idar Barstad and Ronald Smith (both Yale University) and P. Smolarkiewicz quantified the atmospheric water cycle for idealized orographic flows to gain insight into orographic precipitation. They identified three measures of efficiency for characterizing orographic precipitating systems. The global measure, referred to as the drying ratio (DR), which determines the fraction of water vapor influx that turns into precipitation; while the interior measure, condensation ratio (CR) and the precipitation efficiency (PE), describe the conversion processes. In order to assess how these measures depend on external parameters (e.g., mountain width and surface temperature) two distinct mathematical models were used: i) a fully nonlinear numerical model that conserves water substance (EULAG), and ii) a linear orographic-precipitation model that has linearized micro-physics and airflow dynamics. A series of simulations of 2D flows past a Gaussian-shaped ridge, using a warm rain scheme in the nonlinear model, revealed that DR increases for decreasing temperatures and increasing mountain width. The idealized setup for the numerical experiments is shown in **Figure 29**. The re-evaporation efficiency of condensated water (PE) is strongest at low temperatures. Despite discrepancies between the two models, both show increased re-evaporation as the mountain width decreases.

Long-time-scale dynamics of mesoscale convective systems

Following the initiation of convection and its growth to a mesoscale convective system, longer-time-scale organization of convection is possible. This organization may take the form of continental-scale coherence of rainfall, involving multiple MCSs. Tropical cyclones are also an example of multi-day coherence of convection. In many problems, the key to understanding, and the crtical issue for representation in regional and large-scale

models, is the upscale growth of vorticity and the emergence of balanced flow structures. Work described herein naturally links with global and regional climate modeling as well as short-range (1-2 day) precipitation prediction.

Continental Convection

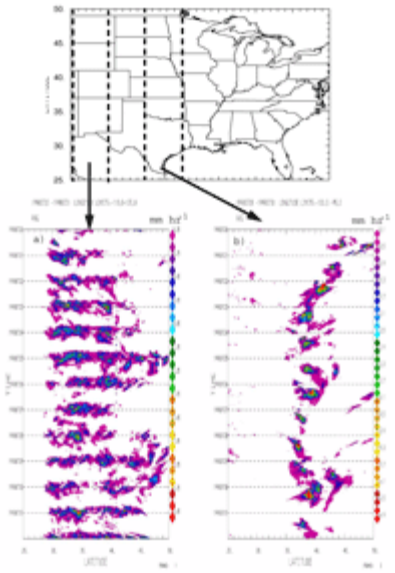

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Figure 30. *Time-latitude (Hovmoller) plots of radar derived rainfall rates averaged over a)110-105 W and b) 95-100 W longitude bands for July 20-31, 1998. The daily occurrence of convection over the higher terrain of the Rocky Mountains from Mexico to the Canadian border (Fig. 3a) is evident, but only a small fraction is long-lived and propagates into the central plains, arriving 8-10 hours later (Fig. 3b).*

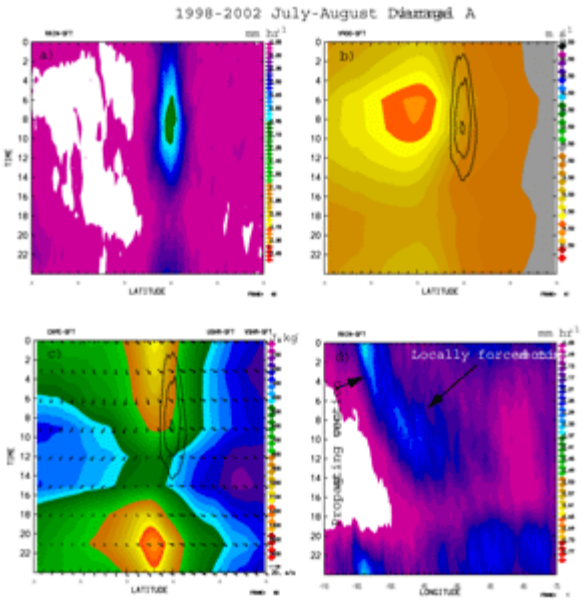

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Figure 31. *Diurnally averaged a) rainfall b) meridional component of the 900 mb winds c) CAPE and low-level wind*

During the midsummer there often exists a well-defined corridor of precipitation episodes across the central U.S. Such corridors are, at best, weakly related to synoptic scale forcings. The corridor location typically persists 3-7 days with significant variability on the inter-seasonal timescale (**Figure 30**). A corridor will experience excessive cumulative rainfall while nearby regions may be well below normal. Understanding the nature and forcing mechanisms leading to the corridors has important implications for QPF and the
quantification of precipitation regimes.

Using the U.S. national composited radar data and RUC (Rapid Update Cycle) model analysis for the 1998-2002 warm seasons (July-August), John Tuttle examined the relationship of precipitation corridors to various forcing mechanisms over the central U.S. While the corridors show the expected correlation to CAPE and shear.

A surprising find is the strong relatioship to the nocturnal low-level jet (**Figure 31**). Even in the five-year averaged data, the precipitation corridor is strongly associated with the exit region of the LLJ (the region of maximum moisture convergence). The precipitation maximum at 6:00-10:00 UTC is a combination of convective systems propagating into the area from the east slopes of the Rockies and convection forming locally in response to the enhanced convergence of the LLJ. On days when the LLJ is weak or non-existent, there are virtually no propagating convective systems. For days having a stronger LLJ, the total precipitation is stronger and a greater percentage of the precipitation develops locally.

A large-domain, convection-resolving simulations of one such corridor lasting 7 days over the Central U.S. was performed by S. Trier, C. Davis and Sherrie Frederick using the WRF model. The observed convection propagated over large longitudinal differences (~1000 km) but was confined to a relatively narrow latitudinal corridor, where deep tropospheric moisture and at least moderate vertical shear were collocated. High resolution simulations with explicit deep convection were able to accurately replicate characteristics of the observed coherent rainfall episodes including frequency, longevity,

shear (between 600 and 900 mb) in time-latitude plots over the domain shown in Fig. 3b and d) rainfall in time-longitude format. During the averaging process the rain and RUC data were shifted in the north-south direction to 40 deg latitude using the centroid of the rain data as a reference. This allows for a presentation of the average RUC fields with respect to the convection.

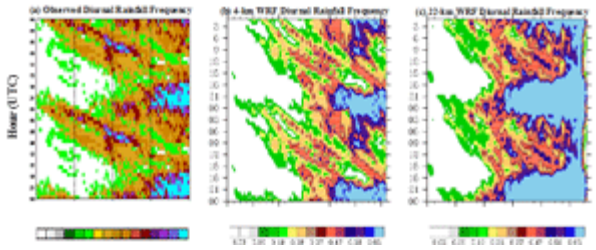

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Figure 32. *Comparison of normalized diurnal frequency diagrams of hourly, latitudinally averaged (30-48 N) precipitation greater than 0.1 mm/h during 3-10 July 2003 derived from (a) stage IV rainfall observations, (b) the 4-km WRF simulation that used explicit deep convection, and (c) the 22-km WRF simulation that used a cumulus parameterization.*

propagation speed and diurnal frequency of precipitation (**Figure 32**).

A broad spectrum of phase speeds were found with both the observed and simulated coherent rainfall episodes in the common large-scale environment suggesting that the propagation is likely to have an internally generated component. Simulations performed on a 22-km grid exhibited fewer rain streaks with a poor representation of the observed distribution of phase speeds. These latter results agree with those obtained by C. Liu, using the MM5 model.

Arlene Laing examined the propagation characteristics of African rainfall as part of a multi-year study of the lifecycles of precipitating systems globally. The study is aimed at understanding rainfall patterns in different regions of the world, and ultimately at validating and improving the prediction of precipitation in weather and climate models. Following Hovmoller techniques developed by John Tuttle for radar data, full resolution Meteosat infrared images were used to identify patterns of deep convection. These analyses showed that precipitating convection in Africa exhibit coherent patterns or episodes that are similar the continental United States (US) and East Asia (**Figure 33**). The mean zonal span and duration for May to August 1999 were 847km and 17.9h. Most episodes had phase speeds of 10 - 20 ms-1, generally near the maximum speed of the African Easterly Jet around 600 hPa. Convection showed orographic initiation and occasional marked coherence in diurnally averaged rainfall frequency (**Figure 34**). These early findings support the notion that that precipitation cycles may be predictable beyond one or two days.

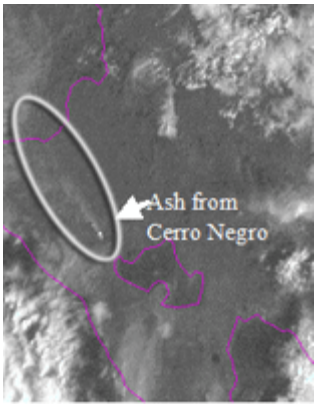

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Figure 33*. Hovmoller diagrams of cloud top brightness temperature <213K for the period of 1-15 July 1999.*

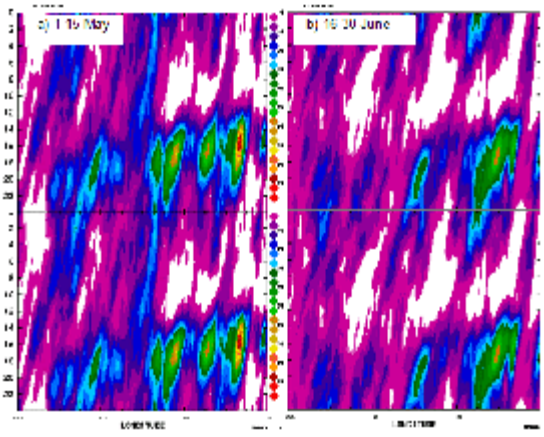

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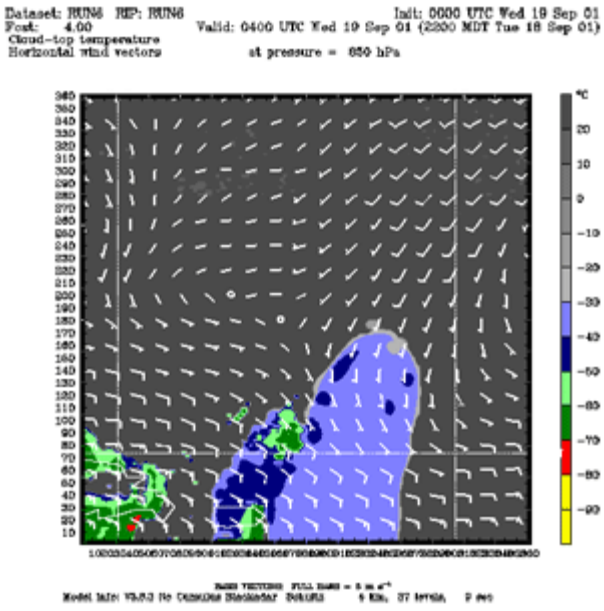
Figure 34. *Mean diurnal cycle for (a) 1-15 May, (b) 16-30 June 1999. Times are UTC. The more rapid movement is the westward march of the solar heating maximum, while the streaks moving around 15 ms-1 are manifested by multiple convection systems.*

Tropical Cyclones

C. Davis and Lance Bosart (University at Albany SUNY) continued their study of the tropical transition of

Atlantic disturbances of extratropical origin. Tropical transition exhibits large interannual variability and tends to produce more storms in years when Cape Verde storms (formation from easterly waves) are less common. Tropical transition can occur close to land and make landfall before appropriate coastal preparations are made (e.g. Hurricane Alex of 2004). C. Davis and L. Bosart have examined the formation of Hurricane Humberto (2001), a storm forming in the subtropics in response to an upper-tropospheric cold low of extratropical origin. The Humberto simulations conducted with MM5 began before lower tropospheric cyclonic vorticity was evident, but produced a tropical storm in 96 h using a fully explicit treatment of convection (**Figure 35**). The development was episodic in the model, featuring numerous bursts of convection, initially triggered downshear from the upper low, and concomitant weakening of the vertical wind shear as relative vorticity increased in a stepwise fashion. A companion simulation, without the upper low, yielded a much broader region of cyclonic vorticity and no well-defined surface cyclone (**Figure 36**).



Click image to view the larger animation.

Figure 35. *Animation of wind at 850 hPa and cloud-top temperature from MM5 simulation of the genesis of Humberto. Time increment is 0.5 h. Winds are plotted every 15 grid points*

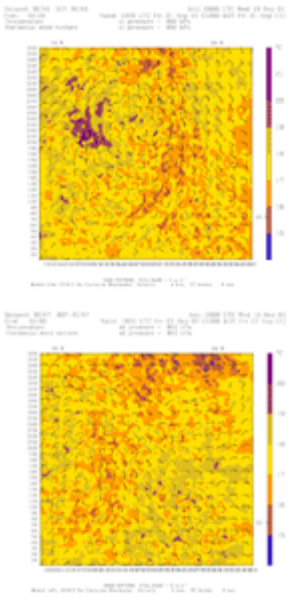


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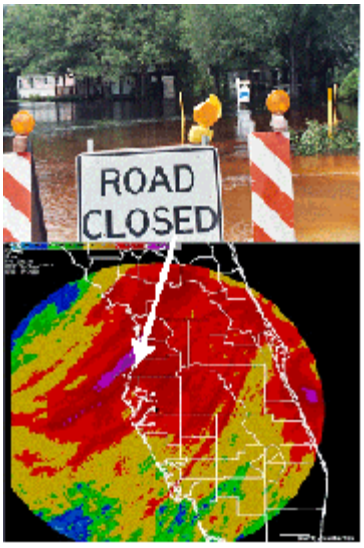
Figure 36. *850 hPa wind and temperature at 66 h from (a) control simulation and (b) simulation with upper-tropospheric cold low removed.*



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Heavy precipitation and associated flooding are among the deadly aspects of hurricanes at landfall. As part of a continuing study of the geographical influences of hurricane-related floods, A. Laing and Graham Tobin (University of South Florida) conducted a three-day field survey of flooding in the aftermath of Hurricane Frances (**Figure 37**). West-central Florida experienced widespread flash floods, urban floods, and several moderate to major river floods. Among the factors that influenced the greater flood impact were

1. antecedent precipitation from two tropical cyclones and above normal precipitation during July and early August;
2. Frances stalled along the east coast and moved very slowly across the peninsula;
3. Frances was approximately twice the size of the previous system, thereby drawing moisture from both the Atlantic and the Gulf of Mexico; and (4) a second landfall along the Florida panhandle brought additional rain bands across the

Figure. 37. Elfers Parkway at Elfers River, Pasco County, Florida, 9 September 2004. b) Storm total precipitation for 4-7 September 2004.

state.

The interaction of inertia-gravity waves and balanced flows

Improved prediction of precipitation, particularly in the short range and at the mesoscale, depends in part on predicting, and understanding, the occurrence of inertia-gravity waves in mesoscale flows. For example, the jet stream in the mid-latitudes is known from observations to be an important source of inertia-gravity waves (IGW), but the mechanisms responsible for such generation of IGW are poorly understood, let alone quantified.

In collaboration with David Muraki (Simon Fraser University, Burnaby, Canada) and C. Snyder, Riwal Plougonven (formerly ASP/MMM postdoc, now University of St. Andrews) is investigating how baroclinic instabilities can generate IGW. The idealized case of baroclinic instabilities on a constant vertical shear allows the analytical quantification of the amplitude of the gravity waves as a function of flow parameters, as shown in Plougonven et al. (2004). This fundamental study contributes to the understanding of the relation between balance and gravity waves in a shear flow.

D. Muraki and C. Snyder also developed exact solutions for a vortex dipole in the surface quasigeostrophic equations (Muraki and Snyder 2004). This dipole is a steadily propagating, balanced, coherent structure that decays rapidly with height. It represents an ideal starting point for examining the interaction of balanced flows with IGW, since any emitted waves will have clear signatures aloft owing to the decay of the dipole.

Cloud microphysics and precipitation

Microphysics studies, both laboratory and field studies, are critical for understanding processes leading to precipitation in clouds and ultimately the integrated effects of phase changes of water on the dynamics of precipitation systems.

Charles Knight completed a study first radar echoes using the STEPS data, emphasizing particularly new information that can be supplied by the differential reflectivity (ZDR) in the early stages of precipitation. It is not uncommon for there to be temporary, positive ZDR columns to 6 or 7 km MSL, indicating mm-sized water drops being elevated to these levels before freezing, just as the first precipitation echo is forming. The ZDR column is at the upshear side of the updraft, and generally separated from what has been conventionally called the first precipitation echo, which forms downshear of the updraft. The freezing of these drops may be important in the spread of the ice phase in these early cumulus clouds.

C. Knight started and completed a study of ice spikes. These form in the early stages of partly-confined freezing of liquid water, by the volume change squeezing water out the last opening in the surface. Sometimes this water does not spread out over the ice surface, but grows into a hollow, water-filled ice spike that grows only at its tip as the liquid water is extruded. These form on freezing drops in the atmosphere, and have been implicated in ideas of ice multiplication in clouds, and also form on ice growing in ice cube trays if pure water is used. The spikes are usually composed of either two or three crystals, and their crystal orientations are a critical factor in determining whether spikes form or not. This has been basic research, leading to a much better understanding of this particular phenomenon (which had not been studied previously in this way), but with no direct, immediate application.

Next Topic: Surface-Atmosphere Interactions

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Surface-Atmosphere Interactions

Land-Atmosphere Interaction

Canopy EOF analysis

Edward Patton, Roger Shaw (University of California, Davis) and John Finnigan (CSIRO, Australia) are using empirical orthogonal function (EOF) analysis to extract the “characteristic eddy” from large-eddy simulations of turbulent flow above and within a plant canopy. The analysis reveals the three-dimensional structure of organized canopy motions with only limited a priori assumptions The eddy structure that emerges from the analysis appears much like the double roller vortices characteristic of plane mixing layers (**see Figure 38**). Future work will use the EOF analysis to develop a low-dimensional model of canopy exchange processes for use in assimilating measurements and parameterizations of land-surface exchange.

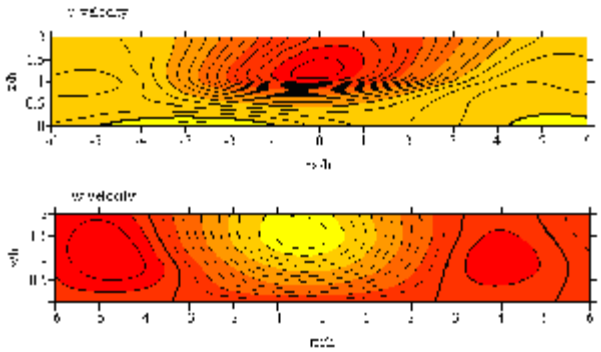

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Figure 38. *Characteristic eddy constructed from the first eigenmodes and first four wavenumbers of a three-dimensional EOF analysis using data from a canopy-turbulence resolving large-eddy simulation. The figure depicts x-z slices through the eddy of u-velocity (top) and w-velocity (bottom), where solid (dashed) lines represent positive (negative) values and the bold line represents zero velocity. The domain is 12h by 2h where h is the canopy height. Notice (center of the figure) how sinking motion brings high momentum fluid from aloft down into the canopy.*

Canopy turbulence under stable stratification

Using high-resolution large-eddy simulations, E. Patton and Peter Sullivan are investigating the interplay between stable stratification and canopy turbulence. Compared to simulations with no vegetation, a stably stratified canopy reduces the height of the nocturnal jet and the pressure drag alters the momentum balance resulting in lower turbulence levels and a reduced PBL depth (**see Figure 39**). Future research will investigate turbulent flow over

canopy covered complex terrain. This work is ultimately aimed at improved upscaling of carbon dioxide measurements and parameterizations of canopy exchange in larger-scale models.

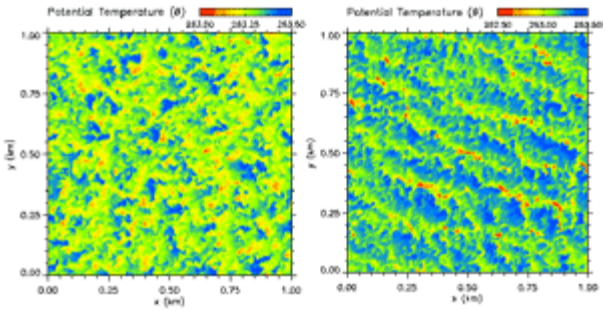

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Figure 39. *Instantaneous horizontal slices of potential temperature at a height of 25m for two large-simulations of stably stratified turbulence (z_i/L=2). Both simulations are identical, except the simulation depicted on the right includes the influence of pressure drag imposed by spatially distributed plant matter. The canopy has dramatically modified the structure of the PBL turbulence.*

Energy transfer under nocturnal stable conditions

Jielun Sun, in collaboration with Sean Burns at NCAR, Richard Coulter (Argonne National Lab), and Robert Banta (ETL/NOAA), continued analyzing the data collected from the Cooperative Atmosphere-Surface Exchange Study-1999 (CASES-99). She focused on the statistical characteristics of various atmospheric disturbances – density currents, solitary waves, and internal gravity waves. She found that these disturbances were more likely to occur with northerly winds of magnitude less than 4-6 m/s. A temperature drop associated with the density current is more obvious at upper levels due to the temperature increase with height at night. High frequency internal gravity waves are frequently observed at higher levels as their counterparts near the surface are easily wiped out due to strong-shear generated turbulence mixing. Under weak wind conditions, density currents are observed about 50% of the time in the early evening and are most often associated with wind perturbations from the northeast. This implies that drainage flows are a possible cause of the observed density currents. In addition, nocturnal temperature oscillations tend to be associated with pressure oscillations that have long periods. Further information can be found at http://www.mmm.ucar.edu/science/abl/cases/cases.html. Future work will compare tower and remote sensing data to identify influences of ground drainage flows and upper low-level jets on intermittent turbulence. Next, she will examine the statistical impact of intermittent turbulence on the nocturnal boundary layer structure. This work will lead to further understanding and parameterization of the nocturnal boundary layer.

CO2 transport over complex terrain

Jielun Sun, along with Russ Monson, Susan Buhr (both University of Colorado), Dave Schimel, Britton Stephens, Steve Oncley, Tony Delany (ATD), Dennis Shoji Ojima (Colorado State University), Leonel Sternberg (University of Miami), and Dean Anderson (USGS), collaborated on an NSF sponsored program to study carbon sequestration in complex terrain. She participated in the aircraft field campaign (ACME, Airborne Carbon in the Mountains Experiment) in May and July 2004 and a ground field campaign (CME-04, Carbon in the Mountains Experiment) that has been underway since May 2004. Also, she continued analyzing data collected at the Niwot-Ridge AmeriFlux site. She found that the spatial distribution of CO2 is sensitive to major steep slopes, small gullies embedded in these steep slopes, and that nocturnal drainage flows associated with topography plays an important role in nighttime CO2 transport. In the early morning, a sudden decrease of CO2 storage in the canopy layer is observed and results from upslope flows and upward turbulent transport. Preliminary analysis of the aircraft data also confirm an accumulation of CO2 at low levels even on large scales. These results provide critical information on the many on-going long term observational programs, which currently ignore horizontal transport in the global CO2 budget. Additional information is provided in http://www.mmm.ucar.edu/science/abl/cme/cme.html. In the future, she will continue to work closely with colleagues funded by the NSF project and from the NCAR Biogeoscience initiative on analyzing data collected during CME-04 and ACME. Meanwhile, she will work on a

new research plan to further investigate CO2 transport over complex terrain on regional scales.

Carbon in the Mountains Experiment: Tower Work

S. Burns in collaboration with Russ Monson (University of Colorado) collected and analyzed meteorological, carbon dioxide, and flux data from the University of Colorado Ameriflux tower. Ameriflux is a network of towers located across North and South America that is attempting to better quantify carbon budgets on continental scales. The Colorado Ameriflux Tower is also part of CME (Carbon in the Mountains Experiment) that took place from May 2004 to July 2004. The tower will continue to collect data throughout FY05. The following animation (**Figure 40 animation**) depicts CO2 evolution at the CME site.

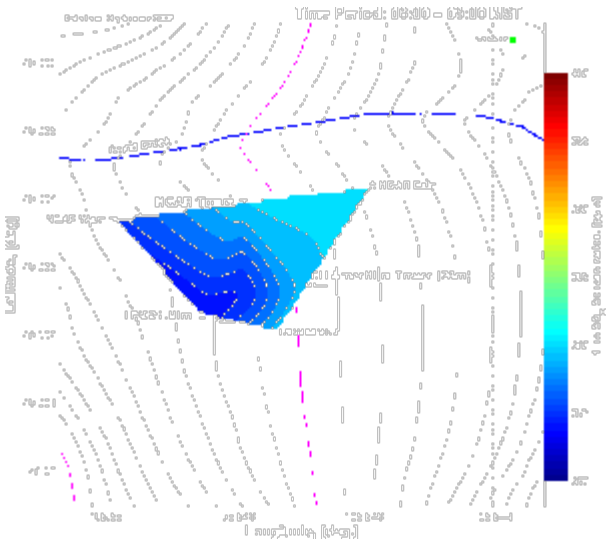

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Figure 40. *The mean diurnal pattern of carbon dioxide concentration at 1-m height in a sub-alpine forest collected during September 2002. The time (MST, mountain standard time) of the image frame is indicated in the upper right of the images. Elevation contours are every 5m.*

CO2 Transport Beneath a Snow pack

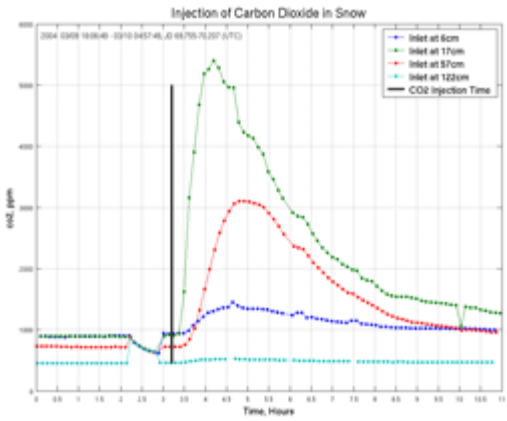

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Figure 41. *Temporal evolution of carbon dioxide concentration at various vertical and horizontal locations within a forest snow pack. The time of the carbon dioxide injection is indicated by the dark vertical line (between 3-3.5 hours).*

S. Burns in collaboration with Tony Delany (ATD), Mark Williams (INSTAAR), and Russ Monson (University of Colorado) examined carbon dioxide diffusion rates within the snow pack of a sub-alpine forest. Transport of CO2 through a snow pack determines the rate at which biologically-generated CO2 in the soil is released to the atmosphere and can significantly impact global CO2 budgets. The rate of CO2 transfer in snow depends on several parameters including: wind speed, snow density, and ice layers. Using "HYDRA" (a multi-inlet CO2 measuring system developed by Tony Delany at ATD) a preliminary study was carried out in 2004 with a more extensive study planned for winter 2004-2005. An example of CO2 transport is shown in **Figure 41**. Here CO2 is injected into a snow pack and the resulting CO2 concentration is monitored at different inlet locations within the snow pack.

International H2O Project (IHOP_2002) surface-impact on the atmosphere

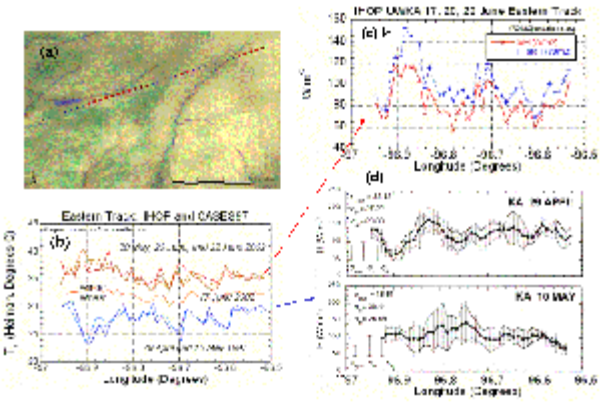

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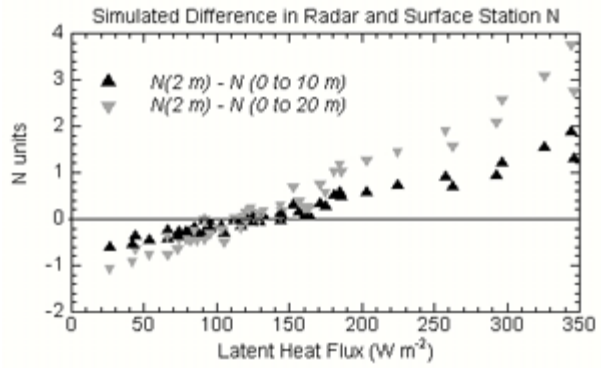
Figure 42. *Effect of surface cover on sensible heat fluxes based on data from the University of Wyoming King Air. (a). AVHRR NDVI. Green areas have more winter wheat; dots denote flight track (figure courtesy Bob Grossman), (b) Radiometric surface temperature fluctuations (1-km averages, averaged over all low-level legs (altitude: 30-40 m for CASES-97, 60-70 m for IHOP), (c) Sensible heat flux H for IHOP (1-km averages, 21-leg average, days weighted equally), and (d) H CASES-97 (4-km averages, 4-leg average).*

Margaret LeMone, Diane Strassberg (MMM student assistant), Joe Alfieri (RAP student assistant), and Robert Grossman (CoRA) compared IHOP data to CASES-97 data to illustrate the important role that vegetation (in this case winter wheat and grass) plays in the distribution of sensible (SH) and latent heat (LE) near the surface. Panel a) of **Figure 65** shows the distribution of winter wheat (green areas on lower right) along the flight track (dots) located southeast of Wichita, Kansas. This flight track is the same one used in CASES-97. The remaining frames show the impact of the surface cover on radiometric surface temperature and sensible heat flux. Note that the IHOP radiometric surface temperature Ts in panel b) of **Figure 42** is relatively warm over the winter wheat area along the western portion of the flight tack, with a secondary maximum corresponding to a second wheat area around -98.7o longitude. For CASES-97, there are Ts minima at the same two locations. The changes correspond to the winter-wheat life cycle: the wheat is green and rapidly growing in late April to early May, matures by late May, and is harvested by the middle of July. Note that the weaker horizontal variation on 17 June is related to recent rainfall (15 June); the other IHOP days had more than five days since the last heavy rain. For CASES-97, there was rain on 7-8 May and there was no rain for over a week before 29 April. The warm surfaces correspond to higher sensible flux. For IHOP, the two warm winter wheat areas have higher sensible heat flux (**Figure 59**). Similarly, the cool growing winter wheat areas have correspondingly low sensible heat flux. The pattern is less strong on 10 May because of more recent rains and less contrast between the grass and winter wheat (panel d) of **Figure 65**. LeMone is also collaborating with Songlak Kang, Ken Davis, and Kenneth Craig of Pennsylvania State University on explaining horizontal variability in surface fluxes along the "Western Track," which runs north-south across the eastern Oklahoma Panhandle.

Verifying radar-based refractivity variations



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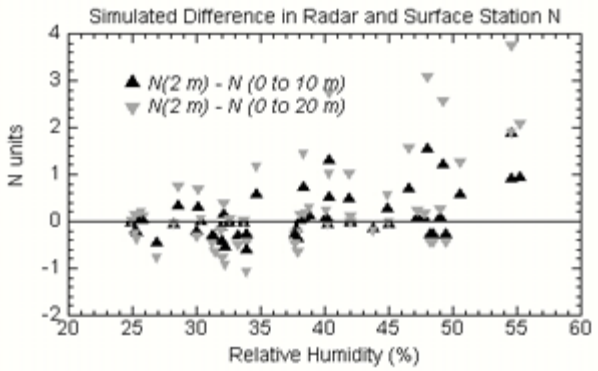

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Figure 43. *Fair-weather noontime data from IHOP_2002 flux stations 1-3, differences between refractivity estimated from 2-m measurements, and average refractivity estimated from standard flux-profile relationships, as a function of (top) surface latent heat flux and (bottom) relative humidity.*

One of the objectives of IHOP_2002 was to test Frederic Fabry's radar-based method to obtain near-surface refractivity (and hence, information about the near-surface mixing ratio and temperature fields). Using software

developed for the GLOBE program to calculate surface-layer profiles, M. LeMone showed that changes in temperature and mixing ratio with height accounted for at least part of the systematic humidity-related change in bias between refractivity determined from radar and refractivity calculated from measurements taken at 2 m found by Tammy Weckwerth and Crystalyne Pettet of ATD, Frederic Fabry and ShinJu Park of McGill, and James Wilson of RAP. M. LeMone assumed that radar estimates of refractivity, based on propagation time from the radar to ground targets, corresponded to averages in the lowest 10-20 m of the atmosphere. Flux-profile relationships predict that larger latent-heat fluxes are associated with steeper falloff of specific humidity with height. This leads to a "low" bias for the radar with high latent-heat fluxes. Because high relative humidity tends to be associated with high latent heat flux for the data used, the low bias is also seen at high relative humidities (**see Figures 43a** and **43b**).

Sensitivity of convective initiation/propagation to land-surface models

Teddy Holt (Naval Research Laboratory), Dev Niyogi (North Carolina State University), Fei Chen (RAP), and Kevin Manning and M. LeMone from MMM compared the sensitivity of precipitating convection modeled in the Navy COAMPSTM model to soil-moisture initiation and LSM representation of evapotranspiration. The differences in simulated fluxes, boundary layer height, and dryline behavior were significant, resulting in significant differences in initiation, horizontal distribution, and propagation of convection, even in a strongly-forced situation. Comparison of modeled and surface near-surface fluxes and means was not straightforward, since small horizontal displacement of modeled features resulted in large differences at a point.

Atmospheric response to spatial variations in soil moisture

Jielun Sun, in collaboration with Larry Mahrt and Dean Vickers (both Oregon State University), Tom Jackson (NASA), Ian MacPherson (National Research Council, Canada), Paul Houser (NASA Goddard Space Flight Center), and Eleanor Burke (University of Arizona), investigated the response of atmospheric moisture flux to temporal and spatial variations in soil moisture and vegetation variability. She reviewed common modeling approaches and investigated alternate formula for computing evapotranspiration taking into account soil moisture and surface type. The aircraft data collected during the Southern Great Plains (SGP) over various surface types are used to examine a simple formula for evapotranspiration. For further information see http://www.mmm.ucar.edu/science/abl/sgp/sgp.html

Numerically Simulated Contaminant Dispersion

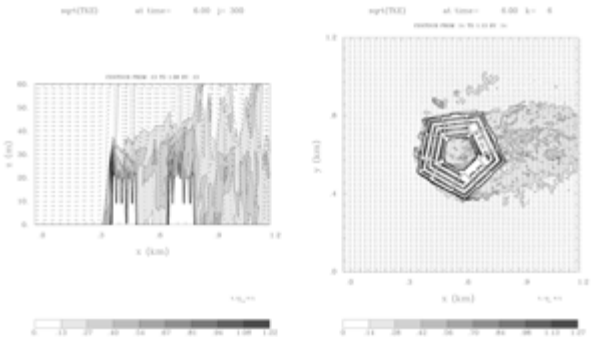

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Figure 44. *Caption: Simulation of a flow past Pentagon building, with 2 and 1 m resolution in the horizontal and vertical respectively, using Gal-Chen & Somerville coordinate transformation. Contours of square root of turbulent kinetic energy are shown in the central y-z cross section(left), and in x-y cross section at z=10 m (right).*

Robert Sharman (RAP) and P. Smolarkiewicz conducted numerical studies of urban boundary layer flows and contaminant dispersion in the vicinity of the Pentagon using EULAG (**Figure 44**). The objective is to quantify airflow characteristics under various meteorological conditions, with emphasis on predicting the concentration levels of hazardous contaminants as they disperse and collect in recesses. A series of simulations for both high and low Reynolds number flows is needed to complement and compare to field observations and wind tunnel measurements. So far, they have focused on high Reynolds number flows for various choices of physical and numerical parameters, in order to assess the optimal model configuration. Among others, the simulations using standard terrain-following coordinates were compared with an immersed-boundary approach. Contrary to experience with other simulation models, EULAG represents steep urban structures as terrain-following orography and produces results qualitatively similar to the immersed-boundary approach. Generalization of this approach should lead to better representations of internal boundaries in atmospheric and oceanic numerical simulation models.

Ocean-atmosphere interaction at turbulence- and mesoscales

Subfilter Scale Motions in Marine PBLs

Peter Sullivan, John Wyngaard (Pennsylvania State University), James Edson (Woods Hole Oceanographic Institute) along with NCAR investigators in MMM and ATD planned, implemented, and carried out the Ocean Horizontal Array Turbulence Study (OHATS) utilizing the air-sea interaction tower (ASIT) operated by Woods Hole Oceanographic Institute. The ASIT is located approximately 3 kilometers off the coast of Martha's Vineyard in 15 meter deep water with a southwesterly exposure open to the Atlantic ocean. The experimental design and layout of the sensors in OHATS targets the measurement of turbulence variables in the marine surface layer along with simultaneous wave information. Turbulence (three velocity components and potential temperature) was measured using 18 sonic anemometers and wave information (height and propagation direction) was collected using 3 laser altimeters. This data will be used to construct subfilter scale motions that are modeled in LES codes and will potentially establish correlations between marine surface layer turbulence and wave states. The duration of the field campaign was approximately two months starting 1 August 2004 and ending 1 October 2004 with continuous data collection. The observations span a regime of light to modest strength winds, unstable to very stable stratification, and a variety of wave states. A preliminary sweep through the dataset has identified more than 280 hours of data that will be interrogated in future analysis. Further information, including a gallery of photographs and preliminary data, can be found at http://www.atd.ucar.edu/rtf/projects/OHATS04 and http://www.whoi.edu/science/AOPE/dept/OHATS/intro.html.

LES of High Wind Ocean Mixed Layers

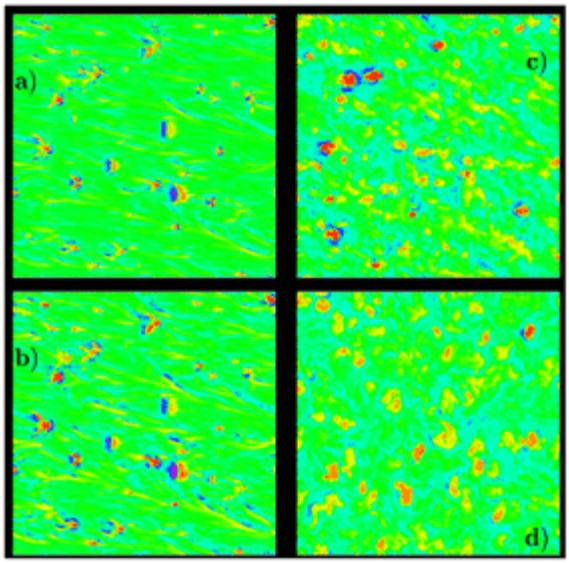

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Figure 45. *Snapshots of instantaneous w velocity in (x-y) planes at various depths in the wind-driven OBL from LES with wave breaking plus Langmuir circulations generated by Stokes drift. U10 = 10 ms-1 and the mixed layer depth h = -35m. Planes a), b), c), d) are located at z = (-0.9, -1.88, -7.05, -19.88)m, respectively. The color bar ranges from red w < -1ms-1 to purple w > 1ms-1.*

P. Sullivan, James McWilliams (UCLA), and Ken Melville (Scripps Institute of Oceanography) are developing a turbulence resolving LES model for wind-wave equilibrium ocean mixed layers that contains surface wave effects; both wave breaking and vortex forces generated by Stokes drift are included in the LES. During the past year, we incorporated the wave breaking model described by Sullivan et al. (JFM, 2004) into a working LES code that also contains Stokes drift. With the assumption of wind-wave equilibrium, we are able to use empirically derived formulas from field observations to specify the total momentum and energy supplied by the atmosphere to the ocean, the shape of the surface wave spectrum, and the characteristics of the wave breaking field. Essentially, the primary input to the LES is then the reference wind speed at a height of 10 meters above the water. LES results illustrate close connections between surface wave conditions and vertical mixing in the OBL. We find that the mean currents, turbulence variances (and TKE), scalar and momentum fluxes, and entrainment at the thermocline all exhibit considerable sensitivity to the surface wave field. One of the most striking results is that the greatest mixing arises when wave breaking and Langmuir circulations (resulting from Stokes drift) act together. Flow visualization and animations indicate that excess horizontal momentum generated by a breaking wave at the surface can be trapped in a lateral convergence zone by Langmuir circulations and subsequently deflected downward into the mixed layer as a vigorous downwelling jet. This sequence of events is depicted in the (x-y) snapshots of **Figure 45**. We are able to trace the downwelling jets in panels c) and d) to surface sites where wave breaking and Langmuir circulations are both active at earlier times. These downwelling jets are not found in LES with Stokes drift or wave breaking acting alone. They found that the vertical velocity skewness is a strong indicator of the presence of these coherent structures.

Critical Layers Near Wavy Surfaces

P. Sullivan and Stephen Belcher, short term visitor from U. Reading (UK), began a numerical investigation to explore the formation and dynamics of critical layers induced by moving wavy surfaces. The objective is to interrogate the Miles critical layer mechanism for wave growth in the presence of a wave group. A series of canonical DNS problems were designed to focus on the vortex dynamics induced by a wave group near a boundary. They find that a flat surface with a fixed sinusoidal varying vertical velocity as a lower boundary condition can interact strongly with the mean profile and thereby induce strong vortical motion. By tracking the solution in time they are able to examine how the critical layer induces a downward flux of vertical momentum which can then lead to substantial wave growth. An animation of this flow is provided in **Figure 46 animation**.

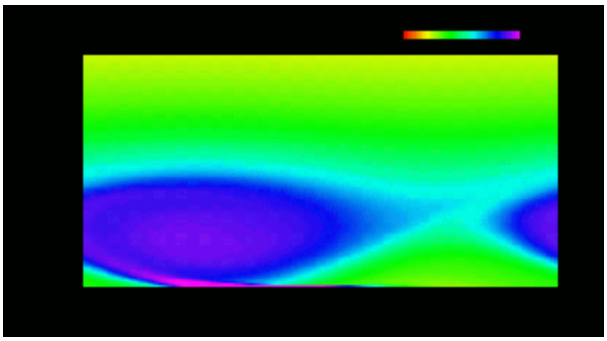

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Figure 46. *Time evolution of vorticity contours from DNS of a flow near a boundary in the presence of a critical layer. Notice that the vortex induces a strong downward flux of momentum that can induce wave growth. The lower boundary condition is a single sinusoidal mode of vertical velocity. In this animation purple contours are positive signed spanwise vorticity.*

Observational studies of air-sea interaction

Jielun Sun, in collaboration with S. Burns, Douglas Vandemark (NASA Goddard Space Flight Center), and Mark Donelan (University of Miami), explored the possibility of retrieving two-dimensional wave spectra using three laser altimeters on board the LongEZ aircraft. They found that a wavelet analysis method is able to retrieve wave propagation direction and wavenumber using the datasets collected from both the Shoaling Waves Experiment (SHOWEX) and Coupled Boundary-Layers/Air-Sea Transfer (CBLAST-low) experiments. She processed all the directional wave spectra from the LongEZ aircraft collected during the CBLAST-Low pilot experiment in 2001. She also worked with James Edson (Woods Hole Institute of Oceanography), and S. Burns and P. Sullivan, Dean Vickers and Larry Mahrt (Oregon State University), and Djamal Khelif (University of California, Irvine), on analyzing the CBLAST tower data and Pelican aircraft data. The role of surface waves on turbulent transport in the marine atmospheric boundary layer is being examined in detail. Eventually, the improved understanding of this complex process will lead to improved models of air-sea coupling and weather forecasts. Web sites http://www.mmm.ucar.edu/science/abl/showex/showex.html and http://www.mmm.ucar.edu/science/abl/cblast/ provide additional information. In FY05, she will continue to work with colleagues involved in CBLAST-Low analyzing and comparing the Pelican aircraft and tower data to better understand the characteristics of energy transport in wave influenced layers.

Numerical investigations of stress-driven turbulent layers bounded by a free surface

Coherent vortical motions just beneath the ocean surface are known to control the transport of soluble gases like CO2 across the air-water interface. However, mechanisms that determine these vortical motions are poorly understood. Possible mechanisms include surface waves, interaction between wave and shear turbulence, and pure shear turbulence. To isolate the turbulence effect from surface waves, Wu-Ting Tsai, Shi-Ming Chen (National Central University, Taiwan) and Chin-Hoh Moeng performed a direct numerical simulation of a stress-driven turbulent layer bounded by a free surface. They observed that even in the absence of waves elongated high-speed streaks and localized low-speed spots are observed on the surface **Figure 47**. Floating Lagrangian

particles aggregate and travel along these streaks similar to those found in the laboratory and Langmuir circulations found in the open ocean. Elongated streamwise vortical motions are also observed just beneath the surface, however, these vortices are shorter in length and less correlated than those arising from Langmuir circulations.

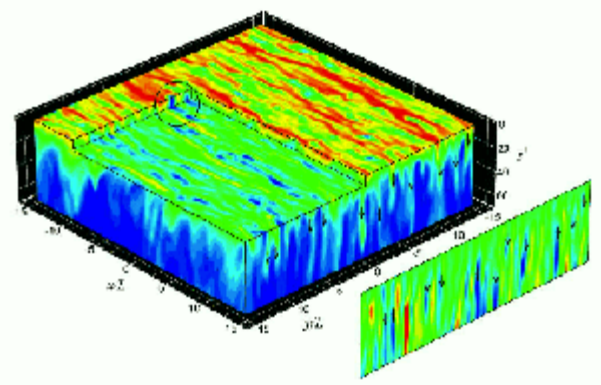

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Figure 47. *Three-dimensional cut-away view of streamwise velocity u. The corresponding contours of vertical velocity w on the facing cross-stream plane are also depicted on an additional vertical section. The downward arrow indicates the occurrence of downdraft beneath the high-speed streaks. The circle highlights a particular region where upwelling occurs.*

Coastal Solitons

Large amplitude solitary waves affect underwater naval operations through their effects on buoyancy and acoustic transmission. A sudden encounter of a lower density area at a depth of high ambient density can cause an underwater vehicle to ascend suddenly to the surface. Underwater signals are perturbed by solitary waves (near-surface solitary waves have been observed to cause large anomalous acoustical signal loss of about 15 dB). As a collaborative effort, a team of researchers led by Alex Warn-Varnas (NRL) and P. Smolarkiewicz, simulated three-dimensional solitary wave generation and propagation using EULAG coupled to the barotropic NCOM tidal model. Newly developed dynamic grid-deformation technology was used. The scenario examined was the site of the ASIAX experiment, **Figure 48a**, where the evolution of solitary waves is particularly complex. The tidal motions in the Strait of Luzon, generate internal bores that subsequently disintegrate into solitary wave packets, which propagate into the South China Sea towards the continental shelf where large-amplitude solitary waves of depression, up to 150 m, are observed. **Figure 48b**, shows simulated isohalines after ~3.3 tidal cycles, using EULAG in an idealized high-resolution setup.

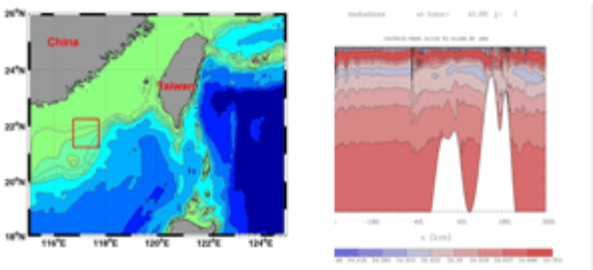

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Figure 48. *Coastal solitones: left panel, location of the Strait of Luzon, South China Sea and ASIAEX experimental site (red box); right panel, 2d idealized simulation.*

Chemical transports and transformations

Wildland fire research: Fire model development and application

Atmospheric diurnal variability in humidity and winds controls the diurnal variability of fires, including their tendency to flare up in the afternoon and subside in intensity at night. Janice Coen has extended NCAR's coupled atmosphere-wildland fire – environment model (CAWFE) to include another feedback loop between the atmosphere and fire allowing fuel moisture, a critical parameter in the fire environment, to respond to changing atmospheric conditions. She has also extended the model capabilities to represent more complex fuel complexes and fire behaviors by adding new fuel models. This new capability allows fire modeling in chaparral, a dominant vegetation type of southern California. In collaboration with Dar Roberts (Dept. of Geography, Univ. of California Santa Barbara) and Phil Dennison (Dept. of Geography, University of Utah), she simulated the Simi Fire, which ignited near Simi Valley, CA, during the firestorms of October, 2003. In this case, fire spread rapidly under severe Santa Ana winds complicated by small-scale canyon winds through extremely dry fuel and complex topography of the Santa Susana Mountains **(Figure 49 animation**). Although verification of the simulation continues, this case is being used to test the capabilities of the model to represent extreme rates of fire spread in complex, spatially heterogeneous fuels.

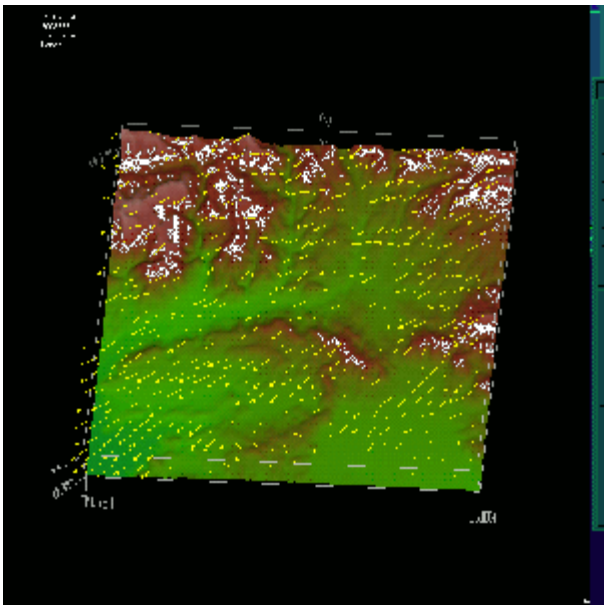

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Figure 49. *Simulation of the Simi fire, during the Santa Ana wind conditions of October 25, 2003. Smoke is shown by the misty white field. Arrows denote the simulated winds near the surface.*

Dynamic data-driven Wildland Fire Modeling

With the support of an NSF Information Technology Grant, J. Coen, collaborators at the University of Colorado Denver (Jan Mandel, Leo Franca, Lynn Bennethum, and Craig Johns), the University of Kentucky (Craig Douglas), Rochester Institute of Technology (Tony Vodacek and Bob Kremens), and Texas A&M University (Wei Zhao) are developing a dynamic data-driven wildland fire model. The goal of this work is to develop methods capable of dynamically assimilating out-of-sequence field data such as airborne infrared imagery of fires and autonomous atmospheric environment detectors into running ensembles of atmosphere-fire models and return results to the field. In this first year, the team has developed a stochastic reaction-diffusion partial differential equation to replace the current fire code, and developed a framework for introducing data into ensemble members. Aside from improvements that are expected in simulating fires by guiding them with real data, the techniques for assimilating data have wide application to other problems where the probability distribution of the assimilated field is not Gaussian (for example, the temperature is either that of ignited fuel or UN-ignited, not a centered distribution).

Real-time fire simulation

J. Coen has tested CAWFE configured for a faster-than-real-time application to wildfires in Colorado during summer 2004. A two-times-daily 48-hr MM5 forecast for the continental U.S. –done by Jim Bresch (MMM)- was used to initialize the domain and update boundary conditions. The atmosphere-fire model used four nested domains to nest from synoptic scale to 556m in the vicinity of an ignition. Skip Edel (Colorado State Forest Service) provided the Colorado fuel database, and Christine Wiedinmyer (ACD) adapted it for a gridded model. Ignition information and local fuel moistures were estimated from the web, and CAWFE simulated the fire progression throughout that day. These results are still being examined for strengths and weaknesses, but demonstrates a first capability to routinely simulate fire behavior, smoke transport, and the fire-affected environment using modest computational capabilities.

Next-generation fire model development

John Daily (University of Colorado Boulder) and Shankar Mahalingam (University of California Riverside) are collaborating with J. Coen to develop techniques to parameterize fine-scale pyrolysis and combustion processes for the spatial and temporal scales of atmospheric models. Daily has developed a detail representation of the complex chemical reactions that occur when wildland fuels are heated and decompose into flammable gases that are burned in wildfires, and has been developing a reduced set of chemical equations that can be used in coupled kinetic-transport models. Mahalingam has:

1. developed a database for live fuel burning behavior under various transition conditions including marginal burning (for example, in ground-to-crown fire transitions);
2. characterized the effects of fuel and the atmospheric environment on the burning behavior; and
3. has refined his subgrid-scale turbulent combustion model based upon this database. They are now addressing the challenge of scaling up to atmospheric length scales.

Implementation of a Wildland Fire Component in WRF (WRF-Fire)

E. Patton and J. Coen are actively porting the fire component of the Clark-Hall model into the WRF framework. Implementing the fire code into WRF will benefit the community by allowing new users to take full advantage of the many services that come with a community model. In particular, WRF is fully supported, it uses state of the art technology, it runs on many computing platforms in both serial and parallel environments, it is easy to switch and/or add physics or numerics, and comes with pre-built analysis tools. Other reasons motivating this conversion is the ability to immediately link with the emissions and chemistry components of WRF, as well as the readily available real-time data initialization and assimilation. The fire-component has been separated from the Clark-Hall model and re-written for implementation into WRF. Implementation of the fire module into WRF is ongoing. We anticipate a working version to be available in the first six months of FY05. This is joint work between MMM and the Wildland Fire Collaboratory.

Next Topic: Planetary Boundary Layers

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Planetary Boundary Layer

Radar observations of turbulence in the cloud-capped PBL

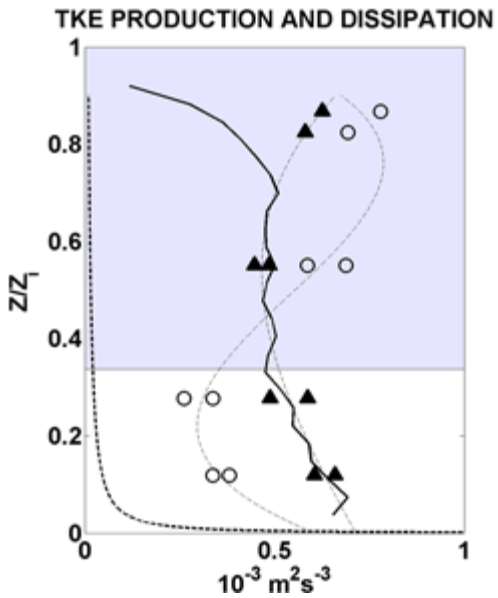

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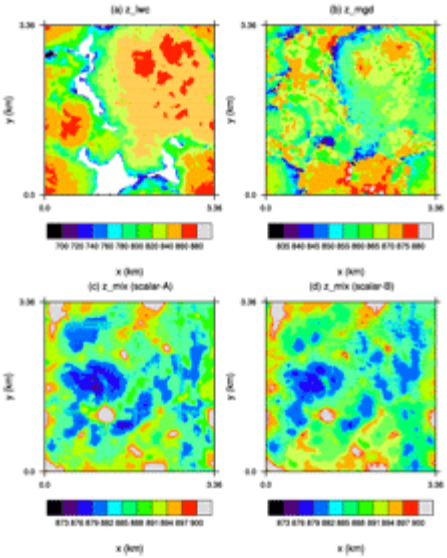
Figure 50. *Profile of turbulence dissipation rate measured by the WCR (solid line) and in situ measurements (triangles) during Flight 7 of DYCOMS-2. The predominant TKE production terms are also displayed: buoyancy (circles; the thin dashed line is a least squares 3rd-order polynomial fit) and shear (thick dashed line). Cloud is indicated by the shaded area. The agreement with in situ measurements is excellent throughout the lower 2/3 of the STBL. The vertically integrated dissipation agrees well with the sum of the vertically integrated buoyancy and shear production terms.*

The stratocumulus-topped boundary layer (STBL), which prevails in the subtropics in regions where the underlying ocean is much colder than the overlying atmosphere, is an important component of the global climate system. However, attempts to quantify and model the processes that control its evolution have fallen short of what is needed for accurate climate prediction. One important issue is the role that turbulence plays in entrainment of warm dry air from the overlying free troposphere. A key to understanding this is to quantify the turbulence kinetic energy (TKE) budget in the STBL. In the Dynamics and Chemistry of the Marine Stratocumulus (DYCOMS-2) Experiment, conducted off the California coast in July 2001, the Wyoming Cloud Radar (WCR) was mounted on the NCAR C-130 aircraft and used to probe the turbulence structure of the STBL. The downward-looking beams were used to resolve droplet velocities throughout regions of the STBL containing droplets. These measurements contain velocity fluctuations due to both real air velocity fluctuations as well as a contribution due to variations in droplet fall velocity. Donald Lenschow and Marie Lothon (visitor from France), along with Gabor Vali and David Leon (both of University of Wyoming) have developed techniques to estimate the fall velocity contribution, and to correct the radar velocity measurements for volume averaging and noise. As a result, they have been able to estimate TKE dissipation throughout the STBL on a day with relatively uniform drizzle distribution, as shown in **Figure 50**. This is an essential step in resolving the TKE budget.

The interfacial structure of the cloud-capped PBL

A commonly-adopted idealization for modeling the stratocumulus-topped PBL (STBL) is that its upper interface is distinguished by all of the following conditions: (1) it separates cloudy and clear air, (2) occurrence of the sharpest jump (maximum-gradient) in local soundings, (3) it separates turbulent motions from the free-atmospheric non-turbulent flow, and (4) it delineates the entrainment zone. Existing theories of cloud-top entrainment instability (CTEI) rely heavily on the assumption that a local sharp-edged interface separates two distinct air masses: one turbulent and completely saturated, and the other non-turbulent and completely unsaturated. How valid is this idealization? Are the cloud-top interface, maximum-gradient interface and turbulence-laminar interface the same? Using large-eddy simulation (LES), Chin-Hoh Moeng, Bjorn Stevens (University of California, Los Angeles) and Peter Sullivan investigated this issue. They found that the cloud-top interface is always below the maximum-gradient interface, and the maximum-gradient interface below the turbulent-mixing interface (**Figures 51**and **52**). The differences between these interfaces are typically larger than 20 meters. This interfacial property could be significant in modeling the entrainment rate and cloud-top entrainment instability of the STBL.



Click image for larger version.

Figure 51. *Contours of (top panels) cloud-top interface $z_{\rm lwc}$ and maximum-gradient interface $z_{\rm mgd}$, and (bottom panels) twoturbulent-mixing interfaces $z_{\rm mix}$ diagnosed from Scalars A and B. The white area in the $z_{\rm lwc}$ contours represent cloud-free columns.*

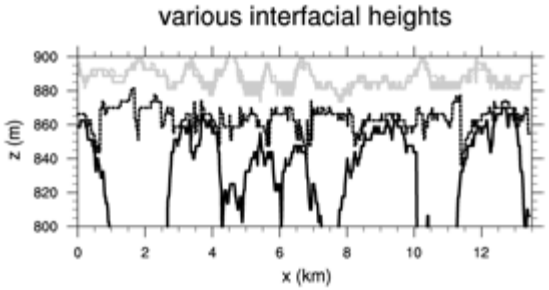


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Figure 52*. Various interfacial heights along four separate horizontal segments linked together from the case shown in Fig. 1: Dark-solid curve is the cloud-top interface, dark-dotted curve is the maximum-gradient interface, and the two light-color curves mark the turbulent-mixing interface diagnosed from two passive scalars.*

Evaluation of large-eddy simulation via observations of cloud-capped PBL

C.-H. Moeng participated in the FY04 intercomparison of LES solutions of marine stratocumulus organized by the GCSS Boundary-Layer Cloud Working Group (see http://www.atmos.washington.edu/%7ebreth/GCSS/GCSS.html). This intercomparison study, led by Bjorn Stevens (UCLA), focused on evaluation of large-eddy simulations using observations of nocturnal marine stratocumulus from DYCOMS-II. The cloud case studied here is particularly challenging for LES because the cloud-top jump condition lies within the controversial range between solid and broken cloud regimes. Many LESs failed to produce the observed solid cloud layer, which led to an important conclusion that most LESs over-estimate mixing at the cloud top due to either numerical diffusion, or subgrid-scale mixing (or both). Too much mixing across the cloud top produced a drier PBL and hence a broken cloud layer.

Increasing the albedo and longevity of low-level maritime clouds

John Latham has further extended his research into a novel idea for the amelioration of global warming by the advertent and controlled enhancement of the albedo A and longevity L of low-level maritime clouds. The consensus view of the scientists participating in the International Symposium on Global Warming Mitigation, held in Cambridge, England, in January 2004--at which Latham presented a paper on this work--was that this approach held promise and should be funded for field tests. More detailed calculations coupled with computer modeling with the UK Meteorological Office GCM, support the quantitative validity of the proposed technique, which involves increasing the droplet concentration in such clouds, with a corresponding increase in both A and L: and thus cooling. The idea involves the dissemination at the ocean surface of small seawater droplets in sufficient quantities to act as the dominant CCN on which cloud droplets form. Satellite control of the overall dissemination rate is envisaged. Collaborators include Dr. Keith Bower & Prof. Tom Choularton (both UMIST, Manchester, UK), Dr. Alan Blyth, Dr. Alan Gadian & Prof. Mike Smith (all University of Leeds, UK), Prof. Stephen Salter, (University of Edinburgh, UK) and Dr. Andy Jones (Hadley Climate Centre, Meteorological Office, UK). If this technique were to prove workable on the scales required, it could be of great societal importance.

Dynamical behavior of the marine stratocumulus regime

A key dynamical variable that regulates marine stratiform cloud is the large-scale divergence in the boundary layer. In DYCOMS-II, two independent techniques are being used to estimate divergence: First, the divergence was obtained for all the flights with a standardized flight pattern in an effort spearheaded by Ian Faloona (University of California, Davis) from the difference between the entrainment velocity and the time rate of change of cloud-top height. The entrainment velocity was obtained from measurements of scalar fluxes extrapolated to cloud-top and the jump in scalar concentration across cloud top. Second, measurements of spatial variations in the mean wind field obtained from circular flight paths at several levels within the boundary layer are being used by D. Lenschow, Bjorn Stevens and Verica Savic-Jovcic (both of the University of California, Los Angeles) to directly measure the divergence. They have found that this measurement is on the edge of what is currently technically feasible with the NCAR C-130 aircraft measuring system, but by recalibrating the standard wind measurements they obtain a consistent pattern of divergence through the set of DYCOMS-II flights.

LES of Marine Boundary Layers with Swell

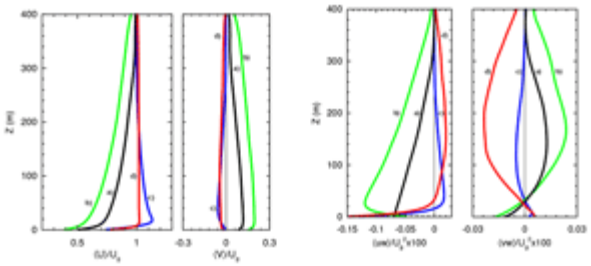

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Figure 53. *Vertical profiles of the mean wind components in the atmospheric boundary layer for flow over waves from LES with a constant geostrophic wind of 5 m/s. The surface conditions are: a) a flat surface; b) a stationary wave; c) swell moving along the U direction at 12.5 m/s; and d) flow over swell with slight convection. [right panel] Total (resolved plus SGS) vertical momentum flux profiles from LES.*

Peter Sullivan, James Edson (Woods Hole Oceanographic Institute), James McWilliams (University of California, Los Angeles), and Chin-Hoh Moeng continued the analysis of their LES solutions for atmospheric flow over surface waves. The emphasis is on light-wind conditions with fast moving swell as observed during the low-wind Coupled Boundary Layers Air-Sea Transfer (CBLAST) field campaign. The simulations span a range of surface conditions and atmospheric stratifications. They have also initiated a comparison with the surface layer data gathered from the Air-Sea Interaction Tower used during CBLAST. LES results dramatically demonstrate (**Figure 53**) that sea state modulates the magnitude and orientation of the mean wind and momentum flux in light winds. For example, at 10 m height, the surface wind, U, is to the left of the geostrophic wind (that is, the normal component V is positive, where the U direction is along the geostrophic wind) as expected for flow over rough surfaces and stationary waves while the opposite is observed in the presence of swell, where the swell here is moving along the geostrophic wind direction at 12.5 m/s. In this case, the surface-layer wind is slightly to the right of the geostrophic wind. The vertical profiles also show that the impact of swell is not

confined to the surface layer but can extend to considerable heights above the surface. With swell, the wind component along the geostrophic profile exhibits a low-level jet around 20 m height, which disappears with slight convection. The weak mean shear in the swell-driven (neutrally stratified) PBL generates little turbulent kinetic energy (TKE) in the region above the jet, an important result of the swell-induced changes in the marine surface layer. Profiles of the total vertical momentum flux further illustrate the important consequences swell has for the momentum balance in the atmospheric PBL. The variation and signs of both components of the momentum flux are consistent with the formation of a low-level jet and in fact are mandatory in order to achieve a steady balance between the pressure gradient forcing and stress divergence. These results demonstrate that wave state needs to be taken into account when parameterizing PBL processes in mesoscale and global scale atmospheric models

Sound propagation in a turbulent atmosphere

Edward Patton and P. Sullivan (in collaboration with Army Research Laboratory, Army Corps of Engineers, Sandia National Laboratory and NOAA/ETL) are using high-resolution large-eddy simulation to investigate the influence of turbulence on atmospheric sound propagation. Simulations employ more than 120 million gridpoints. Sound is propagated through the LES-derived atmosphere using a newly developed finite difference algorithm appropriate for modeling acoustic waves in moving, inhomogeneous 3d media. Although the effects are subtle, atmospheric heterogeneity in sound speed, density, and velocity cause low-amplitude pressure events to trail the main diverging wavefronts (**Figure 54 animation)**. We are actively investigating the influence of atmospheric stability on sound propagation and future research will examine the impact of vegetation.

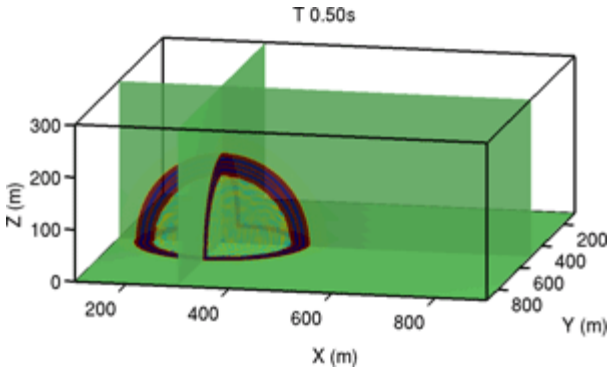

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Figure 54. *Time evolution of acoustic pressure field for a 20-Hz dominant zero-phase wavelet source propagating through an unstable atmosphere (z_i/L = -6) generated by large-eddy simulation. The ground surface is assumed to be perfectly reflecting. Resulting from atmospheric heterogeneities, for times greater than 0.4 seconds, low-amplitude pressure events trail the main diverging wavefronts.*

Observations of two-point turbulence statistics in the clear-air PBL

The turbulent eddies that transport heat, momentum and trace constituents through the convective boundary layer (CBL) are anisotropic. One way to quantify this anisotropy is to calculate two-point turbulence statistics such as the spatial coherence of the air velocity components. Measurements of these statistics, however, are difficult to obtain with traditional in situ measurements techniques. Doppler radars and lidars, however, can measure the radial component of air velocity as a function of distance from the sensor. Marie Lothon (MMM visitor), D. Lenschow, and Shane Mayor (ATD) have used

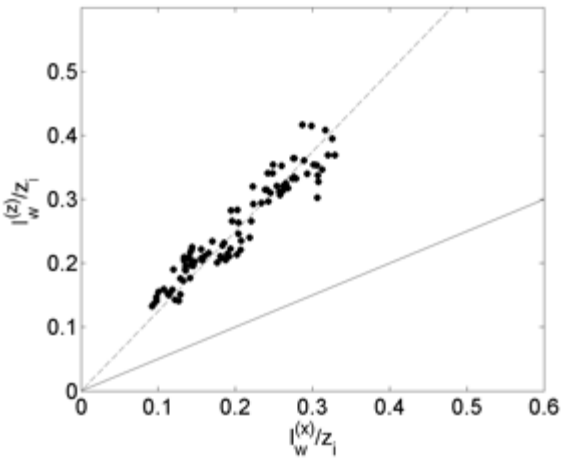

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Figure 55. *Vertical versus horizontal integral length scales of the vertical air velocity normalized by the PBL depth observed with a ground-based Doppler lidar (HRDL) within the mid-day CBL during 11 days in LIFT. A total of nine levels within a 250 m layer are used for this analysis. The solid line is the theoretical ratio for isotropic turbulence; the dashed line is the least squares fit to the observations constrained to pass through the origin.*

measurements of the vertical air velocity from a ground-based zenith-pointing High Resolution Doppler Lidar (HRDL) deployed during the Lidar In Flat Terrain (LIFT) experiment in central Illinois in the summer of 1996 to measure the coherence of the vertical velocity in the vertical, as well as its integral scales in both the horizontal and vertical directions for twelve days during LIFT. They observed that the measured vertical coherence tends to be larger than predicted by isotropic models except at very small scales. They also found that the ratio of the integral scale of vertical velocity along the vertical direction to that in the along-wind direction is more than twice as large as would be the case for isotropic turbulence (**Figure 55**); that is; the eddies are stretched in the vertical relative to the horizontal. The high correlation of this relationship means that the vertical integral scale can be estimated from the more-easily-measured horizontal integral scale.

Next Topic: **Multiscale Convective Cloud Systems and Waves**

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Multiscale Convective Cloud Systems and Waves

The systemic properties of moist convection are fundamental to weather and climate and, in particular, to the Earth's water and energy cycles. Multiscale numerical simulation and mathematical models provide a pathway to improved parameterization. **Figure 56** shows the cross-disciplinary approach adopted in the multiscale investigations reported in this section, which range from observed systems in need of explanation, numerical simulation, super-parameterization and mathematical reductionism, to improved parameterization. History shows that the latter is resistent to solution and thus a major challenge.

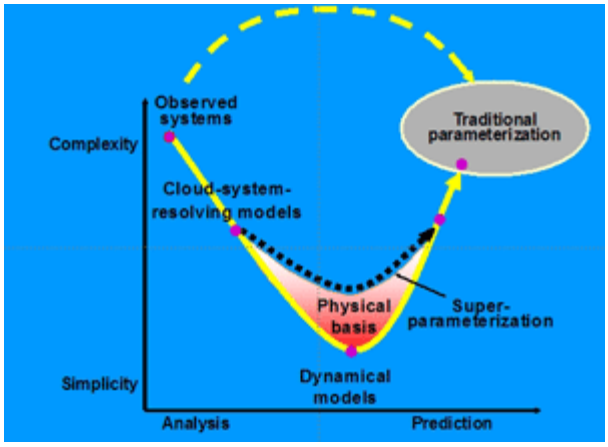

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Figure 56. *Approach uses in studies of multiscale cloud systems and waves*

The research themes reported below center on atmospheric convection, its interaction with the boundary layer and ocean/land interfaces, and wave dynamics. Since no geophysical model can simulate convection from first principles (cloud-microphysics and radiative transfer must be parameterized), improved parameterization of microphysics is needed. Because the multiscale cloud-system models (grid interval ~1 km) resolve mesoscale circulations, the large-scale role of organized convection with its strong dynamical effects, is high on the research agenda.

The multipurpose numerical model framework known as EULAG developed by Piotr Smolarkiewicz and collaborators is the mainstay of the multiscale simulation approach. When a data-assimilating model is required (i.e., real-world case studies), MM5 is used.

EULAG development

EULAG is a numerical code for simulating geophysical flows on all scales – a facility for numerical experimentation in a virtual laboratory with time-dependent adaptive meshes and complex, even time-dependent, computational domains. The underlying anelastic equations are solved in either a EULerian (flux form) or a LAGrangian (advective form) framework. EULAGs generality derives from a unique model design that combines the nonoscillatory forward-in-time (NFT) numerical algorithms (based on the MPDATA family of transport schemes) and a robust elliptic solver in generalized coordinates. The numerical code contains options for controlling numerical accuracy and allows a wide range of numerical sensitivity tests. The model equations

are formulated with various options. For example, in addition to simulation of the Earth's atmosphere, options are available for stellar atmospheres, ocean dynamics, sand-dune propagation and biomechanical flows. The EULAG code is fully parallelized and easily portable between computer platforms. Previous model development and details of the numerical algorithms are published in peer-reviewed papers by P. Smolarkiewicz and colleagues. Developments of EULAG during FY2004 are now summarized.

Dynamic Grid Deformation

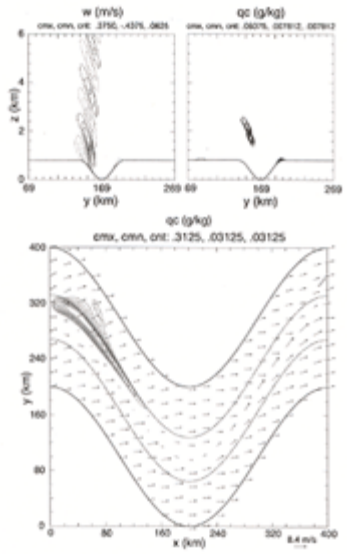

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Figure 57. *Moist stratified rotating flow past a winding valley, with inclusion of boundary layer diabatic effects. Vertical velocity (left upper panel) and cloud water mixing ratio (right upper panel) in the **yz** cross section at x = 120 km and cloud-water mixing ratio at bottom surface of teh model (bottom panel).*

Joseph Prusa (Iowa State University) and P. Smolarkiewicz continued the development of a deformable-coordinate option designed using synergetic interaction between rules of continuous mapping and the strengths of the NFT methods. Previously, they demonstrated that effective multi-scale adaptive numerical models for high Reynolds number geophysical flows can dispense with rigorous evaluation of more cumbersome vector differential operators, such as the curl of the velocity and the strain rate. Nevertheless, these operators are important for budget analyses of the model results, estimating physical uncertainties, driving the mesh adaptivity, and extending applicability beyond standard meteorological situations. Recently they documented extensions of the generic explicitly inviscid approach for curvilinear representation of the vorticity, Fickian diffusion, strain, and stress as well as tensor identities complement the entire development. The benefits of their approach are substantial. The narrower and more complex the geometry of the problem, the more prohibitive the cost of standard simulations on rectangular domains. For example, for a valley flow in the following figure, the gain is about a factor of two.

Spectral Preconditioners

Thomas et al. (MWR, 2003) reported advantages of elementary constant-coefficient spectral preconditioners for elliptic problems in atmospheric flows, in the context of the Canadian MC2 model (a semi-Lagrangian, semi-implicit, elastic, nonhydrostatic, multiscale research/weather-prediction model). A follow-up study by P. Smolarkiewicz, Steven Thomas (SCD), Clive Temperton (ECMWF), and Andrzej Wyszogrodzki (LANL) incorporated spectral preconditioners in EULAG. They tested performance of spectral preconditioners in extreme settings covering a broad range of scales and physical applications: from canonical decaying turbulence in a triply periodic box, through homogeneous flows past large-amplitude undulating boundaries, mesoscale flows past long winding valleys, to idealized climate. Their results do not corroborate the universal superiority of spectral preconditioners (over simple line-relaxation schemes) found in MC2. While elementary spectral preconditioners offer substantial advantages in many applications; in general, their performance is unsatisfactory when significant horizontal inhomogeneity occurs.

Unstructured-Grids

Testing a numerical approach in a parameter space distinct from its normal application is enlightening. Joanna Szmelter (Cranfield University, UK) and Piotr Smolarkiewicz (MMM) continued development of MPDATA in an arbitrary finite-volume framework with a fully unstructured polyhedral hybrid mesh. They

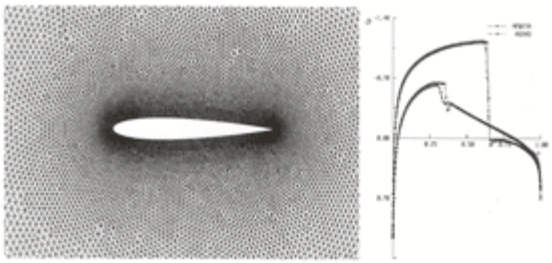

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Figure 58. *Computational mesh for the NACA0012 test cases, and a comparison of the results using MPDATA and the reference AGARD results.*

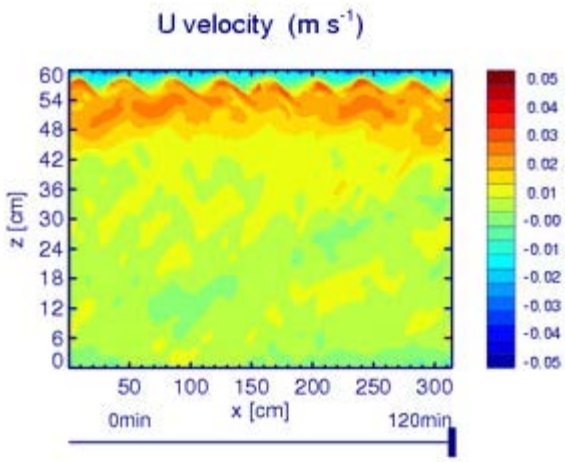
advanced the stability theory, included the monotonicity enhancement and generalized the approach to a fully compressible flow solver. The new framework is well suited to adapting the Cartesian mesh experience with MPDATA in an unstructured grid environment. Their results reported for the transonic flow around airfoils are promising from the perspective that the method is substantially less diffusive than contemporary computations normally used in aeronautical design. Their studies of flow past 2D airfoils are the first documented application of an MPDATA-based flow solver in multi-connected domains. The ease of modeling multi-connected domains using unstructured meshes opens new avenues for MPDATA for atmospheric/oceanic flows, for which the scheme was developed originally.

Dynamical analogues

The objective here is to reduce complex multiscale dynamical systems to simple forms, which is a necessary step toward the understanding that can help parameterization of the systemic effects, especially dynamically based aspects such as momentum transport. Progress toward achieving this objective is summarized below.

Quasi-Biennial Oscillation (QBO)

The QBO represents the dominant variability in the equatorial lower stratosphere, yet complete understanding has remained elusive despite numerous studies. Nils Wedi (ECMWF) and P. Smolarkiewicz continued their basic research of the QBO. Using EULAG, they conducted a direct numerical simulation of the celebrated laboratory experiment of Plumb and McEwan (1978) and its Kyoto-University counterpart---often employed to demonstrate basic properties of the QBO--- reproducing the laboratory results. A series of 2D and 3D numerical simulations exhibits a number of internal gravity wave processes: wave reflection, wave-wave-mean flow interaction, critical-layer formation and subsequent wave breaking. All have atmospheric counterparts. A comprehensive analysis led to the conclusion that spatial background flow perturbations due to internal wave-wave interactions and subsequent momentum flux changes enhanced by wave breaking, grow locally to critical magnitude and merge to form a downward propagating mean shear layer. Furthermore, in contrast to the original explanation the next phase of the laboratory oscillation is a result of the reversed background wind forcing acting against the oscillating membrane.



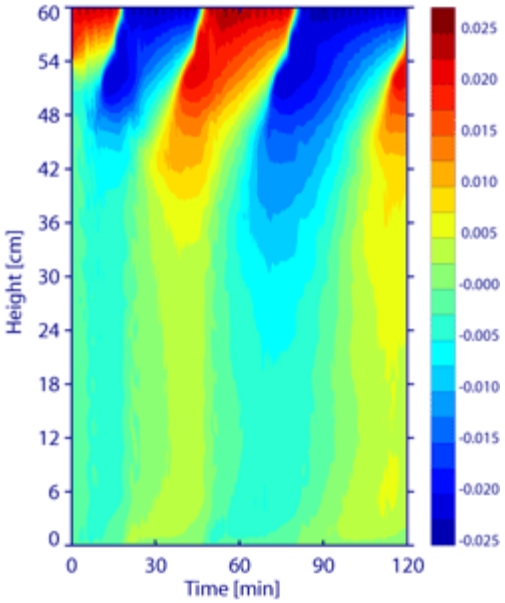


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Figure 59. *Time-height cross-section of the zonal-mean zonal flow velocity component at mid-channel in the 3D numerical simulation of the Plumb and McEwan experiment. The numerical setup is as repeated by the Kyoto university, where the oscillating membrane has been placed at the top of the annulus.*

Click image for a larger animation.

Figure 60. *The animation in time shows the corresponding x-z cross section of the zonal velocity component at mid-channel in the 3D numerical simulation of the Kyoto laboratory setup for the QBO analogue.*

Madden-Julian Oscillation (MJO)

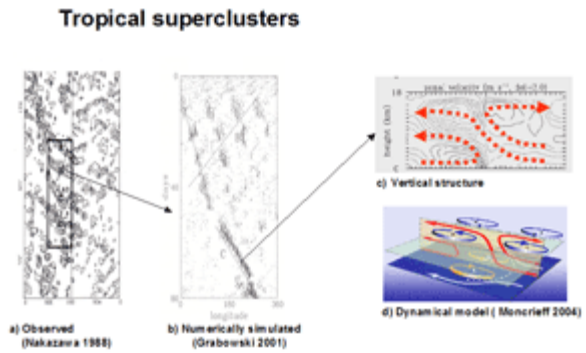

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Figure 61.

Mitch Moncrieff completed a study of nonlinear MJO dynamics. By formulating a dynamical model he showed the pivotal role of the mesoscale organization of convection on the large-scale coherence of tropical convection. The general model formulation consists of two interlocked systems: a mesoscale parameterization of organized convection and a two-layer model of large-scale equatorial dynamics. The lower-layer dynamics is Rossby gyre–like, whereas outflow from organized convection maintains the upper-layer circulation. The transports of zonal momentum in the vertical and meridional directions are key processes. An archetype of the general model (**Figure 61**), in spite of being brutally simplified, represents the convective organization, momentum transport, and equatorial super-rotation realized by the cloud resolving convection parameterization (CRCP) approach developed by Wojciech Grabowski. The mesoscale parameterization is an analytic equivalent of the cloud-system-resolving models used in the CRCP approach. Finally, issues in the parameterization of convective organization were quantified.

Diurnal cycle of convection and effects of orography

The relationship among organized convection, orography (local and remote effects), large-scale flow and the diurnal cycle is inadequately represented in large-scale models that apply convective parameterization. For this reason, simulations that resolve convection, or at least its mesoscale organization, are compared to simulations that apply convective parameterization.

Organized Traveling Precipitation over the U.S. Continent

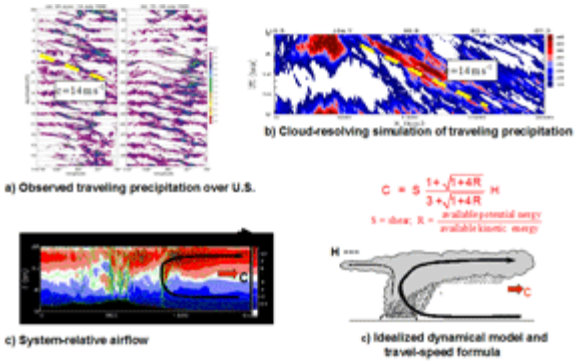

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Figure 62. *Caption. Traveling precipitation over the continental U.S. a) sequences of precipitation from Carbone et al (2002); b) numerically simulated precipitation; c) structure of airflow in the vertical pane; and d) idealized dynamical model and travel speed formula.*

This work is collaborative with the Water Cycle Across Scales initiative, which is now part of The Institute for Multidisciplinary Earth Studies (TIMES). Changhai Liu and M. Moncrieff continued their multiscale simulation of warm-season convection over the U.S. continent using explicit and parameterized approaches -- a set of 7-day simulations (from 3 to 10 July 2003) using MM5 with 3-km, 10-km, and 30-km grid resolution and model domain 2400km x 1800km. MM5 is initialized with the 3-hourly 40-km ETA model analysis. This period is characterized by moderate synoptic forcing, in contrast to relatively benign large-scale conditions in the 10-day period (20 to 30 July 1998) reported in FY2003. Remarkably, both the explicit and parameterized simulations reproduce the observed daily convective regeneration over the Rockies and subsequent eastward propagation (**Figure 62a**). Diagnostic analyses show that cold-pool dynamics and interaction between latent heating and the ambient flow are responsible for the simulated coherent precipitation. The propagation speed is explained by a nonlinear theoretical-dynamical model of convection in shear. **Figure 62b** compares Budget analysis indicate that the coarse-grid simulations underestimate the lower-tropospheric cooling and upper-tropospheric warming and overestimate the convective drying at most levels.

Temporal Variability of Precipitation over the U.S. Continent

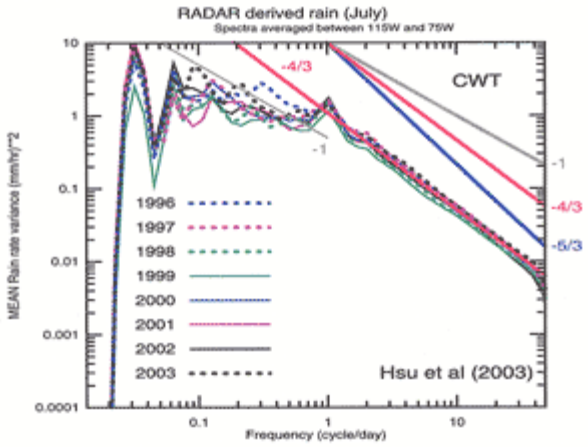

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Figure 63.

Hsiao-ming Hsu (RAP), Wen-wen Tung (ASP), C. Liu and M. Moncrieff analyzed directionally averaged time series of rain rates derived from NEXRAD measurements over the continental U. S. by Carbone et al (2002). Using spectral decomposition methods they found distinct classes of temporal variability. Latitudinally-averaged time series indicated a remarkable self-similarity for the frequency band higher than semi-diurnal, quantified by a power-law scaling with an exponent of -4/3 (**Figure 63**). For the longitudinally -averaged series, the scaling exponent for the frequency band higher than semi-diurnal changes from -4/3 to -5/3. The difference between the latitudinal and longitudinal spectra is interpreted as a consequence of the anisotropy of the patterns of high-frequency precipitation. The scale-invariance is useful for evaluating the statistics of precipitation in fine-scale prediction models and cloud-resolving models. Composites of the higher-frequency bands display eastward propagation of the re-constructed convective patterns, whereas the low-frequency patterns propagate westward. There is a marked inter-annual variability in the dominant periods and the propagation speeds.

Diurnal Variability over the Bay of Bengal

Satellite observations by Yang and Slingo, (2001) show that propagating deep convection over the Bay of Bengal during the summer monsoon originates over the mountainous region of eastern India, in broad agreement with observations over the Bay obtained during the JASMINE Pilot Study (Webster et al. 2002). C.

Liu, M. Moncrieff and John Tuttle have started an observational analysis of organized convection and diurnal variability over the Bay of Bengal. TRMM rainfall data, zonally averaged from 82.5E to 92.5E for three warm seasons (May-September 2002, 2003 and 2004), show frequent propagating convection during active phases of the monsoon. Convection initiates over the Eastern Ghats in the afternoon or evening and subsequently travels hundreds of kilometers towards the equator. Documentation of the statistical properties of propagation speed, longitudinal scale, and morphology of the rainfall streaks is underway. This is intended to be a basis for idealized numerical simulation and theoretical-dynamical modeling of diurnal variability and convective organization.

Diurnal Variability over the Tibetan Plateau

Xiaodong Liu (Institute of Earth Environment, Chinese Academy of Sciences, China) and C. Liu have started investigations of the warm-season diurnal variations of convective activities over the Tibetan Plateau and adjacent regions. This research is intended to document the mean diurnal variabilities of rainfall, radiative fluxes, and clouds and to quantify the performance of modern mesoscale numerical models in capturing the observed diurnal variations. In the observational analysis, the TRMM rainfall data, the Japanese GMS IR data, and the ERBE data are used to examine the diurnal variations of precipitation, cloudiness, and outgoing long-wave radiation, respectively. In the numerical modeling, a regional climate model is employed to conduct a set of three-year simulations.

Resolved Orographic Forcing in a Global Model

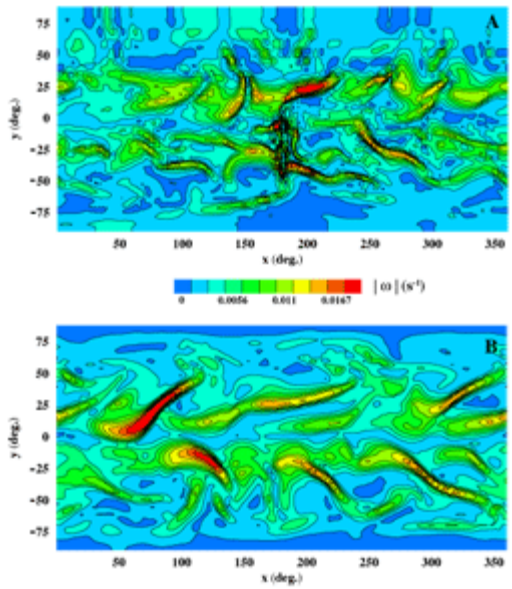

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***Figure 64**. Instantaneous vorticity at the Earth's surface. The upper panel shows the field resulting from the global simulation with idealized Andes topography; the lower panel shows the corresponding result without topography. Both results are based upon horizontal grid with (12 8zonal x 64 meridional) nodes. Grid stretching in the upper panel results in 3x higher horizontal resolution near the topography (depicted by elongated vertical ellipse) compared to lower panel.*

J. Prusa and P. Smolarkiewicz examined the effects of grid refinement in the vicinity of the Andes Mountains, in the context of Held-Suarez climate simulations. The complex geometry and narrow east-west extent of the Andes is a challenge for numerical models. To address this problem, the adaptive grid-refinement approach in EULAG was utilized in global simulations to locally enhance resolution in the vicinity of an idealized topography. Their results show that insufficient local resolution strongly impacts global behavior. The conditions under which regional errors produce significant global errors depend on the terrain elevation and local climate. At mid-southern latitudes, their model gives reasonable global climate statistics even with resolution so coarse that the mountains are approximated (longitudinally) by a Delta function. However, for the weaker zonal flow in the equatorial region, insufficient resolution spuriously generates a westerly jet near the equatorial tropopause, making it necessary to fully resolve significant orography. About an order of magnitude gain is achieved by the adaptive grid compared to a uniform high-resolution grid. **Figure 64** shows the global effect of orography.

Multiscale convective organization in the Tropics

Understanding the multiscale behavior of convection over the tropical oceans is largely a problem in convective-radiative-dynamical quasi-equilibrium, which is addressed by multiscale numerical models in large domains, global models operating super-parameterization and regional prediction models.

Large-Scale Organization in the Indian Summer Monsoon Region

Wen-wen Tung (ASP), M. Moncrieff and Hsiao-ming Hsu (RAP) have started a regional modeling study of the meso- to large-scale convective organization in the Indian summer monsoon region. They are running MM5 with three interactively nested domains. ECMWF TOGA analysis provides large-scale background and lateral boundary conditions. The simulation in the largest domain is nudged toward the analysis using the FDDA technique. The subsequent domains with finer resolution are judiciously placed to further resolve the convective events in the Bay of Bengal. Their objective is to understand the multiscale organization of convection and its predictability in the Bay, with the emphasis on the physical processes controlling diurnal to several-day convective variability. The results are compared against TRMM satellite-observed rainfall during Auguest 2003. Numerous tests are being done on the effectiveness of cumulus parameterization and microphysical schemes. Preliminary results suggest that, under the current FDDA and nesting framework, the combination of the Betts-Miller cumulus parameterization and the GSFC microphysical schemes produces convective organizations with realistic phase and orientation over the Bay.

Vertical Evolution of Convection

Tetsuya Takemi (Osaka University, Japan) and C. Liu completed investigations of the relationship between the vertical development of tropical cumulus convection and the vertical profiles of environmental temperature and moisture. The analyses of observational data obtained in the tropical western Pacific region reveal a strong correlation between the development of shallow and middle-topped cumulus clouds and the existence of dry layers in the middle to upper troposphere. In contrast, the difference in static stability profiles is insignificant among cloud regimes. The observed importance of the tropospheric moisture in modulating cumulus modes is supported by cloud-resolving numerical simulations, which show a strong sensitivity of cumulus heights to the mid- to upper-level relative humidity, while the mid-level stable layer has less impact.

Variability over the Tropical Pacific

Wen-wen Tung (ASP), M. Moncrieff and Jian-Bos Gao (University of Florida) completed a study of multiscale convective variability over the Pacific Ocean using a high-resolution index (ITBB) derived from satellite imagery. They found that convective activity with lifetimes ranging from about 1 h to 21 days have a cross-scale interdependence described by power laws. The ITBB displays long-range dependency, meaning that intense convection tends to be followed by another intense event, and vice versa for weakened events or droughts. This tendency is stronger with larger- domain averaging due to larger-scale variability such as superclusters associated with the MJO. The evolution of cloud clusters within an MJO event showed that convective activity along the front, center, and rear parts of the event continuously intensify approaching the date line and indicate multifractal features in the range of 1 h to about 5–10 days. Convective activity along the front and rear edges of the MJO event are more intermittent than in the center. The multifractal features of the ITBB time series were approximated by a random multiplicative cascade process, suggesting multiscale behavior and sobering for the predictability of observed phenomena.

NCAR-NCMRWF Collaborative Research

NCAR and the National Centre for Medium Range Weather Forecasting (NCMRWF), New Delhi, India have a memorandum of understanding addressing three objectives:

1. Mesoscale data assimilation and convection studies in the Indian monsoon region;
2. simulation of tropical weather systems observed in tropical field campaigns, and
3. the genesis of MJOs in the eastern Indian Ocean. The first objective is being met by incorporating the MM5-3DVAR data assimilation system into the NCMRWF operational weather prediction model. Dale Barker and M. Moncrieff helped two visitors from the NCMRWF (Munmun Das and John George) address the first objective. Because the background fields are provided by a short-term NWP forecast, the background model error has to be computed for a strongly convective environment. Preliminary tests were performed at NCAR, and the data assimilation system is now being tested in an operational environment at the NCMRWF. Besides being important for improved operational prediction in the Indian locale, this progress will enable the second and third research objectives associated with the Indian summer monsoon, and the MJO in particular, to be addressed with increased fidelity.

Convective parameterization

From the start of numerical weather prediction over half a century ago and the start of modern climate modeling in the early 1990's, the parameterization of convection and the radiative properties of convectively generated clouds has been the root of major uncertainty. Reducing uncertainty is a problem having many facets. Our approach is to use cloud-system-resolving models, evaluation of single-column models, with focus on the diurnal cycle and organization of deep convection. Much effort has been put into improving convective parameterization using fine-scale models, and is now a world-wide effort involving international programs.

Daytime Convective Development over Land

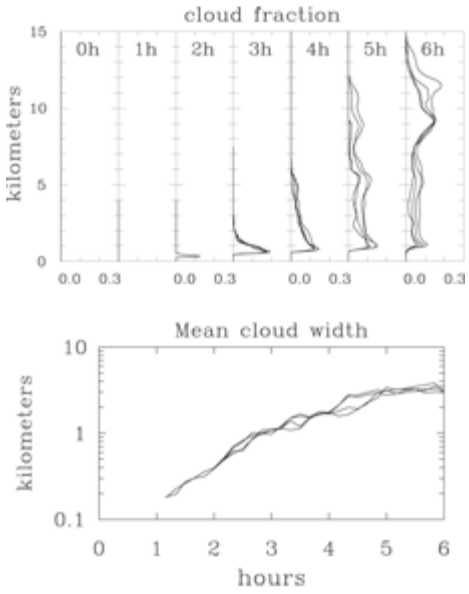

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Figure 65.

The GEWEX (Global Energy and Water Cycle Experiment) Cloud System Study (GCSS), which is an international coordinating body consisting of five working groups, has existed since the early 1990s. For two years, ending January 2004, the working group on Precipitating Convective Cloud Systems was chaired by W. Grabowski. He fostered collaborative work on daytime convective development over land in single-column models (SCMs) and cloud-resolving models (CRMs). The scientists involved are Peter Bechtold (ECMWF), Anning Cheng and Kuan-Man Xu (both NASA-Langley), Richard Forbes, Carol Halliwell, Jon Petch, and Ricky Wong (all from UK Met Office), Marat Khairoutdinov (Colorado State University), Steve Lang and Wei-Kuo Tao (NASA Goddard), Tomoe Nasuno (Japan Agency for Marine-Earth Science and Technology), and Xiaoqing Wu (Iowa State University). They developed an idealized model intercomparison based on observations of the diurnal cycle during the rainy season in Amazonia. The focus was a 6-hr period between sunrise and early afternoon, previously identified as being critical for the diurnal cycle over summertime continents. This period is characterized by the formation and growth of a well-mixed convective boundary layer, proceeding to shallow convective clouds as the convective boundary layer deepens,and subsequent transition to precipitating convection around local noon. A benchmark custom-designed set of simulations was devised. The SCMs reproduced previously-identified problems with premature development of deep convection, less than two hours after sunrise. CRMs with ~1 km horizontal grid-resolution capture the benchmark simulations qualitatively, but with significant differences among the models. Two-dimensional CRMs tend to simulate too rapid a transition from shallow to deep convection and too-high a cloud cover.

Cloud-Resolving Convection Parameterization in the CAM

Michal Ziemianski (visiting post-doctoral fellow from the Institute of Meteorology and Water Management, Poland), in collaboration with W. Grabowski, M. Moncrieff, and William Collins (CGD) completed an investigation of convective organization over the tropical western Pacific warm pool using the cloud-resolving convection parameterization (CRCP, or super-parameterization) and the Community Atmospheric Model (CAM) of the Community Climate System Model (CCSM). The CRCP simulations show significant improvements of the warm pool climate. The cloud condensate distribution is much improved

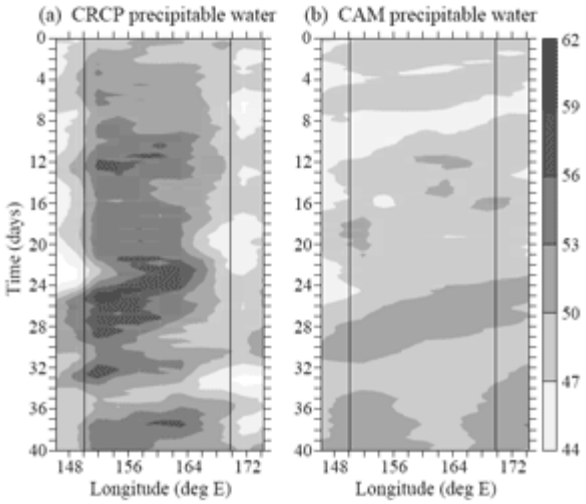

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Figure 66.

as well as the bias of the tropopause height. More realistic structure of the inter-tropical convergence zone (ITCZ) during the boreal winter and better representation of the variability of convection are evident. In particular, the diurnal cycle of precipitation has phase and amplitude in good agreement with observations. Also improved is the large-scale organization of the tropical convection involving superclusters associated with Madden-Julian Oscillation (MJO)-like systems. Location and propagation characteristics, as well as lower tropospheric cyclonic and upper-tropospheric anticyclonic gyres are more realistic than in the standard CAM. The simulations support an analytic theory of dynamical coupling between organized convection and equatorial beta-plane dynamics.

Evaluation of Cumulus Parameterization

James Hack, Julie Caron (both CGD), C. Liu, and M. Moncrieff have started the evaluation of the convective parameterization scheme in CCSM through cloud-resolving and single-column model (SCM) modeling. They are particularly interested in the capability of the cumulus parameterization in reproducing the observed phase of the diurnal cycle of US middle-summer convection. In their three-step approach, multi-day cloud-resolving simulations are conducted with a mesoscale model. Then, the advective tendencies for temperature and moisture averaged over a selective area are derived and are used to drive an SCM as "large-scale" forcing. Finally, the performance of the convective parameterization is evaluated through comparing the SCM results against cloud-resolving model results and observations. They are currently focusing on two 300km x 300km regions, which are characteristic of afternoon-evening maximum convection over the Continental Divide and nocturnal maximum rainfall over the Great Plains, respectively. The cloud-resolving simulations have been completed, and the SCM simulations are still under way.

Next Topic: Cloud-Microphysics and Small-Scale Processes

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Cloud-Microphysics and Small-Scale Processes

Cloud-microphysical processes and processes smaller than about 1 km have to be parameterized in present cloud-systems resolving models. Improved understanding is needed to improve the parameterizations.

Turbulent Mixing in Clouds

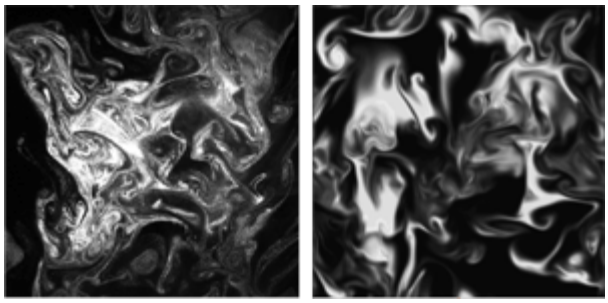

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Figure 67. *Text*

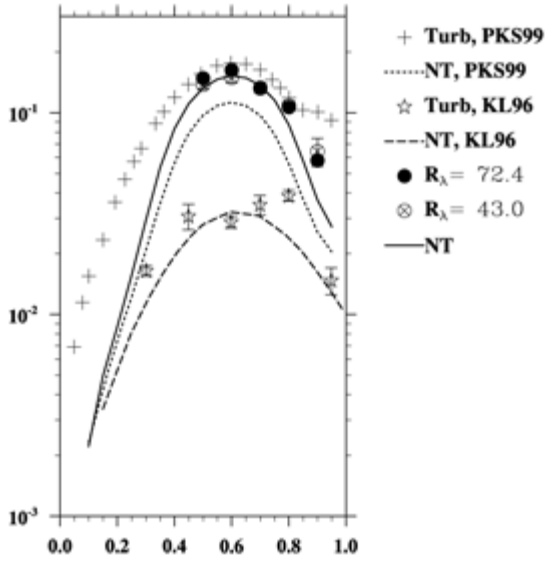

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Figure 68. *Text*

Miroslaw Andrejczuk and Szymon Malinowski (both at Warsaw University, Poland) continued collaborative investigation with W. Grabowski and P. Smolarkiewicz of the small-scale dynamics of decaying moist turbulence reported in FY2003. This problem is important for radiative transfer through clouds, initiation of precipitation in warm (i.e., ice-free) clouds, and parameterization of small-scale and microscale processes in models resolving larger scales. The most recent research focused on the validity of low spatial resolution simulations reported in previous fiscal years and on sensitivity to the initial fraction of the volume occupied by the cloudy air. The latter is important for macroscopic properties of buoyancy-reversing systems and determines the extent of microphysical transformations (i.e., the homogeneous versus inhomogeneous mixing) during the small-scale

turbulent mixing and homogenization. A series of model simulations applying detailed microphysics approximation for the moist thermodynamics with variable initial fraction of the volume occupied by the cloudy air and with the variable input of the turbulent kinetic energy (TKE) suggests that the evolution of the mean cloud droplet spectrum during mixing follows a universal path determined primarily by TKE. These results suggest that it is possible to develop a simple parameterization of the cloud droplet evolution resulting from cloud entrainment usable in cloud-resolving models that apply bulk cloud-microphysics parameterization.

Turbulent Mixing, Collision Rate and Collision Efficiency of Droplets

Lian-Ping Wang (University of Delaware) and W. Grabowski (who is an Adjunct Professor at the University of Delaware), with two graduate students Orlando Ayala and Yan Xue (University of Delaware), continued investigations of the effects of turbulence on the geometric collision rate and collision efficiency of cloud droplets when droplet inertia, gravity, and turbulence microstructure are all considered. This is an important problem because the impact of cloud turbulence on microphysical processes (warm rain initiation in particular) remains ambiguous. A significant progress in the last year is the development of a methodology for conducting DNS of hydrodynamically interactive droplets in turbulent flow. The method combines DNS of air turbulence with an improved formulation of the superposition method for treating hydrodynamic interactions. They validated the new methodology against the hydrodynamic-gravitational problem and against mechanics of random suspensions. It allows the problem of collision efficiency of hydrodynamically interactive droplets in a turbulent flow to be addressed. They found that turbulence enhances the collision efficiency because, in turbulent flow, hydrodynamic interactions become less effective in reducing the average relative radial velocity and that the increase in the collision efficiency depends on the flow dissipation rate. Turbulence can increase the net collision rates by a factor of 2 to 3 at dissipation rate of 400 cm s . They plan to develop a parameterization of collision-enhanced efficiency due to turbulence.

Convection Effects and Particle Generation

Effects of Absorbing Aerosols on Subtropical Shallow Convection

Observations during the Indian Ocean Experiment (INDOEX) showed that isolated trade-wind cumuli were embedded in the widespread anthropogenic haze over northern Indian Ocean. Prof. Gregory McFarquhar and Hailong Wang (University of Illinois, Urbana-Champaign), and Wojciech Grabowski examined factors affecting cloud cover, seeking to better characterize the semi-direct and indirect effects of three-dimensional limited-domain simulations of trade wind cumuli in the Indian Ocean region. The Eulerian version of EULAG running with warm-rain bulk microphysics parameterization was used. A control experiment without environmental soot and sensitivity experiments with soot examined the effects of absorption on cloud formation and development. The daytime reduction of cloud fraction and liquid water path by soot was found to be at 0.8% and 5.3gm . They found that at the ocean surface (top-of-model atmosphere) absorbing aerosols exert a total diurnal radiative forcing of -15.1 Wm (-1.0 Wm) and a semi-direct forcing of 1.4 Wm (1.5 Wm), respectively. The main conclusion is that downdrafts, updrafts, total water mixing ratio, potential temperature and the diurnal evolution of cloud fraction, liquid water path and cloud heights are sensitive to not only to the concentration and absorption properties of soot, but also to its vertical distribution.

Convectively Generated Tropical Ice Clouds

Andrew Heymsfield and Larry Miloshevich, and Cynthia Twohy Oregon State University), Michael Poellot (University of North Dakota), and Ann Fridlind (NASA Ames Research Center), studied the formation of ice in convective cells and anvil genesis and radiative properties associated with tropical convection. They investigated the conditions facilitating the presence of supercooled liquid water in convective cells at temperatures below –30C, which, if present, will lead to copious small ice crystals to be produced by homogeneous ice nucleation and highly reflective anvils. Observations in deep, low-latitude vigorous convective cells, together with calculations of droplet and ice particle growth and homogeneous ice nucleation were used to investigate the influence of large ice particles lofted in updrafts from lower levels on the homogeneous nucleation process. The pre-existing large ice particles act to suppress homogeneous nucleation through competition via diffusional and accretional growth, mainly when the updrafts are <5 m/s. In deep convective

updrafts > 5-10 m/s. The anvil is the depository for the small, radiatively important ice particles (homogeneously nucleated) and the large ice particles from below. This result could and should be included in cloud resolving and general circulation models to more realistically treat the convective cloud-anvil radiative interplay.

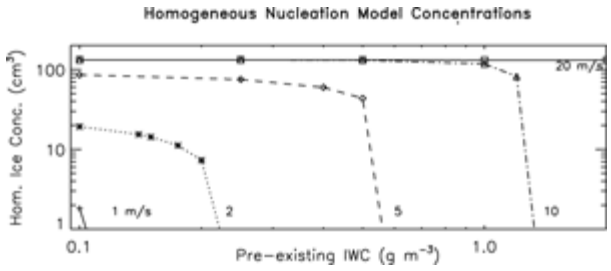

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Figure 69. *Model ice concentrations formed by homogeneous ice nucleation in convective updrafts with vertical velocities of from 1 to 20 m/s as a function of the ice content comprised by the large ice particles generated lower down in the convection. This figure shows that with low vertical velocities homogeneous ice nucleation is effectively suppressed when ice contents are more than a few tenths g/m3.*

Microphysics and Measurement

Ice-Phase Characteristics Derived from Satellite Measurements

John Latham (long-term visitor) and collaborators Hugh Christian, Walt Petersen & Wiebke Deierling (NASA/MSFC), Alan Gadian & Alan Blyth, (University of Leeds, UK), Dr Rumjana Mitzeva (University of Sofia, Bulgaria), Scott Ellis (ATD) and James Dye are continuing their examination of the extent to which it is possible to determine thundercloud ice characteristics from satellite observations of lightning, which are now routinely made on a global scale, using NASA/MSFC devices. A specific goal is to ascertain whether measurements of lightning frequency (f) can yield estimates of precipitating and non-precipitating ice fluxes. Computations – and particularly, recent data analysis - support the hypothesis that f is roughly proportional to the product of the downward flux (fg) of graupel through the body of the thundercloud and the upward flux (fi) of ice crystals into its anvil. This raises the possibility of determining, on a global basis, values of fg and/or fi from lightning measurements. Such information could have considerable climatological and nowcasting importance, particularly with respect to flooding.

In-Situ Measurements of Electric Field and Microphysics in Anvils

The threat of the shuttle or other space vehicles triggering lightning when launched through anvils and other seemingly benign clouds is considered a major hazard at Kennedy Space Center (KSC). As a result of the loss of an Atlas-Centaur rocket in 1987 due to triggered lightning, the present Lightning Launch Commit Criteria for the launch of the shuttle and other vehicles is very restrictive. In order to better understand the conditions in which the threat of triggered lightning might be present and with the hope of increasing launch availability, an airborne project was conducted near KSC during June 2000 and 2001. The project, lead by James Dye, used the University of North Dakota Citation II jet aircraft to obtain in-situ measurements of electric field and microphysics in anvils and other clouds in coordination with radar observations from KSC and the NEXRAD radar at Melborne FL. Collaborating investigators in the effort were Anthony Grainger (University of North Dakota), Hugh Christian, Monte Bateman, and Douglas Mach (all NASA Marshall Space Flight Center), Philip Krider and Natalie Murray (University of Arizona), Paul Willis (NOAA National Hurricane Division), John Willett (Garrett Park, MD), Francis Merceret (NASA KSC) and by Sharon Lewis and William Hall.

Results from the more than 30 anvils studied during the project have now been analyzed and show that there is often an abrupt increase in electric field when the aircraft entered regions of reflectivity of 10 dBZ or greater. **Figure 70** presents one such example of the Citation penetration of an anvil from the downwind tip toward the convective core of the storm. Note that the abrupt increase in electric field is not reflected by similar changes in particle concentration. The particle concentrations in all size ranges show gradual increases throughout the

penetration. This and similar results of this investigation are now being used to develop new, less restrictive Lightning Launch Commit Criteria for NASA and Air Force.

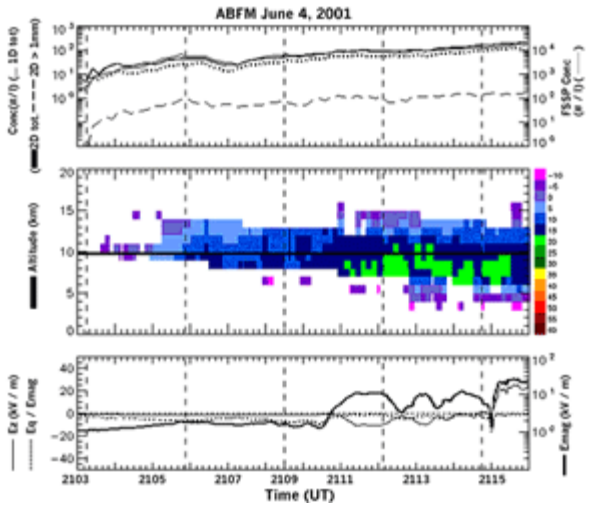

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Figure 70. *Top Panel: Time history of Particle concentrations: PMS FSSP total conc. (1 to 48 mm) light, solid line on right scale;PMS 2D-C (30 mm to ~3 mm), bold line = total conc., dashed line = conc. >1 mm on left scale;PMS 1D-C total conc. (15 to 960 mm), dotted line = total conc. on left scale.Middle panel: Radar reflectivity curtain above and below the aircraft from NEXRAD radar at Melborne FL, bold line = aircraft altitude.Bottom panel: Vertical component of the electric field, Ez, light line on left on a linear scale, and total vector field, Emag, bold line on right on a log scale.*

Next Topic: **Chemistry, Aerosols, and Dynamics Interactions**

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Chemistry, Aerosols, and Dynamics Interactions

The foci of studies on chemistry, aerosols, and dynamics interactions are to examine the effect of physical and dynamical processes on chemical species and to study the effect of chemistry on aerosols and cloud condensation nuclei. Ongoing projects within the program include studies of the effects of boundary layer processes on chemical species distributions, cloud chemistry process studies, and prediction of chemical constituents on the cloud scale to mesoscale.

Effect of boundary layer processes on chemical species distributions

Segregation of Chemical Reactants in a Shallow Cumulus Boundary Layer— Simple Chemistry

Shallow cumulus clouds enhance vertical transport and mixing but scatter solar radiation, which initiates photochemistry in the atmosphere. Because chemical reactions may proceed more slowly if these boundary layer processes segregate reactants, studies of the covariance between two reacting chemical species are being performed by Mary Barth (joint with ACD), Jordi Vila-Geurau de Arellano (Wageningen University, The Netherlands), Si-Wan Kim (visitor, Seoul National University), and Edward Patton for the shallow cumulus boundary layer. A two reaction system, where species A and B produce C and C dissociates to form A and B, was simulated with two large-eddy simulation models, the NCAR LES and the Dutch LES. Preliminary results show that for a cloud fraction of 25-30% the segregation between A and B was significant in regions below cloud, but was negligible when averaged over the boundary layer. Further simulations are being performed to determine the sensitivity of these results to different amounts of cloud fraction.

Segregation of Chemical Reactants in a Shallow Cumulus Boundary Layer— Complex Chemistry

Shallow cumulus clouds provide locations for aqueous chemical reactions in addition to enhancing transport and mixing and scattering radiation. Barth, Kim, and Chin-Hoh Moeng used the NCAR LES coupled with gas and aqueous chemistry (over 50 species) to investigate the segregation between hydroxyl radical (OH) and isoprene, species which react to eventually produce ozone. Knowing the degree of segregation between reactants will help improve regional and global-scale chemistry simulations that assume the reactants are well-mixed;

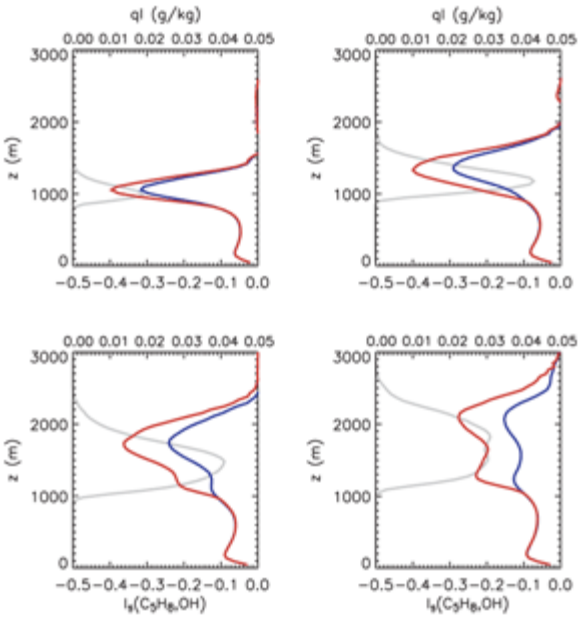

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Figure 71. *Intensity of segregation between isoprene and OH at (a) 1200 LT, (b) 1300 LT, (c) 1400 LT and (d) 1500 LT. Red lines with aqueous chemistry, blue lines with only gas chemistry. Gray lines are liquid water content (scaled at top of figure).*

it will also improve interpretation of chemical species measurements in the atmospheric boundary layer. Results of a simulation with only gas-phase chemistry show that segregation of OH and isoprene reaches 30% in the cloud layer. Inside the cloud layer, the turbulent flux of isoprene is positive and the vertical gradient of the mean OH concentration is also positive. This leads to a major sink of the covariance between these species, and hence a larger segregation. When aqueous-phase chemistry is also included, the segregation between the two species reaches 40% in the cloud layer, further indicating the importance of cloud chemistry on the distribution of OH and isoprene. These LES results will continue to be analyzed to determine which chemical reactions are contributing to the covariance of isoprene and OH.

Lagrangian Dispersion Modeling in the CBL Using LES Fields

In collaboration with Chin-Hoh Moeng and Peter Sullivan, Jeffrey Weil (visitor, University of Colorado) used velocity fields from large-eddy simulations (LES) to drive a Lagrangian model of dispersion in the convective boundary layer (CBL). In this combined LES - Lagrangian stochastic model (LSM), passive “particles” were tracked with a velocity given by the sum of the filtered and random subfilter-scale (SFS) LES velocities. The SFS velocity was modeled using an adaptation of Thomson's (1987) LSM, in which the random forcing was based on the SFS fraction of the total turbulent kinetic energy (TKE). The modeled crosswind-integrated concentration (CWIC) fields were in good agreement with 1) surface-layer similarity theory for a surface source in the CBL, and 2) convection tank measurements of the CWIC from an elevated source in the CBL surface layer. The comparison included the modeled evolution of the vertical profile shape with downstream distance, which showed the attainment of an elevated CWIC maximum and vertically well-mixed CWIC far downstream, in agreement with the tank data. For the proposed model, the agreement with the data and theory was better than that found with an earlier model in which the SFS fraction of the TKE was assumed to be 1, and significantly better than a model that neglected the SFS velocities altogether.

Turbulent Dispersion of Scalars

The fumigation process, where an elevated source of a scalar is entrained into a growing convective boundary layer (CBL), is controlled by turbulent dispersion. By using a Lagrangian particle model, Jeffrey Weil (visitor, University of Colorado/CIRES), Si-Wan Kim (Seoul National University, Korea), C.-H. Moeng, and Mary Barth, examined the distribution of passive particles along the LES-generated turbulent velocity flow. Analysis of the simulations showed that fumigation from sources above the entrainment zone and within the entrainment zone should be treated separately. The translation from time to space coordinates (so that pollutants advected into a growing boundary layer can be studied) needs to be determined with the time-dependent mean boundary layer wind rather than the initial mean boundary layer wind because the mean boundary layer wind speed decreases as the simulation proceeds. They plan to improve the subgrid-scale velocity model to improve predictions of particle concentrations at the surface in a rapidly growing CBL.

Cloud Chemistry Process Studies

The Importance of the Cloud Drop Representation on Cloud Chemistry

Previous studies have shown that the representation of cloud drop microphysics affects the amount of sulfate produced by aqueous chemistry because aqueous sulfur chemistry depends on pH and pH varies with drop size. Because other aqueous chemical reactions (e.g., those involving hydro peroxy radical and formic acid) also depend on pH, M. Barth is using a cloud parcel model coupled with gas and aqueous chemistry to investigate the importance of the model's cloud drop representation on cloud photochemistry. M. Barth's study focused on ozone, hydrogen peroxide, formaldehyde and formic acid under remote and moderately polluted chemical and aerosol conditions. Results of the study showed that formaldehyde and formic acid are sensitive to the cloud drop representation, while ozone and hydrogen peroxide are not.

Modeling for Field Experiment Analysis

As a collaboration with Jorgen Jensen (ATD), the cloud parcel model coupled with chemistry will be used as part of the Rain in Cumulus over the Ocean (RICO) project. Results of the model will be evaluated with field measurements of sulfur dioxide, hydrogen peroxide, and ozone, and will also be used to estimate the age of a cumulus parcel, which is one of the research objectives of RICO.

WRF-AqChem, a coupled meteorology and multi-phase chemistry model

Development and Initial Results of Model

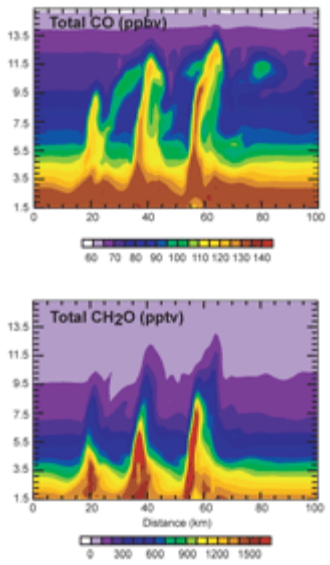

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Figure 72. *Cross-section of the total (gas + cloud water + rain + ice + snow + hail) mixing ratio of carbon monoxide (CO) and of formaldehyde (CH_2O). Both species are found in high concentration near the surface and lower concentration above the boundary layer. Carbon monoxide, an insoluble species, is primarily transported to the upper troposphere, while CH_2O, a soluble and reactive species, has a fraction reacted or precipitated to the ground.*

M. Barth, William Skamarock, and Si-Wan Kim implemented a simple gas and aqueous-phase chemistry mechanism into the WRF model to begin investigations on the effect of convection on the chemical environment. Convection plays an important role in transporting pollutants from the surface to the upper troposphere, scavenging soluble species and depositing much of the soluble species to the surface, and converting species chemically in the cloud drops. Simulations of the 10 July 1996 STERAO storm were performed to provide a way to evaluate the modeled chemistry results with observations. Sensitivities of the chemical species distributions to the cloud microphysics representation are currently being investigated. This WRF-AqChem model will continued to be developed by incorporating the aqueous chemistry modules into the community WRF-Chem model, by incorporating lightning production of NOx and interactions between gas and ice phase species. M. Barth and W. Skamarock also plan to continue collaborations with John Worden and Kevin Bowman (both at JPL) to examine the feasibility of using convective-scale cloud chemistry modeling with satellite data retrieval of ozone and carbon monoxide.

Intercomparison of Convective Cloud Chemistry Models

M. Barth designed and led an intercomparison study for convective cloud chemistry models as part of the 6th International Cloud Modeling Workshop, Cloud Chemistry Case.
http://box.mmm.ucar.edu/individual/barth/TracerTransportDeepConvection.html. An intercomparison of these

models will show how well-reputed models perform when simulating the same storm, giving a range of results that agree reasonably with observations. The intercomparison case focused on the 10 July 1996 STERAO storm for which observations of carbon monoxide, ozone, and nitrogen oxides (NOx)are available. Barth and Si-Wan Kim contributed results from the WRF-AqChem model. These results are being compared to those from Chien Wang (Massachusetts Institute of Technology), Jean-Pierre Pinty and Celine Mari (Laboratoire d'Aerologie, Toulouse, France), Ann Fridlind (NASA-Ames Research Center), Vlado Spiridonov (Hydrometeorological Institute. Skopje, Macedonia), Maud Leriche and Sylvie Cautenet (Laboratoire de Meteororologie Physique, Clermont-Ferrand, France), and Ken Pickering, Lesley Ott (U. Maryland) and Georgiy Stenchikov (Rutgers U.). Passive tracer transport show similar results among the models and agree fairly well with observations. The intercomparison of NOx produced from lightning and of the soluble species, nitric acid, hydrogen peroxide and formaldehyde, is currently being pursued.

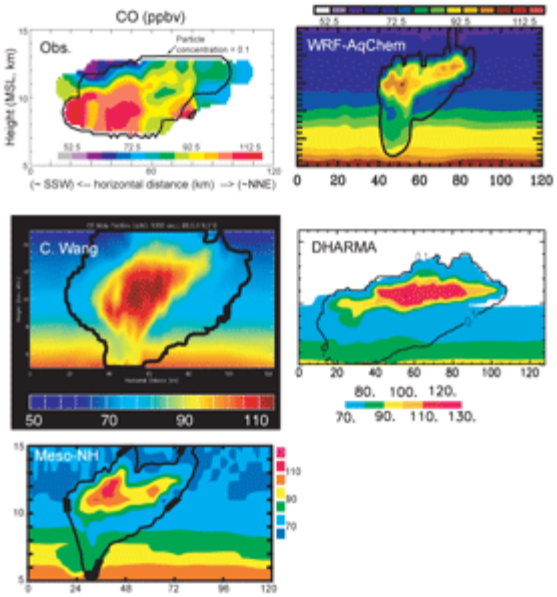

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Figure 73. *Vertical cross-sections of carbon monoxide (CO) across the storm anvil. Observations are from Skamarock et al. (2003). Results of WRF-AqChem are provided by Barth and Kim, results of C. Wang are provided by Chien Wang (MIT), results of DHARMA are provided by Ann Fridlind (NASA-Ames), and results of Meso-NH are provided by Jean-Pierre Pinty (Obs. Midi-Pyrenees, Toulouse, France). Cloud particle conentration of 0.1 per liter is marked by the solid black line, indicating the cross-sectional area of the anvil. Although anvil sizes vary between simulations, all model results show CO mixing ratios of 100 ppbv or greater in the anvil as is also found in the observations.*

End of Research Narrative

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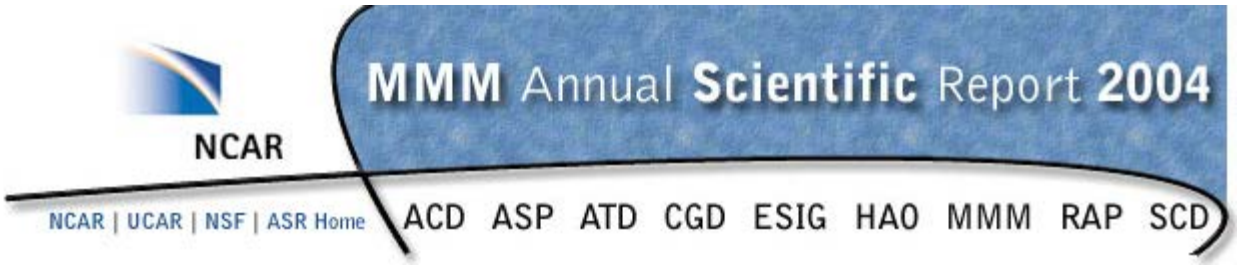

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Teaching Arrangements

- **Dale Barker**: Director of ISSAOS, University of L'Aquila, Italy.
- **Roelof Bruintjes**: Honorary Professor, University of Witwatersrand, South Africa.
- **Sean Burns**: Professional Research Asst., University of Colorado.
- **Christopher A. Davis**: Adjunct Professor, North Carolina State University and Colorado State University.
- **James E. Dye**: Affiliate Faculty, Colorado State University and University of Alabama in Huntsville.
- **Wojciech W. Grabowski**: Adjunct Professor, University of Delaware, and Faculty Affiliate, Colorado State University.
- **Andrew J. Heymsfield**: Affiliate Professor, University of Wisconsin-Madison.
- **Charles A. Knight**: Adjunct Professor, Colorado State University and University of Wyoming.
- **Ying-Hwa Kuo**: Adjunct Professor, National Central University in Taiwan and University of Hawaii.
- **John Latham**: Emeritus Professor, University of Manchester Institute of Science & Technology; visiting professor, University of Leeds, UK.
- **Margaret A. LeMone**: Affiliate Professor, Colorado State University, University of Colorado, and the University of Wyoming.
- **Chin-Hoh Moeng**: Affiliate Professor, Colorado State University.
- **Richard Rotunno**: Adjunct Professor, North Carolina State University.
- **Piotr Smolarkiewicz**: Visiting Professor, Yale University.
- **Chris M. Snyder**: Adjunct Professor, Texas A&M University.
- **Peter P. Sullivan**: Affiliate Professor, Colorado State University.
- **Morris L. Weisman**: Adjunct Professor, State University of New York at Albany, and Florida State University; Affiliate Professor, Colorado State University.
- **C. Larrabee Winter**: Adjunct Professor, University of Arizona.

Individual Courses Taught

- **Richard Rotunno**: "Observations and Theory of Orographic Precipitation" (Summer School), University of Trento, Italy.
- **Piotr Smolarkiewicz**: "Numerical Methods for Geophysical Flows" (Flint Lecturer) at Yale University.

Graduate Research Advisors

- **Wojciech Grabowski**: Warsaw University.
- **Andrew Heymsfield**: University of California, Los Angeles and University of Manchester Institute of Science & Technology.

- **Ying-Hwa Kuo**: National Taiwan University (3 students), and University of Colorado.
- **Arlene Laing**: University of Bologna and University of South Florida.
- **John Latham**: University of Alabama, Huntsville.
- **Piotr Smolarkiewicz**: European Centre for Medium Range Weather Forecasting.
- **Peter Sullivan**: Colorado State University.
- **C. Larrabee Winter**: University of Arizona.

Thesis Committee Members

- **Roelof Bruintjes**: University of Witwatersrand, South Africa (3 students), and University of Colorado.
- **Christopher A. Davis**: Colorado State University (2 students) and Texas A & M University.
- **James E. Dye**: University of Alabama in Huntsville.
- **Wojciech W. Grabowski**: University of Deleware and University of Illinois at Urbana-Champaign.
- **Andrew J. Heymsfield**: University of Colorado.
- **Ying-Hwa Kuo**: University of Colorado.
- **John Latham**: University of Alabama, Huntsville.
- **Margaret A. LeMone**: University of Wyoming.
- **Donald Lenschow**: University of Colorado.
- **Chin-Hoh Moeng**: National Central University, Taiwan (2 students).
- **Richard Rotunno**: North Carolina State University.
- **Chris Snyder**: Texas A & M University, University of Washington, and University of Illinois at Urbana-Champaign.
- **Peter P. Sullivan**: Colorado State University.
- **Juanzhen Sun**: University of Iowa.
- **Morris Weisman**: State University of New York at Albany (2 students), and Colorado State University.
- **C. Larrabee Winter**: University of Arizona.

Participation in UCAR/NCAR/UOP Programs (top)

Significant Opportunities in Atmospheric Research and Science (SOARS)

Website: http://www.ucar.edu/soars/

SOARS students mentored by MMM staff this year totaled nine:

Erick Adame. Science Research Mentor: Ying-Hwa Kuo.
Melissa Burt. Science Research Mentor: Christopher Davis.
Roberto Cancel. Science Research Mentor: Jielun Sun.
Anthony Didlake. Science Research Mentor: Andrew Crook.
Braxton Edwards. Science Research Mentor: Margaret LeMone.
Deanna Hence. Science Research Mentor: L. Jay Miller.
Clarence Mann. Science Research Mentor: Rebecca Morss.
Garymar De Rivera. Writing and Communications Mentor: Mary Golden.
Dione Lee Rossiter. Science Research Mentor: Ying-Hwa Kuo.

The GLOBE Program

GLOBE is a new world-wide hands-on program to develop primary and secondary school-based education and science programs. It is a co-operative agreement between UCAR, Colorado State University, and NASA. GLOBE One: Margaret LeMone is involved in the planning for this project and serves as Lead Scientist.

Website: http://www.globe.gov/globe_flash.html

Non-Technical and Educational Outreach (top)

Outlined below are some of the outreach activities performed by MMM staff.

Name	
Dale Barker	"Forecasting the Weather" for High Peaks Elementary School in Boulder, CO on September 28, 2004
N. Andrew Crook	Presentation to Miss Miller's Fourth Grade Class at Central Elementary School in Longmont, CO on April 19, 2004.
Margaret A. LeMone	"Women in Science" presentation in Boulder, CO on May 4, 2004.
Margaret A. LeMone	"Women in Science" presentation in Boulder, CO on March 18, 2004.
Margaret A. LeMone	GLOBE Science Presentation in Fort Collins, CO on August 16 and September 20, 2004
Margaret A. LeMone	"GLOBE and Hydrological Observatories" at CUAHSI in Logan, UT on August 24, 2004.
Margaret A. LeMone	"Science in GLOBE" presentation at the GLOBE International Conference in Boulder, CO on July 27, 2004.
Margaret A. LeMone	A presentation on Atmospheric Oberservations during the Workshop for GLOBE Teacher Trainers in Ft. Collins, CO on July 12, 2004.
Margaret A. LeMone	GLOBE ONE Field Campaign presentation at Northern Iowa University on Februry 25, 2004.
Margaret A. LeMone	A presentation on GLOBE Science Plans at NCAR on January 26, 2004.

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Education and Outreach | Community Service | Awards | Publications | People | ASR 2004 Home

Community Models (top)

MM5 Model Development and User Support

The number of MM5 users who subscribe to our news list continue to increase this year. At the end of September, 2004, that number is 1120 from 566 institutions worldwide. About 2440 emails were answered in the year. A new user information and registration page (http://www.mmm.ucar.edu/mm5/institutes.html) has been developed by Cindy Bruyere and Kristin Conrad. The page has improved viewing and maintenance of the database. User pages on Frequently Asked Questions and computer related issues have been expanded to accommodate many users' need to run the modeling system on various new systems and/or with new compilers (such as the new Intel compiler).

WRF Model Development and User Support

The number of WRF users continued to increase in the last year. Another 800 people (in addition to the previous 1400) have visited the WRF site and downloaded the code. Over 960 users have subscribed to the WRF news list, compared to the 600 people reported last year. In May 2004, the WRF ARW, SI, and 3DVAR Version 2.0 was released in which the nesting capability was included. Two minor version releases were followed in late May and early June. The WRF User page has been redesigned and made its debut with the WRF Version 2 release in May. The number of user emails continues to increase. During FY04, W. Wang and other MMM staff answered 1130 user emails, which is a 66% increase over the previous year.

Model Workshops

- MM5 and WRF Workshop:

The Fourteenth Annual MM5 Users' Workshop was held on 22-25 June 2004 in conjunction with the Fifth WRF Users Workshop. About 170 participants arrived from 90 institutions worldwide. Twenty foreign countries participated. One hundred papers were received for the workshop. W. Wang, J. Klemp, J. Dudhia, and J. Powers organized the event.

Educational Activities for Models

- MM5 Tutorial:

We continued to offer a MM5 modeling system tutorial this year, in January 2004. The last one will be offered in FY05, January. A total of 35 participants (8 from foreign countries) from 28 institutions worldwide attended the classes. Jimy Dudhia, Dave Gill, Kevin Manning, Cindy Bruyere, Dale Barker, and Wei Wang lectured at the

tutorials.

- WRF tutorial:
A four-day WRF followed the Users' Workshop during the summer of 2004. The dates were 28 June – 1 July. The WRF model, WRF Standard Initialization, and WRF 3DVAR were taught at the tutorial. Practice sessions were a part of the WRF tutorial for the first time. In order to accommodate the 115 participants, sessions were divided. 75 institutions and 15 countries were represented. A new User's Guide was developed and distributed at the tutorial. Cindy Bruyere, Shu-hau Chen (University of California, Davis), Jimy Dudhia, David Gill, Yong-Run Guo, Wei Huang,, John Michalakes, and Wei Wang, along with John Smart and Paula McCaslin (NOAA/FSL), lectured at the WRF tutorial. ***Website:*** http://box.mmm.ucar.edu/events/workshop04/

Data Access and Analysis Software Support (top)

Sherrie Fredrick and Jay Miller continued support of the CEDRIC (Custom Editing and Display of Reduced Information in Cartesian space) software system that is used for the analysis of regularly gridded datasets from both numerical models and observational systems. This software package continues to be used heavily by researchers at universities and government agencies, both domestic and foreign.

Fredrick modified CEDRIC source code to output MDV format from CEDRIC.

Field Campaigns (top)

AIRS-2: (Second Alliance Icing Research Study II) aims to investigate the microstructure and spatial distribution of mixed phase clouds. Aaron Bansemer participated in the late Fall 2003 study in Colorado.

AWEX: (AIRS Water Vapor Experiment) is a part of the AIRS program (Second Alliance Icing Research Study II). Larry Miloshevich was the PI for this study.

CIFEX: (Cloud Indirect Effects Experiment). Carl Schmitt was an investigator in this study. This experiment was held during April 2004.

CME-04: (Carbon in the Mountains Experiment) This experiment was set up in the mountains west of Boulder, Colorado, at Niwot Ridge. in the Spring and Summer of 2004. Jielun Sun, Edward Patton, Donald Lenschow, Sean Burns participated.

ACME: (Airborne Carbon in the Mountains Experiment) is the first aircraft field campaign of a program supported by the NSF Biocomplexity Program and NASA Interdisciplinary Science. The goal of the project is to understand carbon dynamics in mountain forest regions by developing new methods for estimating carbon exchange at local to regional scales.

M-PACE: (Mixed-Phase Arctic Clouds Experiment) The major objective of the project is to collect the focused set of observations needed to advance the understanding of dynamical processes in Arctic mixed-phase clouds, including the cloud microphysical processes and radiative transfer through the clouds. Aaron Bansemer participated in this experiment during late September early October 2004.

MidCIX: (Mid Continental Cirrus Experiment) Andrew Heymsfield was the principal investigator and Aaron Bansemer participated on the instrumentation. Project was in California.
NAME: (North American Monsoon Experiment) was conducted in July and August 2004 in La Cruz, Sinaloa, Mexico. James Done and David Ahijevych participated . The objective was an improved understanding necessary to advance warm season precipitation prediction. It is an internationally coordinated, joint CLIVAR-GEWEX process study aimed at determining the sources and limits of predictability of warm season precipitation over North America, with emphasis on time scales ranging from seasonal-to-interannual.

OHATS: (Ocean Horizontal Array Turbulence Study), is a collaborative effort between NCAR, Woods Hole Oceanographic Institute, and Pennsylvania State University. The field experiment was held south of Martha's Vineyard to investigate wind-wave interactions and improve our ability to assess the impacts on weather

forecasts and climate variability. Time-frame was August to October 2004.

Principle Investigators from MMM for the project are Peter P. Sullivan, Donald Lenschow, Chin-Hoh Moeng, and Jeffery C. Weil (long-term visitor from CIRES, University of Colorado). Edward Patton (long-term visitor from Pennsylvania State University) and Jielun Sun participated.

Pentagon Shield Field Program: Part of the DARPA project, long-term visitor from CIRES, University of Colorado, Jeffrey Weil was the co-director of this program which was held from 4/29/04 to 5/10/04. The purpose was to model fine-scale flow around the Pentagon, and to determine the impact of point/continuous chemical release on the building.

Pre-AVE: (Pre Aura Validation Experiment) occurred in January 2004 in Costa Rica, sponsored by NASA. Andrew Heymsfield and Alan Hills participated.

RAMS-2: (Riming, Aggregation, & Melting Layer Study) was scheduled during March 2004. Aaron Bansemer was one of the investigators.

Looking Ahead……..

RICO: (Rain in Cumulus over the Ocean) will study the use of S-Pol, C-130, Dropsondes, and SABL to measure precipitation processes and to determine their importance in shallow, maritime, cumulus convection, one of the prevalent cloud types on the planet. This project will be held in November 15, 2004 - January 24, 2005 in Antigua, Barbuda.

RIME: The Ross Island Meteorology Experiment, a basic and applied research program, will explore in detail the atmospheric processes over Antarctica and their interactions with lower latitudes via the Ross sea sector, as a prerequisite to exploring the role of Antarctica in global climate variations. Local and regional

measurements to be made during the summer-early fall of 2005/2006 and the spring of 2007 will be complemented by an extensive numerical modeling effort to accurately simulate and understand transports of heat, water vapor, and mass to and from Antarctica along with their modification by the topographic and mesoscale processes. Jordan Powers is involved in the planning stages and strong international collaborations will be a hallmark of RIME that will span June 2003 to June 2010.
http://polarmet.mps.ohio-state.edu/PolarMet/index.html

THORPEX: (THe Observing system Research and Predictability EXperiment) a Global Atmospheric Research Programme is an international research programme to accelerate improvements in the accuracy of 1 to 14 day weather forecasts for the benefit of society and the economy. The programme builds upon ongoing advances within the basic-research and operational-forecasting communities. Melvin Shapiro (long-term visitor in MMM), David Parsons (MMM/ATD), Chis Snyder, and Rebecca Morss are intrigally involved with is program. ***Website:*** http://www.mmm.ucar.edu/uswrp/programs/thorpex.html

Scientific Community Interactions (top)

Collaborative Visits to Universities and Agencies

John Latham had two month-long collaborative visits to the University of Manchester Institute of Science & Technology in the UK, one in June and July of 2004 and another in September of that same year.

Richard Rotunno visited the University of Trento, Italy from August to November 2003
and University of L'Aquila, Italy from November to December 2003.

Piotr Smolarkiewicz finished his five-month collaborative visit at Yale University in December 2004.

Visitor Program

Collaboration and study has led to much of the success in research within MMM. The MMM Visitor Program speaks strongly of this. Senior scientists, professors, students, all have gathered here as members of the meteorological community. MMM hosted 463 visitors during FY04. Forty percent of these visitors arrived from foreign countries.

The Affiliate Scientist program within NCAR enabled MMM to work closely with six outside scientists (during FY04) for the duration of three years or longer. Based on an agreement between their university and NCAR, these scientists and their MMM hosts desire an extended, highly interactive set of opportunities. The six Affiliate Scientist appointments during FY04 were: Lance Bosart (State University of New York, Albany), L. Ruby Leung (Pacific Northwest National Laboratory) (shared with CGD), and Douglas Lilly (University of Oklahoma), Larry Mahrt (Oregon State University), Bjorn Stevens (University of California, Los Angeles), and Xiaolei Zou (Florida State University).

Website: See the MMM Visitors and Collaborators List

MMM Visitors Statistics

MMM VISITOR STATISTICS

	FY04	FY03	FY02	FY01	FY00
Total visitors	463	387	403	398	405
Total of visits (several visits by one visitor)	519	440	460	437	446
Domestic affiliations	333	283		326	331
Foreign affiliations	130	104		111	115
Short-term visits (1 day to 6 months)	428			400	413
Long-term visits (more than 6 months)	35			37	33
US Universities represented	72	45	53	56	62
US Agencies represented	25		41	39	34
Foreign countries represented	27	25	26	26	21
Private Sector represented	39		15	20	18

ASP postdoctoral fellows who worked closely with MMM scientists were Judith Berner, George Bryan, Joshua Hacker, Riwal Plougonven, Axel Seifert, and Wen-Wen Tung. An ASP Graduate Fellow, Justin Peter, also is in MMM. As will be mentioned in the Educational Activities chapter, MMM hosted nine SOARS students who were mentored by MMM staff during the summer of 2004. The staff members served either as science research mentors or writing and communication mentors.

Workshops and Colloquia

Robert L. Gall organized a number of workshops for the USWRP this year. The Mesocsale Observing System Workshop was held in Boulder in December and was host to 109 participants. Also in December, Gall organized the Regional Real-time NWP Workshop and it was equally well-attended by 120 participants. In February, Gall organized the Cool Season Workshop. In January, as part of the AMS annual meeting, Gall organized the USWRP Symposium. One hundred people attended that event. ***Website:*** http://box.mmm.ucar.edu/projects/uswrp_ams/

Wojciech Grabowski organized several events this year including the GEWEX Cloud System Study (GCSS) Working Group 4 Workshop. This workshop was held in Broomfield, Colorado in October. He also planned the NCAR Geophysical Turbulence Program (GTP) Workshop on the Cumulus Parameterization Problem in the Context of Turbulence Studies. This workshop was held in Boulder, Colorado in February.

Another event organized by Wojciech was the WMO International Cloud Modeling Workshop held in Hamburg, Germany in July. Mary Barth also helped to organize the WMO event and served as a session chair. ***Website:*** http://box.mmm.ucar.edu/events/wmo_workshop04/

Andrew J. Heymsfield organized the Ice Initiation Workshop in Boulder, Colorado in June of 2004. ***Website:*** http://box.mmm.ucar.edu/events/ice_workshop04/

Joseph Klemp co-organized, with Cindy Bruyere and Wei Wang, the WRF/MM5 2004 Workshop in Boulder, Colorado. One hundred and seventy five active participants attended the workshop. ***Website:*** http://box.mmm.ucar.edu/events/workshop04/

Ying-Hwa Kuo and Joseph Klemp organized two major international WRF workshops in FY04; one at the Seoul National University in December 2003; and the other at Taiwan's Central Weather Bureau in September 2004.

Arlene Laing was a Session Chair for the 13th AMS Conference on Satellite Meteorology and Oceanography in Norfolk, Virginia in September.

Margaret A. LeMone served as Session Chair for the 2nd International IHOP Science Workshop in Toulouse, France in June.

Jordan Powers organized the AMS Annual Meeting WRF Sessions as part of the AMS Annual Meeting in Seattle, Washington in January. He also organized the AMPS Users' Workshop at the Space and Naval Warfare Systems Center in Charleston, South Carolina in June.

Richard Rotunno and Chin-Hoh Moeng organized the Mesoscale Meteorology and Atmospheric Turbulence GTP Workshop in June.

Wei Wang and Cindy Bruyere organized the MM5 Tutorial held in January as well as the MM5/3DVAR Tutorial in June.

Morris Weisman organized the Bow Echo and Mesoscale Convective Vortex Experiment (BAMEX) Workshop in St. Louis, Missouri in March. This workshop was a follow-up to the BAMEX field study, which was held 19 May and continued through 7 July 2003. The BAMEX study took place in and around the St. Louis, MO area and included scientists from NCAR, NSSL, NOAA (National Weather Service), Colorado State University, Pennsylvania State University, University of Alabama, Texas A&M, and University of California, Los Angeles.

Scientific or Technical Seminars and Presentations outside of UCAR/NCAR

1) Scientific or Technical Presentations held at Universities. (open Excel Spreadsheet - larger view)

Name	Seminar	Location	Date	Fiscal Year
Dale Barker	A 3DVAR System for the MM5/WRF data assimilation communities.	McGill University, Montreal, Quebec	October 1, 2003	2004
Dale Barker	WRF Variational Data Assimilation Development at NCAR	National Taiwan University, Taipei, Taiwan	September 21, 2004	2004
Dale Barker	Polar NWP Workshop	University of Alaska	October 8, 2003	2004
Mary Barth	The Second International Workhso pon Next Generation NWP Models	Yonsei University, Seoul, Korea	May 17, 2004	2004
Mary Barth	Cloud Chemistry from the Global Scale to the Microscale	Seoul National University, Seoul, Korea	May 20, 2004	2004
Cindy Bruyere	Highly Resolved Wind Field Modeling in Lower PBL Using MM5 & WRF	University of Oldenburg, Germany	February 23, 2004	2004
Janice Coen	Tutorial on the NCAR Atmosphere-Fire Model.	University of Colorado, Denver	April 15, 2004	2004
Janice Coen	Software Architecture and Model execution.	University of Colorado, Denver	May 13, 2004	2004
Christopher A. Davis	Organized Convection and Mesoscale Vortices	University of Reading, Reading, Uk	September 4, 2004	2004
Christopher A. Davis	Observations and Analyses of MCVs from BAMEX	Univ. Of Wisconsin - Madison	March 4, 2004	2004
Jimy Dudhia	WRF Version 2.0 Physics Update	National Taiwan University, Taipei, Taiwan	September 23, 2004	2004
Wojciech W. Grabowski	Seminar: "Daytime convective development over land"	Institute of Geophysics, Warsaw University Poland	November 13, 2003	2004
Wojciech W. Grabowski	Seminar: "Clouds and Climate"	Department of Mechanical Engineering, University of Delaware	December 1, 2003	2004
Wojciech W. Grabowski	Planning\Workshop for the Proposed NSF Science and Technology Center on Multi-Scale Modeling of Atmospheric Processes	Colorado State University, Fort Collins, CO	December 18, 2003	2004
Wojciech W. Grabowski	Representation of moist precipitating thermodynamics in numerical models of atmospheric flows	Courant Institute of Mathematical Sciences, New York University	April 27, 2004	2004
Wojciech W. Grabowski	Super-parameterization: global context for cloud-scale processes	Courant Institute of Mathematical Sciences, New York University	April 28, 2004	2004
Wojciech W. Grabowski	Super-parameterization: global context for cloud-scale processes	McGill University	May 17, 2004	2004
Wojciech W. Grabowski	Daytime convective development over land	McGill University	May 19, 2004	2004
Joseph B. Klemp	WRF Numerics and its application to convection resolving forecasting	Colorado State Univeristy Atmos. Sci. Dept., Ft. Collins, CO	December 3, 2004	2004
Charles A. Knight	Ice Cube Spikes	University of Colorado at Boulder	September 17, 2004	2004
Margaret A. LeMone	International Water Vapor Experiment (IHOP)	University of Wyoming	April 16, 2004	2004
Changhai Liu	Mesoscale Convective Systems: A Review of Progress over the Last 20 Years	Chendu University of Information Technology, Chendu China	June 24, 2004	2004
Chin-Hoh Moeng	Department seminar	John Hopkins University	October 17, 2003	2004
Mitchell W. Moncrieff	"Organized convection in the context of MMF", CSU Planning Workshop for a Multiscale Modeling Framework (MMF)	Colorado State University, Fort Collins, CO	December 18, 2003	2004
Rebecca Morss	Designing observing networks for weather prediction: Atmospheric science and public policy perspectives	Texas A&M University	October 16, 2003	2004
Jordan Powers	Workshop on Short-to-Medium Range Regional Numberical Weather Prediction (NWP) in the Arctic and Antarctic	University of Alaska	October 10, 2003	2004
Richard Rotunno	"Simulations of Moist Neutral Flow Over a Ridge", Harris Lecture (Fall)	Texas A&M University	November 4, 2003	2004
Richard Rotunno	"Simulations of Moist Neutral Flow Over a Ridge"	Dept. of Meteorology, University of Reading	January 22, 2004	2004
Richard Rotunno	"Simulations of Moist Neutral Flow Over a Ridge"	North Carolina State University	September 20, 2004	2004
Chris M. Snyder	"Adventures with simulated radar observations and an ensemble Kalman filter"	Oregon State University	October 3, 2004	2004
Chris M. Snyder	An introduction to data assimilation	University of L'Aquila, L'Aquila Italy	September 4, 2004	2004
Chris M. Snyder	Ensemble Kalman filtering for radar data assimilation	University of L'Aquila, L'Aquila Italy	September 4, 2004	2004
Chris M. Snyder	Atmospheric Data Assimilation	International Summer School on Atmospheric and Ocan Sciences, L'Aquila Italy	August 29, 2004	2004
Peter P. Sullivan	An Overview of Turbulence Simulations of the Atmospheric and Oceanic Boundary Layers	University of Colorado, Aerospace	April 15, 2004	2004
Peter P. Sullivan	Current Research Topics in Large-Eddy Simulation Applications and Measurements	AHPCRC Workshop on Mesoscale and Microscale Meteorology for Military Applications Jackson State University	May 25, 2004	2004

2) Scientific or Technical Presentations held at Non-University Locations. (open Excel Spreadsheet - larger view)

Name	Seminar	Location	Date	Fiscal Year
Dale Barker	WRF Data Assimilation	Korean Meteorological Administration, Seoul, Korea	December 9, 2003	2004
Dale Barker	Modeling spatial background error covariance's in 3/4D-Var	Korean Meteorological Administration, Seoul, Korea	December 10, 2003	2004
Dale Barker	WRF 3D-Var Status	NOAA/NCEP, Camp Springs, MD	January 21, 2004	2004
Dale Barker	WRF Variational Data Assimilation Development at NCAR	AER Inc., Lexington, MA	July 9, 2004	2004
Dale Barker	WRF Variational Data Assimilation Development at NCAR	Air Force Weather Agency, Omaha, NE	July 23, 2004	2004
Dale Barker	Practical Implementation of 3/4D-Var	Taiwanese Central Weather Bureau, Taipei, Taiwan	September 23, 2004	2004
Janice Coen	Infrared imagery applied for insights into wildland fire dynamics. 5th Symposium Fire & Forest Meteorology/2nd International Fi	Orlando, FL/AMS	November 17, 2003	2004
Janice Coen	Simulation of wildfire incidents using coupled atmosphere-fire modeling. 5th Symposium Fire & Forest Meteorology/2nd Internati	Orlando, FL/AMS	November 17, 2003	2004
Janice Coen	Information Technology Research 2004 Grantees Meeting. Poster.	Crystal City, VA	June 9, 2004	2004
Janice Coen	Coupled Atmosphere-Wildland Modeling: Developments, Challenges I Fire Spread Prediction, and Collaborative New Directions.	NASA GSFC	September 8, 2004	2004
Christopher A. Davis	Organized Convection and Mesoscale Vortices	Laboratoire d'Aerologie, Toulouse France	September 4, 2004	2004
Jimy Dudhia	WRF: Status and Plans	Pacific Northwest Lab, Richland, WA	February 26, 2004	2004
Jimy Dudhia	Weather Research and Forecasting Model	UK Met Office, Exeter, UK	August 6, 2004	2004
Wojciech W. Grabowski	BMRC Modeling Workshop, "Current Issues in the Parameterization of Convection."	BMRC, Melbourne Australia	October 13, 2003	2004
Wojciech W. Grabowski	Seminar: "Daytime convective development over land"	BMRC, Melbourne Australia	October 10, 2003	2004
Wojciech W. Grabowski	Seminar: "Coupling cloud processes with large-scale dynamics using the cloud-resolving convection parameterization (CRCP)"	CSIRO, Aspendale	October 20, 2003	2004
Wojciech W. Grabowski	Seminar: "Daytime convective development over land"	CSIRO, Aspendale	October 21, 2003	2004
Wojciech W. Grabowski	ECMWF Workshop on Simulation and Prediction of Intra-Seasonal Variability	ECMWF, Reading UK	November 3, 2003	2004
Wojciech W. Grabowski	Seminar: "Daytime convective development over land"	Institute of Geophysics, Warsaw University Poland	November 13, 2003	2004
Wojciech W. Grabowski	Community Climate System Model (CCSM) Atmospheric Model Working Group Meeting	NSF	March 9, 2004	2004
Wojciech W. Grabowski	Summer Workshop on Physical Mechanisms of Climate Change	European Commission, Piaski, Poland	June 21, 2004	2004
Andrew J. Heymsfield	Tropical Cirrus Clouds	Seattle, WA, ARM Working Group	January 7, 2004	2004
Joseph B. Klemp	Evaluation of WRF for Convection Resolving NWP	SRNWP Workshop, Bad Orb Germany	October 27, 2003	2004
Joseph B. Klemp	Overview of WRF System & High resolution Forecast Applications	Korean Meteorological Association Seoul Korea	December 3, 2004	2004
Joseph B. Klemp	The Weather Research and Forecasting Model	MetService, Wellington, New Zealand	February 4, 2004	2004
Joseph B. Klemp	Model Numerics for Convective Storm Simulation	Geophysical Turbulence Workshop, Boulder	June 4, 2004	2004
Margaret A. LeMone	Surface/Atmosphere interaction and Boundary Layer results form IHOP	Toulouse, France (MeteoFrance)	June 14, 2004	2004
Changhai Liu	Explicit and Parameterized Realizations of Warm-season Precipitation Sequences	Broomfield, CO / GEWEX	October 30, 2003	2004
Changhai Liu	Multi-scale Simulations of Warm Season Convection over North America	Beijing China	June 29, 2004	2004
Changhai Liu	Sciences in NCAR	Institute of Earth Environment, Xian China	July 5, 2004	2004
Changhai Liu	Mesoscale Convective Systems: A Review of Progress over the Last 20 Years	Meteorological Bureau of Shanxi Province, Xian China	July 5, 2004	2004
Chin-Hoh Moeng	Merging mesoscale and computational fluid dynamics modeling capabilities	AMS workshop, Seattle	January 11, 2004	2004
Chin-Hoh Moeng	The cumulus parameterization problem in the context of turbulence studies	GTP workshop, Boulder	February 24, 2004	2004
Mitchell W. Moncrieff	"Precipitation Convective Cloud Systems at Large-scales"	Water Cycle Across Scales Science Meeting NCAR/MMM	November 11, 2003	2004
Mitchell W. Moncrieff	"Representing the mesoscale organization of convection in prediction models"	3rd TRMM Latent Heating Workshop, Nara, Japan	September 11, 2004	2004
Mitchell W. Moncrieff	"Surrogate precipitation and feedback in high-resolution NWP models." Workshop on Current Issues in the Parameterization of Con	Bureau of Meteorology Research Center, Melbourne Australia	October 13, 2003	2004
Mitchell W. Moncrieff	"Analytic representation of the large-scale organization of tropical convection." ECMWF/CLIVAR Workshop on Simulation and Predi	ECMWF, Reading UK	November 3, 2003	2004
Mitchell W. Moncrieff	"Organized precipitating convection in a large-scale context.", Workshop on Convection	UK Met office/ NCAS Centre for Global Atmospheric Modeling, Farnham UK	January 6, 2004	2004
Mitchell W. Moncrieff	"Analytic approximation of MJO-like systems in super-parameterization." Symposium for Forecasting the Weather and Climate of th	AMS Conference, Seattle	January 12, 2004	2004
Mitchell W. Moncrieff	"Explicit Multiscale Convection-Radiation Moisture Feedback in the Tropics", Meeting of Experts: Climate Sensitivity and Feedbacks	UKMO, Exeter, UK	April 19, 2004	2004
Rebecca Morss	USWRP Open Workshop on the Implementation of THORPEX	USWRP, Boulder, CO	August 19, 2004	2004
Jordan G. Powers	The Weather Research and Forecasting Model: A Next-Generation Community Mesoscale Modeling Capability	Desert Research Institute	March 4, 2004	2004
Richard Rotunno	Theory and Observation of Orographic Precipitation	CNR, Lecce Italy	July 19, 2004	2004
Piotr Smolarkiewicz	"Spectral Preconditioners for Nonhydrostatic Atmospheric Models: Extreme Applications" ECMWF Seminar on Recent developments in	ECMWF, Reading UK	September 6, 2004	2004
	Nonoscillatory forward in time differencing for fluids: Simulation of			

Piotr Smolarkiewicz	Geophysical Turbulence	Los Alamos National Laboratory	January 9, 2004	2004
Piotr Smolarkiewicz	Effective eddy viscosities in implicit large eddy simulations of turbulent flows	Los Alamos National Laboratory	January 9, 2004	2004
Piotr Smolarkiewicz	"Simulation of Geophysical Turbulence: Dynamic Grid Deformation" ECMWF Seminar on Recent developments in numerical methods for	ECMWF, Reading UK	September 6, 2004	2004
Stanley B. Trier	MCVs and the Convective Forecast Problem	Burlington, VT/ NWS WFO	May 19, 2004	2004
Stanley B. Trier	MCVs and the Convective Forecast Problem	Albany, NY/ NWS WFO	May 20, 2004	2004
C. Larrabee Winter	Workshop on Computational Geoinformatics	Carnegie Geophysical Laboratory, Washington, DC	May 1, 2004	2004
C. Larrabee Winter	ASCE Joint Specialty Conference	Sandia National Laboratory, Albuquerque, NM	July 25, 2004	2004

Editorships of Peer-Reviewed Journals

- **Roelof Bruintjes**, Associate Editor, Journal of Applied Meteorology, from 1999 to present.
- **Alain Caya**, Reviewer, Monthly Weather Review, form 2004 to present.
- **N. Andrew Crook**, Associate Editor, Monthly Weather Review, from 2001 to 2003.
- **Christopher A. Davis**, Associate Editor, Monthly Weather Review, from 1996 to 2003.
- **Jimy Dudhia**, Associate Editor, Monthly Weather Review, from 2000 to present and Associate Editor, Weather; and Forecasting, from 2004 to present.
- **Wojciech W. Grabowski**, Associate Editor, Acta Geophysica Polonica, from 2003 to present; Associate Editor, Atmospheric Science Letters, from 2000 to present; and Associate Editor, Quarterly Journal of the Royal Meteorological Society, from 2001 to present.
- **Andrew J. Heymsfield**, Associate, Atmospheric Research, from 2001 to present; and Editor, Journal or the Atmospheric Sciences, from 2003 to present.
- **Joseph B. Klemp**, Publications Commissioner, AMS, from 2001 to present.
- **Ying-Hwa Kuo**, Co-chief editor, Monthly Weather Review, from 1998 to present and Associate Editor, Terrestrial, Atmospheric and Oceanic Sciences, from 1999 to present.
- **Arlene Laing**, Referee, Bulletin of the American Meteorological Society, from 2004 to present; Referee, Monthly Weather Review, from 2004 to Present; and Referee, Water Resources Research, from 2004 to present.
- **Margaret A. LeMone**, Guest Editor, JAS, 2003.
- **Donald H. Lenschow**, Editorial Board, Boundary-Layer Meteorology, from 1995 to present and Editorial Board, Journal of Atmospheric Chemistry, from 1993 to present.
- **Chin-Hoh Moeng**, Editor, Journal of Atmospheric Sciences, from 2000 to present; and Guest Editor, Journal of Terrestrial, Atmospheric and Oceanic Sciences from 2004 to present.
- J**ordan G. Powers**, Contributing Editor, Commemorative Volume: Observations, Theory, and Modeling.
- **William Skamarock**, Co-Chief Editor, Monthly Weather Review, from 2003 to 2006 and Editor, Monthly Weather Review, from 2000, 2003.
- **Piotr Smolarkiewicz**, Associate Editor, International Journal of Applied Mathematics & Computer Science, from 1996 to present and Associate Editor, Journal of Computational Physics, from 1996 to present.
- **Chris M. Snyder**, Associate Editor, Journal of Atmospheric Sciences, from 2000 to present.
- **Peter P. Sullivan**, Editorial Board, Dynamics of Atmospheres and Oceans, from 2004 to 2007; and Associate Editor, Journal of Atmospheric Science, from 2002 to present.
- **Jielun Sun**, Editorial Board, Boundary Layer Meteorology, from 2004 to present.
- **Jeffrey Weil**, Editorial Board, Boundary-Layer Meteorology, from 1998 to present.
- **Morris L. Weisman**, Editorial Board, BAMS, from 2003 to present, Advisory Board, Encyclopedia of Atmospheric Sciences, from 1999 to present and Associate Editor, Monthly Weather Review, from 1998 to present.

External Scientific, Policy, or Educational Committees or Advisory Panels

Roelof Bruintjes	Chariman, AMS Committee on Weather Modification, Inadvertent and Advertent (June 2003 to June 2006); Member, National Academy of Sciences/National Research Council Panel on Status and Future Directions in US Weather -- Modification and (2001 to present); Executive Member & Past-President, Weather Modification Association and executive board (1987 to present).
Janice Coen	Alliance Allocation Board (AAB) (June 2003 to present); National Resource Allocation Committee (NRAC) (June 2003 to present).
N. Andrew Crook	Member, NSF External Committee for the Center for Adaptive Sensing of the Atmosphere (2004 to 2009)
Chris Davis	Member, SCD Advisory Panel (January 2004 to present)
James E. Dye	Member, International Committee on Atmospheric Electricity (June 2003 to present); Member, NASA/USAF Lightning Advisory Panel (May 2003 to present).
Mary Golden	Member, AMS Manuscript Tracking System Advisory Committee; Outreach Liaison, UCAR-Geological Society of America.
Wojciech W. Grabowski	Chair, GEWEX Cloud System Study, Working Group 4 (January 2001 to present); Member, International Committee on Clouds and Precipitation (ICCP) (August 2000 to present).
Andrew J. Heymsfield	Scientific Steering Group, GCSS (May 2002 to present); New Investigator Award Panel – NASA..
Joseph B. Klemp	Member, AMS Awards Oversight Committee (January 2001 to present); Chair, AMS Information Systems Committee (1995 to present); Chair, AMS Publications Commission (1986 to present); Member, LEAD External Advisory Panel (2003 to present).
Arlene Laing	Member, AMS Committee on Satellite Meteorlogy and Oceanograph (2003 to 2006) Member, National Academy of Sciences, Committee on Climate Data Records form Environmental Satellites (2003-
Margaret A. LeMone	Member, AMS Ethics Committee (2003 to present); Member, AMS Planning Commission (2000 to present); Member, Board of Atmospheric Science and Climate (BASC) (2001 to 2004); Chair, NAE Section 12 (2003); Member, NAE Program Development Committee (2001 to 2004); Member, NRC Committee on Strategic Guidance for NSF's Support of Research in the Atmospheric Sciences (2004 Member, NRC Committee Surface Transportation: The Roadway Environment (February 2003 to Present); Member, NRC Committee. Tracking & Predicting the Atmosphere Dispersion of Hazardous Material Releases: Implications for Homeland Security (2002 to 2003); Member, University of Chicago Review Committee for Environmental Research Division (1998 to present).
Donald H. Lenschow	Member Of US Planning Committee, Surface Ocean Lower Atmosphere Study (April 2000 to June 2004).
Chin-Hoh Moeng	AMS Committee on Meteorological Aspect of Air Pollution (2003); Review Panel for Swedish Research Council (March 2004).
Mitchell W. Moncrieff	Member, Cloud System Study (GCSS) Science Panel (1992 to present); Member, Advisory Board of the Encyclopedia of Atmospheric Sciences (2000 to present); Member, Advisory Panel, Cooperative Institute for Mesoscale Meteorology, University of Oklahoma/National Severe Storms Laboratory (CIMM) (1991 to present); Member, NASA CloudSat Applications Advisory Group (2002 to present); Member, NASA Earth System Science Panel (ESSP) Science Panel (1999 to present); Member, NASA Precipitation Science Team (2003 to present).
Rebecca Morss	Member Of Advisory Panel, NCAR Climate and Weather Impact Assessment Initiative (2003 to present); Member, NOAA THORPEX Science and Implementation Team (March 2003 to present); Member, North American THORPEX science planning committee, representative on societal impacts (2003 to Member, THORPEX, The Observing -system Research and Predictability Experiment: International Scientific Steering Committee (April 2002 to present); Co-Chair, THORPEX, The Observing -system Research and Predictability Experiment: Societal and Economic Applications sub-program (April 2002 to present); Member, UCAR/NCAR/UOP Distinguished Achievement and Outstanding Accomplishments Award Jury (2001
Jordan G. Powers	Member, Antarctic RIME Science Board (April 2004 to present) Member, Developmental Testbed Center (DTC) activity Steering Committee (March 2003 to present).
Roy M. Rasmussen	Member, Observing Facility Advisory Panel (October 1999 to present).
Richard Rotunno	Member, External Review Committee for the Department of Earth and Atmospheric Sciences, Purdue University Member, Scientific Steering Committee, Mesoscale Alpine Programme (MAP) (January 2001 to present); Member, Thorpex International Scientific Steering Committee (March to present).
William Skamarock	AMS Mesoscale Prosess Committee (January 2002 to present).
Chris Snyder	Member Scientific Committee, 2005 Program on Data Assimilation in Geophysical Systems, Statistical and Applied Mathematical Sciences Institute (February 2004 to present)
Peter Sullivan	National Academy of Science: Workshop on challenges in representing physical processes in coupled atmosphere-ocean-land models (July 2004)
Jeffrey Trapp	Member, AMS STAC committee on Severe Local Storms (1999 to present).
Jeffrey Weil	Chair, AMS/EPA Regulatory Model Improvement Committee (June 1991 to present).

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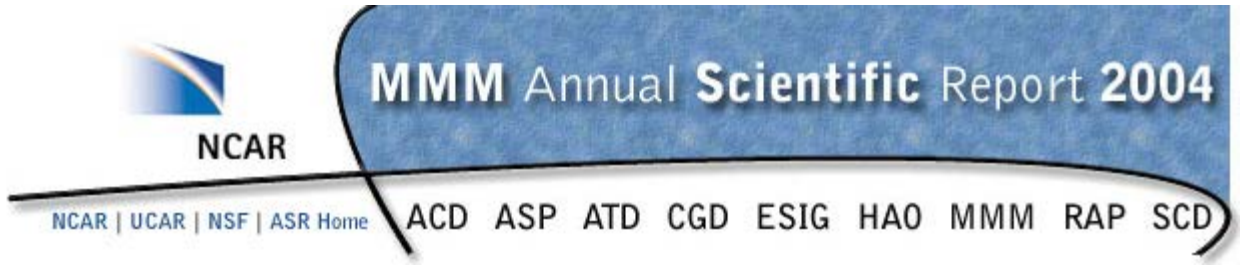

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MMM Awards

Honors and Awards

John Latham: CIMMS Fellow, 2003

Margaret A. LeMone: AMS Anderson Award 2004, January 2004

Jordan G. Powers: NCAR 2003 MMM Outstanding Paper of the Year, December 2003

Richard Rotunno: AMS Jule G. Charney Award, January 2004

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Fiscal Year 2004 Refereed Publications (top)

Note: Bold face denotes University collaborators, * denotes non-NCAR collaborators

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MMM Staff, Visitors and Collaborators

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MMM Staff (top)

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- Mary Hanson
- Sudie Kelly
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- Richard Rotunno (Assistant Director and Acting MMM Director)

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- Xiaolei Zou (Florida State University)

MMM Visitors and Collaborators (top)

In FY2004, MMM hosted 428 short-term visitors (1 day to 6 months) and 35 long-term visitors (more than 6 months). The visitors were affiliated with 333 domestic institutions, including 72 U.S. universities, and 130 foreign institutions. Click here to see the complete visitor list.

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RAP's Director's Message

The Research Application Program's central mission is in concert with that of NCAR/UCAR: to conduct significant applied scientific research and to facilitate the transfer of the information, expertise, and technology it develops to the public and private sectors. This mission is rooted in the founding philosophy of Walter O. Roberts, the first Director of NCAR, who originally saw NCAR's mission as "science in service to society."

The role of UCAR/NCAR as an integrator is very much at the heart of our work. RAP collaborates with the national community (e.g., federal agencies, national laboratories, universities, and various industries), and also with the international community with projects in places such as Taiwan, Colombia, the People's Republic of China, the United Arab Emirates, the Sultanate of Oman, Greece, and Italy (2004).

The division contributes to the depth of fundamental understanding in atmospheric science and works to develop new sources of support for such research. Through its program of technology transfer, RAP expands the reach of atmospheric science into weather-sensitive human endeavors that are not currently using weather information or are using such information in inefficient ways. Educating potential users of weather information in the "art of the possible" is an important element in securing new investments in research and development for application towards the betterment of society. The pursuit of science applications that are truly useful to society means that we must have a strong connectivity between our work and the needs of end-users; therefore, end-user requirements are considered at each step along the development path. Our work tends to be heavily oriented towards real-time operational systems, which leads to an emphasis on algorithm development, specialized graphical displays, systems engineering, operational demonstrations, and the associated scientific validations as well as user-oriented evaluations.

Twenty years ago, RAP began as a small effort from within the Atmospheric Technology Division aimed at weather issues involved in aviation safety. Today the division is one of the largest in NCAR with a staff of 180, comprised of 80 scientists, 65 software engineers/systems administrators, 20 managers and administrative staff, and 15 student assistants. Our total expenditures in FY04 were just over $23M, with more than $13M in modified total direct costs. Aviation weather still represents the majority of our work, but significant research, development and technology transfer efforts exist in other application areas such as national security, numerical weather prediction, hydrometeorology, and surface transportation. RAP is a vibrant program with both depth and great breadth, and I am pleased to present it to you in this year's Annual Scientific Report.

Accomplishments in 2004

The Annual Scientific Report presents an opportunity for reflection and consideration of the accomplishments of the Research Applications Program over the past year. Let me summarize a few of them.

In the aviation weather arena, RAP scientists and engineers developed and conducted initial testing of the SPolKa radar system which combines a Ka-band (0.86 cm) radar with ATD's SPol S-band (10 cm.) weather radar. This work was funded by the FAA and NSF and conducted in conjunction with ATD. A commercial prototype of the Weather Support to Deicing Decision Makers (WSDDM) system is now in full operational use at Denver International Airport and serves as a testbed for developing new products as well as obtaining user feedback. A new company, WSDM Technologies, Inc., has been formed to market, build, operate and maintain WSDDM systems at aviation facilities in the future. And, after years of scientific research and development, the operational prototype of the Juneau Airport Wind System was successfully evaluated and installed for testing at the Juneau, Alaska airport.

2004 saw significant expansion in our work for the U.S. Department of Defense. In addition to continued development of 4-Dimensional Weather Systems (4DWX) for U.S. Army Test and Evaluation Command ranges, new programs for other DoD agencies and the Department of Homeland Security were launched. High-resolution analyses and forecasts of winds were created to aid in calculating the transport and dispersion of hazardous materials released into the atmosphere. Global Meteorology on Demand, a tool developed at RAP which allows a non-meteorologist to launch MM5 anywhere in the world, was used in support of counter-terrorist operations at the Athens Olympics. Also in 2004, an operational atmospheric-hazard assessment and prediction system to protect the Pentagon and its 25,000+ inhabitants was developed and tested at the Pentagon. This RAP-led effort includes collaboration with ATD, the University of Colorado, NOAA, and DARPA.

Closer to home, we continued to lead interdivisional activities associated with three NCAR strategic initiatives: Water Cycle Across Scales, the Wildland Fire Research and Development Collaboratory, and Geographic Information Systems. RAP scientists and engineers participate actively in these collaborative efforts, as well as in the Weather and Climate Impact Assessment initiative. 2004 also marked the start of the USWRP Societal Impacts Program, joined with ESIG, aimed at understanding the societal benefits of better weather information for end-users and policy makers.

RAP moves into 2005 as the Research Applications Laboratory (RAL), with NCAR's Developmental Testbed Center joining our ranks. As RAL we remain committed to conducting a comprehensive program of research, development and technology transfer in service to society.

- Brant Foote, Division Director

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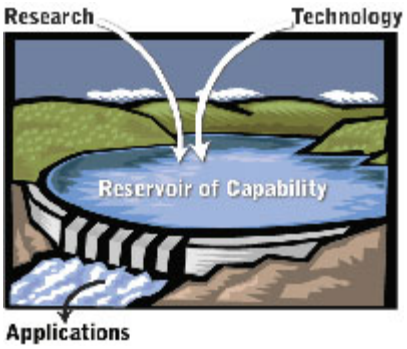
Research Applications Program
Executive Summary

Introduction

The central mission of the Research Applications Program is consonant with that of NCAR and UCAR: To develop and transfer knowledge and technology to the public and private sectors. The motivation for this is embodied in what Walter O. Roberts, the first Director of NCAR, termed “science in service to society.”

Through a program of directed research aimed at solving practical problems, RAP contributes to the depth of fundamental and practical understanding in atmospheric science and develops new sources of support for such research. Through a program of technology transfer, RAP expands the reach of atmospheric science into weather-sensitive human endeavors that are not currently making practical use of weather information or are using such information in naïve or inefficient ways. Educating potential users of weather information in the “art of the possible” is an important element in securing new investments in research and development.



Over the past two decades RAP has developed a large reservoir of capabilities in basic science, applied-research methods, software engineering, technology transfer, and program management. Those capabilities have been brought to bear on problems in a variety of application areas, demonstrating the potential of advanced weather information to benefit society.

Aviation Applications

In collaboration with FAA and NASA sponsors, national laboratories and universities, RAP works to improve the detection, measurement, and forecasting of hazardous weather and to transfer information, expertise and new technologies to those working to improve the safety and efficiency of the nation’s airspace. These efforts have established NCAR as a leader, both nationally and internationally, in aviation weather research and development

In-Flight Icing

Research within the In-flight Icing program is focused on achieving better characterization of cloud and weather conditions associated with icing environments. In 2004 improvements to the MM5 and WRF models, including microphysical parameterizations to more accurately forecast cloud liquid, drizzle and rain, were made in collaboration

with NOAA/FSL and NCEP. Development of an operational liquid water path retrieval algorithm based on satellite-based passive microwave sensors was also accomplished. A new NASA-sponsored effort was initiated to increase and optimize the use of its satellite datasets in products developed for the FAA. Early efforts are focused on assessing whether satellite data can improve the performance of the Current Icing Potential algorithm.

RAP scientists led the effort to develop and conduct initial testing of the SPolKa radar system which combines a Ka-band (0.86 cm) radar with ATD's SPol S-band (10 cm.) weather radar. This work was funded by FAA and NSF and conducted in conjunction with ATD. RAP also planned and executed the Winter Icing and Storms Project 2004 field program, deploying research radars and radiometers in the Boulder area to evaluate remote sensing techniques for characterizing cloud icing conditions. The transfer of new aviation weather products to the user community continued with the successful transfer of the Current Icing Potential product for Alaska and an icing severity algorithm. Both have been approved for use as experimental products by the National Weather Service.

Snowfall and Freezing Precipitation

RAP continued to work to improve the detection, measurement, forecasting, and reporting of frozen precipitation, as well as to develop new data analysis, product synthesis, and decision support tools. While the focus remains largely on aviation applications, it has become clear that this work could have significant benefit in the surface transportation domain as well.

Scientists in the FAA-funded Winter Weather Program demonstrated this year that major jet engine damage—recorded in three separate incidents in Denver and Oslo, Norway—was due to heavy freezing drizzle. Official weather observations had reported only light snow and mist or light drizzle, and thus proper precautions were not taken to protect the planes as they prepared for departure. RAP scientists conducted a training class for United Airlines pilots on lessons learned from these cases and will publish their results in a journal article accepted for publication in 2005.

Several technologies developed at RAP were successfully transferred to the private and public sectors this year. The Hot-Plate precipitation gauge developed by RAP and the Desert Research Institute has been transferred to Yankee Environmental Systems for production and marketing. A commercial prototype of the Weather Support to Deicing Decision Makers (WSDDM) system is now in full operational use at Denver International Airport and serves as a testbed for developing new products as well as obtaining user feedback. A new company, WSDM Technologies, Inc., has been formed to market, build, operate and maintain WSDDM systems at aviation facilities in the future.

Convective Weather

The Convective Weather Program's overarching goal is an improved ability to predict the location, intensity and organization of convective storms in the 0-6 hour forecast period. With NSF funding, RAP scientists conducted fundamental research into convective storm initiation and evolution processes and worked to improve microphysical parameterizations of precipitation.

The development of operational forecast systems continued with support from the FAA and the U.S. Army Test and Evaluation Command. The Auto-Nowcaster (ANC), an automated, regional-scale forecast system that produces high-resolution 0-2 hour forecasts, was demonstrated for a third year as part of the FAA's Regional Convective Weather Forecast (RCWF) Program in the Chicago area. The boundary layer version of the Variational Doppler Radar Analysis System (VDRAS) was also demonstrated at RCWF, assimilating data from five WSR-88D radars. An explicit storm version of VDRAS moved from research mode to operational status in 2004 and was run in real-time over the RCWF domain during the summer.

A second forecast system developed at RAP, the National Convective Weather Forecast product (NCWF) was substantially improved and transferred to the National Weather Service for testing. The new product, NCWF-2, provides better quality control and use of RUC model winds, incorporates a large-scale trending algorithm that captures dissipation of storms within a region rather than simply tracking individual storms, and establishes 1 and 2 hour probabilities which allows for quantification of uncertainty inherent in forecasts.

Turbulence

Fundamental research aimed at characterizing different kinds of turbulence and the mechanisms that generate it expanded substantially in 2004. Funding from FAA and NASA supported a number of high-resolution numerical simulations of cases involving encounters with turbulence induced by mountain waves, island wakes, convection, and the urban environment.

Progress continued to be made in detecting atmospheric turbulence using both in-situ measurements from on-board commercial aircraft and, increasingly, from information provided by airborne and ground-based Doppler radars. This year RAP scientists refined and tested the NCAR Turbulence Detection Algorithm, a new algorithm designed for use on the nation's NEXRAD and TDWR radars. Initial verification efforts show promise for the algorithm's ability to detect moderate-or-greater turbulence before an aircraft encounters it. A new software package that provides automated scoring tools to evaluate airborne turbulence detection was also completed and delivered to NASA and will become part of a toolset for researchers and radar manufacturers in tuning their detection systems.

The effort to improve short-term forecasting of turbulence continued with improvements made to the Graphical Turbulence Guidance (GTG) product which was developed at RAP and is run operationally by the NWS. In 2004 work focused on extending the capability of GTG to detect clear air turbulence below 20,000 ft MSL and to incorporate a new capability to forecast convectively-induced turbulence.

In the technology transfer arena, the operational prototype of the Juneau Airport Wind System was successfully evaluated and installed for testing at the Juneau, Alaska, Airport.

Remote Sensing

Funding from the FAA's Advanced Weather Radar Techniques program supported RAP scientists' participation in the Winter Icing and Storm Project 2004. A two-dimensional video disdrometer and the NCAR S-Pol radar were fielded in an on-going effort to develop algorithms for classifying hydrometeor types, quantifying winter precipitation, and improving the parameterization of winter storm microphysics in numerical forecast models. Preliminary studies of the WISP datasets indicate that radar can detect subtle changes in particle habits and that it should be possible to estimate the governing parameters of hydrometeor distributions. Evaluation of the NCAR hail detection algorithm concluded in 2004 with a final report that indicated that polarimetric radar has important advantages for specifying the location of hail and perhaps its size. Testing of the NCAR freezing level algorithm was also successfully completed in 2004; results of this work will be published in two journal articles in 2005.

Ceiling and Visibility

Adverse ceiling and visibility (C&V) conditions are a contributing factor in over 35% of all weather-related accidents in the US civil aviation sector and a major cause of flight delays nationwide. RAP scientists worked throughout 2004 to better understand C&V conditions and to develop national and terminal-area forecast systems. Progress is being made in forecasting C&V through the development of an automated meteorological database to improve forecast integration efforts; use of Knowledge Discovery in Databases techniques for improved analysis and translation of model results; and new data mining techniques to create rulesets for forecasting C&V at specific sites. RAP scientists also studied the feasibility of making short-term visibility forecasts using radar data calibrated to a surface visibility sensor.

RAP staff continued to work with colleagues from MIT/Lincoln Laboratory to develop and display more accurate forecasts of operationally significant changes in ceiling height and/or visibility near major airports in the Northeastern US 2004 marked the successful completion of the development of a San Francisco Marine Stratus Forecaster Display which provides accurate forecasts of the time that fog will clear in the approach to the San Francisco Airport. This system has now been transferred to the NWS and is now running operationally.

Oceanic Weather

The Oceanic Weather (OW) program worked to improve the forecasts of aviation hazards in data-sparse oceanic regions of the world. In 2004 the OW team developed new methods for diagnosing convection and turbulence over the ocean, the first step in meeting the goal of a reliable 0-2 hour forecast of these phenomena. Development of a new volcanic ash product advanced with the creation of a new means of interpreting and graphically displaying text-based volcanic ash warnings issued for aviation by countries around the world. The decoding of these messages and consistent presentation of them on an automated web-based world display makes it possible for the first time to see at a glance where advisories exist for volcanic ash.

Numerical Weather Prediction Applications

Numerical weather prediction in RAP involves developing, testing and implementing operational forecasting systems throughout the world. Models are used for public weather forecasting, for defense and homeland security applications,

for the prediction of aviation-related hazards such as icing and turbulence, and for the support of field programs. In addition, weather models are being coupled with other models that compute cloud ceiling and visibility, transport and dispersion, stream flow and sound propagation.

A number of new developments have become apparent: Models used for research and operations have had progressively greater horizontal resolution; urban modeling, using .5-1.0 km grid increments, has become an important new focus. To resolve at the building level, collaboration with others proficient in the use of computational fluid dynamics models has become critical. Another important change has been a methodical migration from MM5 to WRF in RAP's operational modeling systems. New capabilities developed at RAP for WRF, such as the Newtonian relaxation-data assimilation code, are being transitioned to the community version of WRF. Work also continues to develop next-generation land-surface physics for WRF, as well as a high-resolution land data-assimilation system (link to LSM).

Department of Defense/Homeland Security Programs

RAP continued to refine the four-dimensional weather systems (4DWX) currently deployed at six US Army test ranges. An ensemble prediction system was tested, improved verification methods developed, MM5 and WRF forecasts inter-compared, advanced data assimilation concepts developed, and new bias-correction procedures created. The 4DWX system was also adapted for use over metropolitan areas this year, and new capabilities were tested in a field program at the Pentagon in April-May, 2004.

New Homeland Security applications in 2004 included:

- Production of high-resolution analyses and forecasts of winds to aid in calculating the transport and dispersion of hazardous materials released into the atmosphere.
- Use of Global Meteorology on Demand, a tool developed at RAP which allows a non-meteorologist to launch MM5 anywhere in the world, in support of counter-terrorist operations at the Athens Olympics.
- Adaptation of the Variational Doppler Radar Assimilation System to assimilate Doppler lidar radial-wind data (VLAS). The high-resolution gridded wind fields that result are used in transport and dispersion models.
- Development of an operational atmospheric-hazard assessment and prediction system to protect the Pentagon and its 25,000+ inhabitants. This RAP-led effort includes collaboration with ATD, University of Colorado, NOAA, and DARPA.

Land Surface Modeling

In a highly collaborative effort with MMM, RAP scientists worked to understand the complex interactions between the land-surface and the atmosphere and to integrate this knowledge into numerical mesoscale weather prediction and regional climate models. Accomplishments this year included:

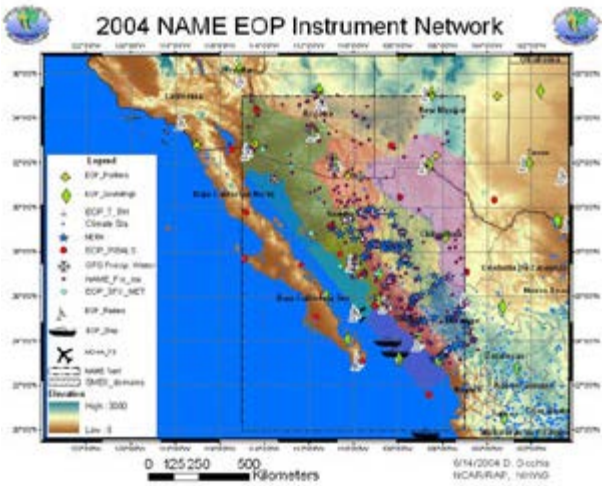
- Development and implementation of the unified Noah land-surface modeling (LSM) system in the WRF model V2.0, released in May 2004.
- Development of a High-Resolution Data Assimilation System (HRLDAS) to support application of high-resolution numerical weather prediction models. HRLDAS uses observed precipitation, solar radiation derived from satellite data, and surface wind and temperature data to force a land-surface model to simulate the evolution of soil moisture.
- Coupling a single-layer urban canopy model with the Noah LSM to simulate urban heat island effects. This work is important in representing the effect of the urban environment on local and regional weather within NWP models.

Geographical Information Systems

The NSF-funded GIS Initiative aims to promote and support the use of GIs as an analysis and infrastructure tool in atmospheric research. The program, a collaborative effort with ESIG, focused this year on providing support for the Community Climate System Model effort. Model results from CCSM were converted to GIs-compatible formats for distribution in 2005 to the GIs user community via a public website. This effort will put detailed climate change information in the hands of decision-makers, educators and researchers.

Hydrometeorological Applications

RAP's water resource-related activities expanded substantially in 2004 as new programs, sponsors, and collaborations were established. Working with colleagues across NCAR, RAP scientists engaged in NSF-sponsored research in the "Water Cycle Across Scales" initiative. This effort is focused on achieving better understanding of water cycle processes in order to improve convective, land surface and microphysical parameterizations in weather and climate models. Water cycle efforts at RAP were focused in three areas: Analysis of data from the 2001 IMPROVE II field program in Oregon to improve cloud microphysical parameterizations; analysis of IHOP data to better parameterize convection within models; and studies of land-atmosphere interactions and the role of land surface processes in triggering convection to improve land surface models.



In other research endeavors, NOAA funding supported RAP's participation in the North American Monsoon Experiment. In collaboration with scientists from the University of Arizona and Mexican institutions, progress was made in diagnosing and modeling key aspects of rainfall climatology in western Mexico and their relationship to regional streamflow. RAP also participated in an NSF-sponsored effort to define a vision for integrating research between the atmospheric and hydrological science communities through the Consortium for the Advancement of Hydrological Sciences, Inc. (CUAHSI).

In a more applied vein, RAP engineers and scientists worked with the Denver Urban Drainage and Flood Control District to demonstrate the usefulness of NCAR's Thunderstorm Identification, Tracking and Analysis (TITAN) system and the Auto-Nowcaster in improving short-term forecasts of flash floods in urban areas. A new program was launched in the United Arab Emirates to develop and implement a customized hydro-meteorological analysis and display system, a new decision support tool for water resource managers. RAP scientists, in collaboration with the American Water Works Association and ESIG, brought water utility planners and climate scientists together in a workshop to discuss the scientific basis of climate change and how decision makers could plan to address the impact of global warming on water resources.

Precipitation Enhancement

In addition to finding ways to better manage existing resources, RAP scientists work to scientifically assess the feasibility of increasing water supplies through cloud seeding. The rainfall enhancement assessment program in the United Arab Emirates entered its second phase with randomized seeding operations conducted over the summer months. Data from that field program and from a smaller effort in Saudi Arabia are currently being analyzed. An initial study to assess the feasibility of rainfall enhancement in Oman was completed with results indicating that there is sufficient summertime convection over the Oman Mountains to make cloud seeding feasible. In addition to these studies, RAP scientists continue to serve as expert resources, providing guidance and advice to governments around the globe interested in the potential of weather modification.

Surface Transportation Applications

The effort to build a surface transportation program continued with RAP staff heavily involvement in several national initiatives to build advocacy for surface transportation research. The program development effort resulted in funding for new programs to improve road and bridge frost prediction for Peak Weather/Meteorlogix; to create a Weather Response System for traffic, incident, emergency management and highway maintenance for the Missouri Dept. of Transportation; and to develop and demonstrate a tactical decision support system for snow and ice control for AURORA, an international partnership of public agencies who collaborate on rod weather information systems research.

RAP's flagship program in the surface transportation arena continued to be the Maintenance Decision Support System effort for the Federal Highway Administration. In 2004 a second field demonstration was conducted in Iowa, and system enhancements were made in response to recommendations of maintenance operators there. Significant scientific lessons learned included confirmation that data fusion techniques used in the forecast system improved the forecasts; the use of "hot start" mesoscale models improved the 0-6 hour precipitation forecasts; probabilistic products were well-received by end users; and expansion of the rules of practice logic to include winter storm event characterization greatly improved the stability and accuracy of treatment recommendations.

A stakeholder group meeting was held in NCAR in July to discuss the program and the results of the field program. Seventy-five participants representing FHWA, 23 State DOTs, 23 commercial weather providers, and a variety of national laboratories and universities participated. A technology transfer workshop was held after the stakeholder meeting to facilitate the transfer of MDSS technologies into operations. In recognition of its significance as an end-to-end R&D program, RAP has nominated the MDSS program for UCAR's 2004 Outstanding Performance Award for Scientific and Technical Advancement.

Assessment Activities

Verification

RAP's Verification Group provides independent verification of forecasts and forecasting systems, a critical component of the technology transfer process. Much of the group's work to date has focused on aviation applications. Working closely with NOAA/FSL the group evaluates the capabilities of experimental aviation weather products and advises the FAA and NWS on their readiness for consideration for operational status. In 2004 the group conducted major evaluations of two in-flight icing algorithms, a convective forecasting system, and a turbulence forecasting algorithm. The group also began to study the ability of the Current Icing Potential product to detect icing conditions above 18,000 ft. (currently the product is only operational at lower altitudes).

In addition to its important role in evaluating products, the group works to develop new statistical techniques and verification approaches. Highlights from 2004 include:

- Development of a verification toolkit using the "R" programming language. The toolkit was made available to the general public on the R-project website.
- Creation of new verification methodologies based on cross-validation for use in situations where independent data are not available for evaluating a forecast.
- Progress in formulating an object-oriented approach for evaluating spatial forecasts of precipitation and convection. This approach, developed in collaboration with MMM, was applied to gridded precipitation forecasts from a 22-km version of the WRF model and produced much more information about forecast performance than can be obtained using standard verification statistics.
- Initial development of new verification techniques for data-sparse regions.
- Exploration of new verification methods to better represent the real value of a forecast to a particular user group (link to Model Verification in NWP).

USWRP: Societal Impacts Program (SIP)

Funded by NOAA and NSF, the Societal Impacts Program is a new collaborative effort with ESIG and COMET. SIP works to improve the societal gains from weather forecasting and minimize social and economic losses and damage from weather by infusing social science and economic research, methods, and capabilities into the planning, execution,

and analysis of weather information, applications, and research directions. Much of the SIP work in 2004 focused on program development, hiring of the SIP team, and project initiation. New programmatic efforts focused on the development of a conceptual approach and work plan for a broad-based assessment of the sensitivity of all US economic sectors to weather impacts and benefit assessment of weather information, and creation of a Hurricane Forecast Socio-Economic Working Group (HFSEWG) to improve society's understanding and use of hurricane forecasts and to inform the weather community of user impacts from, and needs and values for, current and improved hurricane forecasts.

Climate and Weather Impact Assessment Science Strategic Initiative

The NCAR Climate and Weather Impact Assessment Science Initiative (CWIASI) investigates how climate and weather create both hazards and opportunities for society and seeks to improve the ways in which scientific knowledge is generated and communicated to decision makers. RAP scientists led an effort to integrate elements of the hydrologic cycle, climate change science and conceptual models of ecosystem services within a water resource management model. This work is directed toward creation of an improved decision support for freshwater ecosystem services managers in the Sacramento, California, watershed.

Members of RAP's Verification Group worked to develop new methods to assess extreme weather events such as icing, convection and turbulence which can have a major impact on aviation. Extreme value theory is being explored as a potentially useful new approach in forecasting these weather hazards because it focuses on properties of events that occur rarely or have an unusual magnitude. A related effort, in collaboration with ESIG, has produced an "extremes toolkit", a user-friendly, interactive program for analyzing extreme value data using the R statistical programming language. The toolkit, with tutorial, is now available on the Web.

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6. New microwave satellite-based technique for retrieving liquid water path over land
7. Satellite and aircraft comparison case study
8. SLD and non-SLD environments
9. Benchmarking in-flight icing detection products for future upgrades

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3. WSDDM system at Denver International Airport
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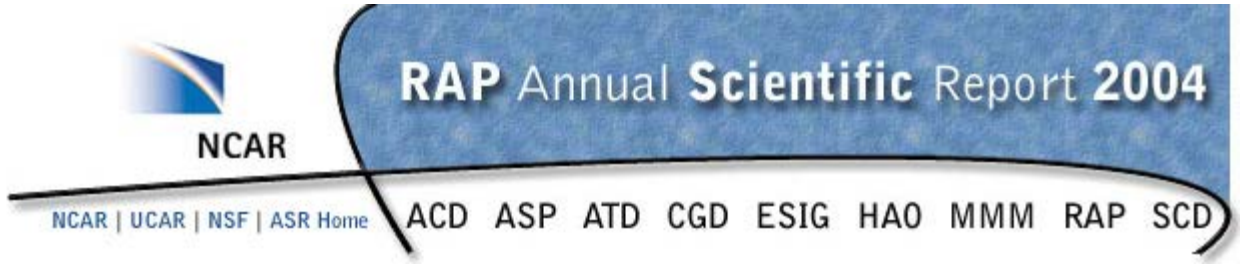

Education and Outreach

Teaching Appointments
Advising on Graduate Research
Member of Thesis Committee
Workshops and Colloquia
Seminars and Presentations
Education & Training - Professional
Education & Training - K-12 World
Mentoring
Field Campaigns

Educational Activities

Staff Name	Teaching Appointment	Department	Institution
Kent Goodrich	Mathematics Professor	Mathematics	Univ. of Colorado
Andrea Hahmann	Adjunct Asst. Research Professor	Atmospheric Sciences	Univ. of Arizona
Matt Pocernich	Adjunct Faculty	Mathematical & Computer Sciences	Metro State Univ. (Denver)
Tom Warner	Meteorology Professor	Program in Atmospheric & Oceanic Sciences	Univ. of Colorado
David Yates	Adjunct Research Professor	Civil & Environmental Engineering	Univ. of Colorado
Staff Name	**Advising on Graduate Research**	**Department**	**Institution**
Fei Chen	Jeff Fung Lo (Ph.D)	Center for Coastal & Atmospheric Research	Hong Kong Univ. of Science & Technology
Fei Chen	Ethan Gutmann (Ph.D)	Geology	Univ. of Colorado
David Gochis	Kazungu Maitaria (Ph.D)	Hydrology & Water Resources	Univ. of Arizona
David Gochis	Edgar Uribe	Hydrology & Water Resources	Univ. of Arizona
Kent Goodrich	Christen Davis (M.S.)	Mathematics	Univ. of Colorado
Joshua Hacker	Li Huang (Ph.D)	Earth & Ocean Sciences	Univ. of British Columbia

Andrea Hahmann	Ana L. Mosor (Ph.D)	Atmospheric Sciences	Univ. of Arizona
Tom Warner	Robert Tardif (Ph.D)	Program in Atmospheric & Oceanic Sciences	Univ. of Colorado
Tom Warner	Christian Sutton (Ph.D)	Program in Atmospheric & Oceanic Sciences	Univ. of Colorado
Tom Warner	Eric Thaler (Ph.D)	Applied Mathematics	Univ. of Colorado
Jim Wilson	Andrea Lima (Ph.D)	Meteorology	Universidate Estadual Paulista (Brazil)
David Yates	Joseph Alfieri, (M.S.)	Geography	Univ. of Colorado
David Yates	Alyssa McCluskey (Ph.D)	Civil & Environmental Engineering	Univ. of Colorado
Staff Name	**Thesis Committee**	**Department**	**Institution**
Fei Chen	Andrew Schmit (M.S.)	Geology	Univ. of Colorado
Kent Goodrich	Robert Tardif (Ph.D)	Program in Atmospheric & Oceanic Sciences	Univ. of Colorado
Kent Goodrich	Yan Yin (Ph.D)	Electrical & Computer Engineering	Univ. of Colorado
Kent Goodrich	Jonas D'Andrea (M.S.)	Mathematics	Univ. of Colorado
Kent Goodrich	Preston Slaughter	Mathematics	Univ. of Colorado
Joshua Hacker	Li Huang (Ph.D)	Earth & Ocean Sciences	Univ. of British Columbia
Andrea Hahmann	Ana L. Mosor (Ph.D)	Atmospheric Sciences	Univ. of Arizona
Andrea Hahmann	Er Lu (Ph.D)	Atmospheric Sciences	Univ. of Arizona
Andrea Hahmann	Nadia Vinogradova (Ph.D)	Atmospheric Sciences	Univ. of Arizona
Andrea Hahmann	Carlos Minjarez-Sosa (M.S.)	Atmospheric Sciences	Univ. of Arizona
Tom Warner (Committee Chair)	Robert Tardif (Ph.D)	Program in Atmospheric & Oceanic Sciences	Univ. of Colorado
Tom Warner (Committee Chair)	Christian Sutton (Ph.D)	Program in Atmospheric & Oceanic Sciences	Univ. of Colorado
Tom Warner (Committee Chair)	Eric Thaler (Ph.D)	Applied Mathematics	Univ. of Colorado
Jim Wilson	Hanna Murphy (Ph.D)	Meteorology	Univ. of Calif. - LA

Workshops and Colloquia

Staff Name	Title/Subject	Dates	Sponsor
Bob Barron	Juneau Airport Winds System Operational Prototype Technical Interchange Meeting	15-16 June 2004	FAA, NCAR
Jennifer Boehnert	Atmospheric Data modeling Workshop	January 2004	NCAR/NOAA/ESRI
Dan Breed	Radar Meteorology & Operations Workshop	11 Feb 2004	DWRS, NCAR
Dan Breed	Radar Processing, Analyses & Evaluation using TITAN Software Package	30 Apr 2004	WMA
Barb Brown	International Workshop on Forecast Verification (Montreal,	15-17 Sept 2004	World Meteorological Organization, Meteorological

	Quebec, Canada)-Program Committee		Service of Canada
Fei Chen	Workshop on Urban Meteorology (Beijing, China)	12-13 Oct 2003	IUM/NCAR
Eric Gilleland	Summer Colloquia on Climate & Health	21 July 2004	NCAR, Assessment Initiative, NASA, CDC, WHO/Pan American Health Organization
Eric Gilleland	Verification of Quantitative Forecasts Using Baddeley's Delta Metric	September 2004	WGNE/WWRP, WMO WCRP, MSC, NCAR
Eric Gilleland	Optimizing METAR Network Design to Remove Potential Bias in Verification of Cloud Ceiling Height & Visibility Forecasts	September 2004	WGNE/WWRP, WMO WCRP, MSC, NCAR
Jason Knievel	WRF/MM5 Joint Workshop	22-25 June 2004	NCAR
Jason Knievel	BAMEX Workshop	1-3 March 2004	NCAR
Bill Mahoney	6th Maintenance Decision Support System Stakeholder Meeting	21-22 July 2004	FHWA, NCAR
Bill Mahoney	Maintenance Decision Support System Technology Transfer Workshop	22-23 July 2004	FHWA, NCAR
Marcia Politovich	Government Remote Sensing Meeting	25 August 2004	FAA, NCAR, CRREL, NASA GRC
Daran Rife	USWRP Community Meeting on Real-Time and Restorative Mesoscale Objective Analysis: An Analysis of Record Summit	29-30 June 2004	USWRP
Daran Rife	USWRP Mesocale Workshop	8-10 Dec 2003	USWRP
David Yates	Climate Change & Water Resources	15 Mar 2004	AWWA Research Foundation

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Seminars and Presentations

Staff Name	Title of Presentation	Date	Group
Bob Barron	JAWS Operational Prototype Displays	15 June 2004	NCAR & FAA staff
Bob Barron	JAWS Operational Prototype Composition & Capabilities of Alerts	15 June 2004	NCAR & FAA staff
Jennifer Boehnert	Developing an Atmospheric Data Model for GIS	1 August 2004	Unitdata
Dan Breed	Total Lightning - NMIMT LMA	4 May 2004	ATEC IPR
Dan Breed	Radar Characteristics of Precipitating Clouds in the UAE	21 July 2004	ICCP
Barb Brown	Verification	14 May 2004	NRL Visitors to NCAR
Barb Brown	Grid-Based Probabilistic CCFP	18 May 2004	Weather Applications Working Group, FAA Collaborative Decision Making Program
Barb Brown	Verification Overview	19 July 2004	Beijing Olympics FDP Advisory

			Workshop, Beijing
Barb Brown	Progress in Developing Object-Oriented Verification Approaches	18 August 2004	Weather Applications Working Group, FAA Collaborative Decision Making Program
Barb Brown	Spatial and Object-Oriented Forecast Verification	15 Sept 2004	International Verification Methods Workshop, Montreal, Canada
Barb Brown	Diagnostic Verification Measures Associated with Object-Oriented Verification Approaches	15 Sept 2004	International Verification Methods Workshop, Montreal, Canada
Barb Brown	WWRP/WGNE Joint Working Group on Forecast Verification	November 2004	WMO Working Group on Numerical Experimentation; Salvador, Brazil
Barb Brown	Probabilistic convective nowcasts based on observations	14 Jan 2004	AMS Symposium on Forecasting the Weather and Climate of the Earth and Ocean; AMS Annual Meeting, Seattle, WA
Barb Brown	The Impact of Precipitation Frequency on Gauge-Site Monitoring Algorithms	15 Jan 2004	AMS 14th Conference on Applied Climatology; AMS Annual Meeting, Seattle, WA
Barb Brown	Object-Oriented Verification Approaches Diagnostic Approaches for Verification of Spatial Field Forecasts	October 2004	RAP Retreat
Fei Chen	Recent Advance in the Development of a High-Resolution Land Data Assimilation System for Mesoscale NWP Models	25 April 2004	European Geosciences Union 1st General Assembly, Nice, France
Fei Chen	Urban Land-Use Modeling for Numerical Weather Prediction Models	18 May 2004	The Second International Workshop on Next Generation NWP Model, Yonsei University, Seoul, Korea
Fei Chen	Mesoscale Land-Atmospheric Interactions: Modeling and Observation	18 May 2004	The Second International Workshop on Next Generation NWP Model, Yonsei University, Seoul, Korea
Fei Chen	Recent Progress in Urban Land-Use Modeling for Community MM5 & WRF Model	12 Oct 2004	Joint IUM/NCAR Workshop on Urban Meteorology, Beijing, China.
Fei Chen	Effect of Surface Heterogeneity on the Evolution of PBL and Convection Initiation	29 April 2004	Laboraroire D'Aerologie, Université Paul Sabatier - Toulouse III, Toulouse, France
Fei Chen	Land Surface-Atmospheric Interactions & Their Impacts on Precipitation	6 May 2004	Laboratoire de Météorologie Dynamique, Le Centre national de la recherche scientifique (CNRS), Paris, France
Janice Coen	Infrared Imagery Applied For Insights Into Wildland Fire Dynamics	17 Nov. 2003	5th Symposium Fire & Forest Meteorology/2nd Intl. Fire Ecology & Fire Management Congress (Orlando, FL)
Janice Coen	Simulation Of Wildfire Incidents	17 Nov. 2003	5th Symposium Fire & Forest

	Using Coupled Atmosphere-Fire Modeling		Meteorology/2nd Intl. Fire Ecology & Fire Management Congress (Orlando, FL)
Janice Coen	Tutorial on the NCAR Atmosphere-Fire Model	15 Apr. 2004	Univ. of Colorado, Denver
Janice Coen	Software Architecture & Model Execution.	13 May 2004	Univ. of Colorado, Denver
Janice Coen	Poster	9-11 June 2004	Information Technology Research 2004 Grantees Meeting
Janice Coen	Fire Behavior & Modeling	4 Aug. 2004	Wildland Fire Collaboratory In-Process Program Review (NCAR)
Janice Coen	Coupled Atmosphere-Wildland Fire Modeling: Developments, Challenges in Fire Spread Prediction, and Collaborative New Directions	8 Sept. 2004	NASA GSFC
Tressa Fowler	Verification of Ceiling & Visibility Forecast Products	May 2004	NWS Forecasters
Tressa Fowler	Neighbor Comparisons of METAR & Ceiling & Visibility Measurements	January 2004	AMS Conf. on Probability and Statistics
Tressa Fowler	Neighbor Comparisons of METAR & Ceiling & Visibility Measurements	June 2004	Environmetrics Conference
Eric Gilleland	Optimizing METAR Network Design for Verification of Cloud Ceiling Height & Visibility Forecasts	28 June - 1 July 2004	TIES/ACCURACY Joint Annual Meeting (Portland, ME)
Eric Gilleland	The Extreme Value Tool Kit (extRemes): Weather & Climate Applications of Extreme Value Statistics	May 2004	R User's Conference 2004 (Vienna, Austria)
Eric Gilleland	Improving Forecast Verification through Network Design	January 2004	17th Conf. on Probability & Statistics in the Atmospheric Sciences, 84th Annual Meeting of the AMS (Seattle, WA)
David Gochis	The Arid Lands Initiative: Review, Emergence and Directions in RAP Arid Lands Research	22 Oct. 2003	RAP Retreat
David Gochis	NAME Enhanced Observation Period. North American Monsoon Experiment (NAME) Science Working Group Meeting-5	5-6 Nov 2003	Puerto Vallarta, Jalisco, Mexico
David Gochis	The Boulder Creek/St. Vrain Hydrological Observatory. Oral Presentation.	November 2003	Annual Meeting of the Rocky Mountain Hydrological Research Center
David Gochis	Investigations into Hydrometerological Processes Under the North American Monsoon	12 Nov 2003	Advanced Study Program, Research Reviews
David Gochis	NAME: Status and Plans. A	November 2003	CLIVAR/PAGES/IPCC

	multi-millenia perspective on drought and implications for the future		Workshop (Tucson, AZ)
David Gochis	Assessment of Scale-Dependent Runoff Generation Mechanisms in TOPLATS and Noah-router	8 Dec 2003	Fall Meeting of the American Geophysical Union (San Francisco, CA)
David Gochis	Exploration of Subgrid Routing Responses in the Noah-router Land Surface Model	15 Jan 2004	Annual Meeting of the American Meteorological Society (Seattle, WA)
David Gochis	Integrating hydrometeorological and hydroclimatological research and applications at NCAR	5 March 2004	RAP Division Seminar, Scientist I Interview
David Gochis	NAME Enhanced Observation Period	March 2004	Annual Meeting of the Panel on the Variability of American Monsoon Systems (VAMOS)-7 (Guayquil, Ecuador)
David Gochis	NAME Enhanced Observation Period	April 2004	North American Monsoon Experiment (NAME) Science Working Group Meeting-6 (Tucson, AZ)
David Gochis	Warm Season Precipitation Analyses from the NAME Event Raingauge Network (NERN) '02-'03	April 2004	North American Monsoon Experiment (NAME) Science Working Group Meeting-6 (Tucson, AZ)
David Gochis	Warm Season Precipitation Analyses from the NAME Event Raingauge Network (NERN) '02-'03	May 2004	Mountain Climate Sciences Symposium (Lake Tahoe, CA.)
David Gochis	Warm Season Precipitation and NAME	24-25 Aug 2004	GEWEX Americas Prediction Project Annual Principal Investigators Meeting (Boulder, CO)
Josuah Hacker	Assimilation of Fixed Screen-Height Observations in a Parameterized PBL	25 May 2004	Army High Performance Computing Research Center
Josuah Hacker	Phase & Amplitude in Ensemble Spread	15 Jan 2004	20th Annual Weather & Forecasting/16th Annual Numerical Weather Prediction Conf.(AMS)
Cathy Kessinger	Current & Future Plans for the AP Mitigation Scheme	12-15 Jan 2004	AMS
Cathy Kessinger	AMS Short Course entitled "Applications of Fuzzy Logic Used at the NCAR Research Applications Program"	11 Jan 2004	AMS Members
Cathy Kessinger	Oceanic Weather Convection Diagnosis	10-11 Feb 2004	Oceanic Weather PDT & aviation users
Cathy Kessinger	Oceanic Weather Convection Diagnosis & Nowcasting	2-3 March 2004	Oceanic Weather PDT Members
Cathy Kessinger	NEXRAD Data Quality	6-7 April 2004	OS & T
Cathy Kessinger	An Overview of Research done at the Research Applications Program and at the Naval	13-14 May 2004	Naval Research Laboratory

	Research Laboratory		
Cathy Kessinger	NEXRAD Data Quality Technical Interchange Meeting	19-20 May 2004	NOAA Radar Operations Center, NOAA Office of Hydrology
Jason Knievel	An Overview of the Pentagon Shield 2004 Field Campaign	26 Aug 2004	5th Symposium on the Urban Environment, (Vancouver, BC)
Jason Knievel	Algorithms in the Pentagon Shield System	30 June 2004	Visitors to NCAR from the Defense Advanced Research Projects Agency
Jason Knievel	Recommendations for Diffusion in Idealized Squall Line Simulations by the WRF Model (poster with extended abstract)	24 June 2004	WRF/MM5 Joint Workshop, NCAR
Jason Knievel	Current Status of BAMEX Dropsonde Data	1 March 2004	BAMEX Workshop (Fairview Heights, IL)
Jason Knievel	The Diurnal Mode of Summer Rainfall Across the Conterminous United States in 10-km Simulations by the WRF Model.	9 Feb 2004	NWS employees visiting NCAR as part of the Public Visitors Program.
Jason Knievel	The Diurnal Mode of Summer Rainfall Across the Conterminous United States in 10-km Simulations by the WRF Model.	14 Jan 2004	16th Conf. on Numerical Weather Prediction (Seattle, WA)
Jason Knievel	Are There Weather Holes? An objective analysis.	12 Jan 2004	20th Conf. On Weather Analysis & Forecasting (Seattle, WA)
Jason Knievel	Diurnal Rainfall in the WRF Model	9 Dec 2003	Seoul National Univ. (Seoul, Korea)
Jason Knievel	The Realism of Rainfall Patterns in Preliminary Versions of the Weather Research & Forecasting (WRF) Model	28 Oct 2003	Graduate students visiting NCAR as part of the Public Visitors Program
Todd Lane	High Resolution Estimates of Gravity Wave Momentum Flux from a Cloud Resolving Model	13 Jan 2004	AGU Chapman Conf. On Gravity Wave Processes & Parameterization (Hawaii)
Todd Lane	High Resolution Modeling Studies of Gravity Waves & Tropopause Folds	6 April 2004	NCAR UTLS Model Development Meeting
Todd Lane	Observations & Numerical Simulations of Inertia-Gravity Waves & Shearing Instabilities	1-6 Aug 2004	SPARC General Assembly (Victoria, Canada)
Todd Lane	Introduction to Aviation Turbulence Research at NCAR	23 July 2004	Univ. of Wisconsin, CIMSS
Jeff Lazo	The Household Study of Forecast Use and Value	23 April 2004	NOAA Weather and Water Mission Goal Team Social Science Workshop
Jeff Lazo	Societal Impacts of Weather Information	22 Jul 2004	NOAA /DOC Staff and Budget Offices Social Science Workshop
Jeff Lazo	Overview of NCAR-USWRP Societal Impacts Program	9 September 2004	Briefing of D.L. Johnson - NWS
Jeff Lazo	The Economic Value of Weather Forecasts	17 September 2004	Verification Workshop, Montreal, CA

Jeff Lazo	The Household Study of Forecast Use and Value	30 September 2004	NOAA Boulder Labs Social Science Workshop
Bill Mahoney	MDSS Program Review	15 Oct 2003	FHWA, LL, CRREL, NOAA
Bill Mahoney	AMS Policy Forum - Highway Weather	3-6 Nov 2003	FHWA, State DOTs, Federal DOT, Congressional staff, commercial weather providers, AMS, ITSA
Bill Mahoney	Surface Transportation Weather Technologies	15-17 DEC 2003	Aurora Program Board (15 State Dots)
Bill Mahoney	MDSS Performance Assessment	12 Jan 2004	Transportation Research Board (TRB)
Bill Mahoney	MDSS Program Results & Plans	14 Jan 2004	AMS Annual Meeting
Bill Mahoney	Surface Transportation Weather Research & Development	17 March 2004	Congressional Staff
Bill Mahoney	MDSS Performance Assessment & Program Plans	27 April 2004	Intelligent Transportation Society of America (ITSA)
Bill Mahoney	Winter Road Maintenance Decision Support	8 June 2004	TRB 6th Intl. Symposium on Snow Removal & Ice Control
Bill Mahoney	Winter Maintenance Decision Support	9 June 2004	Pacific Northwest Snowfighters Conf.
Bill Mahoney	MDSS Program Status & Future Plans	18 June 2004	Standing Intl. Road Weather Commission (SIRWEC) Meeting
Bill Mahoney	MDSS Performance Results	22 June 2004	MDSS Stakeholder Meeting
Bill Mahoney	Tactical Decision Support for Road Weather	23 June 2004	Aurora Program Board (15 State Dots)
Bill Mahoney	Winter Maintenance Decision Support - Technology Update	1 Sept 2004	Surface Systems Inc. - Winter Weather Workshop
Bill Mahoney	Advancements in Road Weather	15 Sept 2004	Indiana State DOT Local Technology Assistance Conf.
Cory Morse	An Introduction to Tuning NIMA	21 June 2004	Vaisala
Niles Oien	Introduction to NCAR Software	30 Oct 2003	IPMET group in Brazil
Marcia Politovich	Benchmarking	6 Oct 2004	AMS Conf. On Aviation, Range & Aerospace Meteorology (Hyannis, MA)
Marcia Politovich	Life in RAP	Summer 2004	NCAR Undergraduate Summer Session
Marcia Politovich	Inflight-Icing Challenges	20-22 Oct 2004	RAP Retreat
Daran Rife	New Insights Into the Predictability of Mesoscale Model-generated Forecast Winds As Input to Transport & Dispersion Models	14 June 2004	8th Annual GMU Conf. On Transport and Dispersion Modeling
Daran Rife	Insights Into the Predictability of Near-Surface Wind Field Forecasts by Mesoscale Meteorological Models	4 June 2004	RAP Seminar Series
Daran Rife	Predictability of Low-level WindFields by Mesoscale Meteorological Models	25 Feb 2004	University of Utah
Rita Roberts	Convection Initiation & Future Capabilities	4 Nov 2003	NWS Scientific Operations Officers at COMET
Rita Roberts	NCAR Auto-Nowcaster system	8 July 2004	Dallas/Ft. Worth Weather

			Service Office Forecasters
Rita Roberts	IHOP results	9 June 2004	Watercycle Initiative External Review Panel
Rita Roberts	Assessment of the RUC10 Forecasts of Storm Initiation During IHOP	9 Sept 2004	European Radar Conf. (Visby, Sweden)
Jenny Sun	Mesoscale Needs for Advanced Modeling & Data Assimilation	Dec. 2003	USWRP Workshop on Design & Development of Multifunctional Mesoscale Observing Networks in Support of Integrated Forecasting Systems.
Jenny Sun	Numerical Forecasting of Convective Storms: A Case Study of a Supercell Storm Observed during STEPS	June 2004	NCAR/ASP GTP Symposium
Agnes Takacs	Verification of Oceanic Weather Diagnoses & Forecasts for Aviation Weather Elements	15 Jan. 2004	AMS Conference
Tom Warner	Mesoscale Measurements & Forecasting in Support of the New York Urban Atmospheric Observatory	1 Feb. 2004	NYC Urban Atmospheric Observatory Steering Committee
Tom Warner	Variational Assimilation of Doppler Radar & Lidar Data for Near-Real-time Input to WMD Hazard Models	23 Jan. 2004	DoD Technical Cooperation Panel 9
Tom Warner	Very-High-Resolution Modeling of Land-Atmosphere Interaction in Arid Zones	29 Mar. 2004	SAHRA, Univ. of Arizona
Tom Warner	The Pentagon Shield Modeling System & Field Campaign	25 May 2004	DTRA Urban Dispersion Modeling Working Group
John Williams	Automated Scoring Algorithm Development and Implementation	2 December 2003	NASA-FAA-Industry Airborne Turbulence Detection Systems Certification Workshop #6
John Williams	Automated Scoring Algorithm Task Closeout Review Meeting	30 January 2004	NASA AvSSP Turbulence Prediction and Warning Systems Team
John Williams	The NCAR Turbulence Detection Algorithm for WSR-88D Radars	6 April 2004	NWS Office of Science and Technology Briefing
John Williams	Progress in Development and Validation of the WSR-88D Turbulence Algorithm	22 April 2004	FAA Aviation Weather Research Program Turbulence PDT Science Review
John Williams	Dual-Wavelength Remote Detection of Cloud Liquid Water Content	5 May 2004	FAA Aviation Weather Research Program In-Flight Icing PDT Science Review
John Williams	Aviation Turbulence Research Activities at NCAR/RAP	13 May 2004	Naval Research Laboratory Briefing
Jim Wilson	Convective Initiation & Evolution Studies	June 2004	IHOP Workshop (Toulouse, France)
Jim Wilson	Thunderstorm Nowcasting	August 2004	Radar Weather Office (Tangu, China)
Jim Wilson	NCAR installations for IUM:	August 2004	Institute Urban Meteorology

	Extrapolation, TITAN and VDRAS		(Beijing, China)
Jim Wilson	NCAR installations for IUM: Extrapolation, TITAN and VDRAS	September 2004	European Radar Conf. (Visby, Sweden)
Jim Wilson	Quantitative Precipitation Nowcasting	November 2003	6th Intl. Symposium on Hydrology Applications of Weather Radar (Melbourne, Australia)
Jim Wilson	Small Scale Precipitation Features & Nowcasting	November 2003	Workshop on small scale precipitation features (Aukland, New Zealand)
Mei Xu	Nowcasting For Urban Areas By Variational Assimilation Of Doppler Radar And Lidar Radial Wind Data	12 Jan 2004	Symposium on Planning, Nowcasting, Forecasting for the Urban Zone
Mei XU	Assimilating Radar Data For Real-time Short-term Snowstorm Forecasting	14 Jan 2004	16th Symposium on Numerical Weather Prediction (Seattle, WA)
Mei XU	Assimilating Radar Data For Real-time Snowstorm Forecasting	28 April 2004	FAA Facetime Meeting (Boulder, CO)
Mei XU	Winter Weather Forecasting	13 May 2004	Weather Channel visitors (Boulder, CO)
Mei XU	High Resolution Modeling & Radar Data Assimilation	13 July 2004	National Central University (Chungli, Taiwan)
Mei XU	Weather Support for Decision Making	22 Sept 2004	Air Traffic Control (Beijing, China)
Mei XU	High Resolution Modeling & Radar Data Assimilation	24 Sept 2004	Beijing University (Beijing, China)
David Yates	Global Change Impacts on Aquatic Ecosystem Services of the Sacramento Watershed	24 Feb 2004	RAP Science Seminar
Guifu Zhang	Modern Weather Radar Techniques: Polarimetry & Interferometry	21 Apr. 2004	Univ. of Oklahoma, School of Meteorology
Guifu Zhang	Raindrop Size Distribution Retrieval from polarization Radar Observations to improve Model Parameterization in NWP	4 Oct. 2004	CASA Workshop

Education & Training - Professional

Staff Name	Title of Presentation	Group and date
Fei Chen	Land-Surface/Atmospheric Interaction & Diurnal Cycle of Boundary Layer	Invited Keynote Speaker for the Boundary Layer Symposium, COMET/UCAR, 24 June 2004
Fei Chen	Challenge of Forecasting Urban Weather with Mesoscale NWP Models	Arizona State Univ., 28 June 2004
Fei Chen	Land-Surface/Atmospheric Interaction & Diurnal Cycle of Boundary Layer	Invited Keynote Speaker for the Boundary Layer Symposium, COMET/UCAR, 11 August

		2004
Tara Jensen	Demonstration & Tutoring on use of RAOB Software	Dept. of Water Resources Studies Forecast Team (Abu Dhabi, UAE) 17-31 May 2004
Tara Jensen	How to Read the Clouds & Find Updrafts While Flying Near Convection	Univ. of Witwatersrand/S. African Weather Bureau Pilots (Abu Dhabi, UAE) 1-20 June 2004
Tara Jensen	How to Use & Interpret the New Real-time Four Dimensional Data Assimilation Forecast System for the UAE	Dept. of Water Resources Studies Forecast team (Abu Dhabi, UAE) 15 July - 22 Aug. 2004
Tenny Lindholm	Presentation on Oceanic Weather	Air Traffic Control Assoc. Convention 27-30 Oct 2003, Washington, DC
Tenny Lindholm	Briefing on Turbulence Downlink	MDCRS Management Group,13 Nov 2003
Tenny Lindholm	Oceanic Weather Developments	Intl. Oceanic Airspace Conf. (250 participants representing 30 nations), Honolulu, 18 Nov 2003
Tenny Lindholm	Conducted & briefed oceanic weather science/user workshop	Airline Pilots Assoc., Herndon, VA, 10 Feb 2004
Tenny Lindholm	Briefing on AWRP research	NASA Aviation Safety & Security Program Workshop, Alexandria, 3 Mar 2004
Tenny Lindholm	Briefing on turbulence research programs	Delta Airlines Management, Atlanta, 22 March 2004
Tenny Lindholm	Briefing updates on progress of research-to-operations on all AWRP programs	United, American, Southwest, Recurring
Tenny Lindholm	Briefing on RAL research & product development	International Conf. On Volcanic Ash, Alexandria, 22 June 2004
Tenny Lindholm	Safety seminars on aviation weather products & graphics	General aviation pilots at Centennial Airport, Oct 2003 & Mar 2004
Bill Mahoney	MDSS Technology Transfer Program	MDSS Technology Transfer Workshop - 23 June 2004
Marcia Politovich	Flight in SLD Conditions & On-Line Training	Public Use, directed to pilots - completed July 2004
Daran Rife	User Requirements & Training	White Sands Missile Range - 19-20 Oct. 2004
Daran Rife	User Requirements & Training	Aberdeen Proving Ground - 15-16 June 2004
Daran Rife	User Requirements & Training	Electronic Proving Ground, Tucson Arizona - 12-14 April 2004
Rita Roberts	Radar Observation of Severe Weather	Turkish Weather Service Forecasters (DMI) in Ankara, 16 Dec. 2003
Rita Roberts	Use of Radar in Winter Storm Nowcasting	Turkish Weather Service Forecasters (DMI) in Ankara, 18 Dec. 2003
Rita Roberts	Thunderstorm Nowcasting	Turkish Weather Service Forecasters (DMI) in Ankara, 18 Dec. 2003
Rita Roberts	Laboratory Exercise on Thunderstorm Nowcasting	Turkish Weather Service Forecasters (DMI) in Ankara, 19 Dec. 2003
Rita Roberts	Laboratory Exercise on Thunderstorm Nowcasting	NWS Scientific Operations Officers at COMET, 4 Nov. 2003
Tom Saxen	ATEC Forecaster's Conf. Session on Auto-Nowcaster	Army Range Forecasters (at NCAR) 6-8 April 2004
Tom Saxen	ATEC Forecaster's Conf. Session on Auto-Nowcaster	Army Range Forecasters (at NCAR) 8-10 June 2004
Scott Swerdlin	Global Meteorology On Demand: Application for Rapidly Generating Fine-Scale Model Output	TTCP Technical Panel 9, 9 Feb. 2004

	Anywhere in the World	
Scott Swerdlin	Concept for Creating National-Scale Radar-Based Data Assimilation System	Homeland Security Advanced Research Projects Agency, 19 Feb. 2004
Scott Swerdlin	Overview of Pentagon Shield Concept of Operations	Pentagon Force Protection Agency, 26 Mar. 2004
Scott Swerdlin	NCAR's Homeland Security Program	NASA, 9 Apr. 2004
Scott Swerdlin	Protecting Colorado's Critical Infrastructure From Terrorism	Colorado S&T organizations, sponsored by the Colorado Institute of Technology, 16 Apr. 2004
Scott Swerdlin	Overview of 4DWX & Homeland Security Applications	Australian Bureau of Meteorology, 3 May 2004
Scott Swerdlin	Advance Numerical Weather Prediction Capabilities for the Army Test Ranges	Range Commander's Council Meteorology Group Annual Meeting, 16 Apr. 2004
Scott Swerdlin	Homeland Security & Urban Scale Weather	The Weather Channel, 12 May 2004
Scott Swerdlin	Description of Pentagon Shield Field Campaign	KOAA TV, Colorado Springs, 19 May 2004
Scott Swerdlin	Modeling Urban Weather & Plume Transport & Dispersion	Dept. of Homeland Security Workshop on Bioaerosol Transport, 25 May 2004
Scott Swerdlin	State of the Art in Tracking Airborne Hazards	International Test & Evaluation Workshop, 7 June 2004
Scott Swerdlin	Applying Pentagon Shield Technology to Protecting the National Capitol Region	Dept. of Homeland Security and the Homeland Security Institute, 16 June 2004
Scott Swerdlin	Difficulties in Modeling Plume Dispersion in Stable Atmospheric Conditions	US Air Force Academy, 28 June 2004
Scott Swerdlin	Expanding Pentagon Shield to the Nation	Capitol Hill staffers, 9 July 2004
Scott Swerdlin	Overview of Pentagon Shield Field Program	Annual Transport & Dispersion Conf., George Mason Univ., 13 July 2004
Scott Swerdlin	Overview of NCAR's Urban Modeling Program	Lawrence Livermore National Laboratories, 20 July 2004
Scott Swerdlin	Technical Information Exchange on Data Assimilation with NWP Models	IBM Watson Research Center, 21 July 2004
Scott Swerdlin	Derivative 4DWX Science & Technology for Warfighter Support	Range Commander's Council Executive Group Annual Meeting, 10 Aug. 2004
Scott Swerdlin	Things not Modeled Well in Supporting Warfighter	Air Force Connections Annual Conf., 25 Aug. 2004
Scott Swerdlin	Critical Infrastructure Protection (UDMWG), & Concept of CBR Sensor Data Assimilation (SDEWG)	Urban Dispersion Modeling Working Group, and Sensor Data Fusion Working Group, 27 Sept. 2004
John Williams	Introduction to Fuzzy Logic	Short Course on Artificial Intelligence Methods in Atmospheric & Oceanic Sciences, 84th AMS
Jim Wilson	Instructor, Radar Applications	WWRP Radar Workshop, Brasillia, Brazil - 2 weeks Nov. 2003
Jim Wilson	Instructor, Radar Applications & Nowcasting	Turkey Meteorological Institute, Ankara, Turkey - 1 week Dec. 2003

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Education & Training - K-12/College World

Staff Name	Title of Presentation	Group and date
Dan Breed	Clouds & Weather	Two 8th grade science classes at Casey Middle School, 29 Jan. 2004

Steve Carson	Science with Steve - meekly 1-hr science class	Rocky Mt. School for the Gifted-5th Grade, ongoing
Kyoko Ikeda	Clouds, Wind and Heat	Holiday activity camp sponsored by N.P.O. (an education outreach group for K-12) Tanukimura, Shizuoka, Japan 22-26 Dec. 2003
Mei XU	Weather & the Atmosphere	Boulder Chinese Church High School Students, 15 Aug. 2004

Mentoring

Staff Name	Description
Barb Brown	Mentored Barbara Casati from the Univ of Reading, UK, on verification methods for spatial forecasts.
Andrew Crook	Research mentor for Anthony Didlake, (SOARS)
Tressa Fowler	Mentored Jr. High School student, J.P. Gallo, on probability, proportions, statistical graphics
Jason Knievel	Research mentor for Braxton Edwards, (SOARS)

Field Campaign Work

Staff Name	Project Name and Location	Date	Sponsor
Dan Breed, Project Manager	Rainfall Enhancement Assessment Program, UAE	Summer 2004	DWRS
David Gochis	North American Monsoon Experiment: Science Working Group, Field Documentation	Ongoing	NOAA-Office of Global Programs
David Gochis	North American Monsoon Experiment, 2004 Enhanced Observation Period - Mexico	1 June - 15 Aug. 2004	NOAA-Office of Global Programs
Bill Mahoney, Project Manager	MDSS Iowa Field Demonstration	Winter '03-'04	FHWA
Marcia Politovich, Operations Director	WISP04 - Marshall, CO	Feb.-Mar. 2004	FAA, NSF
Scott Swerdlin	Pentagon Shield	Apr.-May 2004	Defense Advanced Research Projects Agency (DARPA)

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Community Service

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Editorships

Staff Name and your role	Name of Publication
Jennifer Boehnert, Associate Editor	The Aral Seas
Barb Brown, Associate Editor	Weather and Forecasting
Eric Gilleland, Reviewer	Atmospheric Environment
Andrea Hahmann, Manuscript Reviewer	Journal of Climate
Andrea Hahmann, Proposal Reviewer	NOAA Atlantic Program
Andrea Hahmann, Proposal Reviewer	National Science Foundation
Marcia Politovich, Editor, In situ measurements	Journal of Oceanic & Atmospheric Technology

Communicating NCAR science to the public

Staff Name	Description	Date
Jennifer Boehnert	Hosting the Atmospheric Special Interest Group - Developing a Data Model Website	Ongoing
Jennifer Boehnert	RAL GIS Booth at the Intl. ESRI Users Conference	8 Aug 2004
Dan Breed	Science Fair Judge (and mentor) for Casey Middle School	27 Jan 2004
Andrew Crook	Worked at the NCAR Science booth at the Boulder Creek Festival	29 May 2004
Tressa Fowler	Worked RAP booth at NBAA	October 2003
Tressa Fowler	Judge for Kohl Elementary Science Fair	26 Jan 2004
David Gochis	RAL Booth attendee at 2004 Annual AMS Meeting (Seattle, WA)	January 2004
Tara Jensen	Science Fair Judge for Boulder Country Day School	8 Feb 2004
Jason Knievel	Science Fair Judge for Eisenhower Elementary School	7 Feb 2004
Bill Mahoney	Winter Snow Fighting Operations Education - Coordinator for	Sept 2003

	1st City of Louisville Schools Snow Plow Painting Art Program	
Carol Park	Worked at the NCAR Science booth at the Boulder Creek Festival	29 May 2004
John Williams	Staffed NCAR/RAP booth at the 84th AMS Annual Meeting	13 Jan 2004
Mei Xu	Communicating NCAR aviation weather products at Air Traffic Control Exhibition (Beijing, China)	22-24 Sept 2004

Panels and Committees

Staff Name	Name of Panel or Committee	Description
Jennifer Boehnert	GIs Initiative Review Panel	Sponsor
Dan Breed	Lightning Data Center, St. Anthony's Hospital, Denver	Member
Barbara Brown	Joint Working Group on Forecast Verification, WMO World Weather Research Program & WMO Working Group on Numerical Experimentation	Chair
Janice Coen	NCSA Alliance Allocations Board/PACI National Resource Allocations Committee	Member
David Gochis	North American Monsoon Experiment: Science Working Group	Member, GIs Database Creator
Joshua Hacker	Weather Research & Forecasting (WRF) working group for advanced data assimilation	Member
Joshua Hacker	United States Weather Research Program (USWRP) Mesoscale Analysis Committee	Member
Andrea Hahmann	SCD Advisory Panel	Member
Cathy Kessinger	AMS Program Committee on Artificial Intelligence Applications in the Environmental Sciences	Member
Jeff Lazo	ResEcon - listserv network of environmental and natural resource economists	List Administrator
Tenny Lindholm	MCDRS Management Group	Member
Tenny Lindholm	Commercial Airline Safety Team	Leader for team on turbulence issues
Tenny Lindholm	Tri-agency working group	Member
Tenny Lindholm	RTCA Special Committee 195	Member
Tenny Lindholm	FAA Flight Standards Working Group	Member
Bill Mahoney	AMS Economic Development Committee	Member
Bill Mahoney	Intelligent Transportation Society (ITS) Weather Information Applications Special Interest Group	Leader for Developing Road Weather Research Program.
Marcia Politovich	COMET Advisory Panel	Member

Marcia Politovich	AMS Fellows Committee	Member
Marcia Politovich	AIAA Atmospheric & Space Environment Committee	Chair, In-flight Icing Subcommittee; Member, Publications Committee
Marcia Politovich	Society of Automotive Engineers In-Flight Icing Subcommittee	Member
Marcia Politovich	NSF RICO Review Committee	Member
Rita Roberts	National Academy of Sciences, National Research Council panel on Flash Flood Forecasting over Complex Terrain, With an Assessment of the Sulphur Mountain NEXRAD in Southern California	Member
Rita Roberts	AMS Committee on Radar Meteorology	Chair
Jim Wilson	WWRP Nowcasting Working Group	Member
Jim Wilson	NEXRAD Technical Advisory Committee	Member
David Yates	AMS Committee on Societal Impacts	Member

Other Educational Activities

Staff Name	Description	Date
David Gochis	Guest Lecturer: "Desert Meteorology", Univ. of Colorado	8-10 Oct 2003
Kent Goodrich	Taught Introduction to Operations Research, Univ. of Colorado	Spring 2004
Kent Goodrich	Taught Introduction to Abstract Mathematics, Univ. of Colorado	Spring 2004
Kent Goodrich	Taught Real Analysis, Univ. of Colorado	Fall 2004
Kent Goodrich	Taught Honors Calculus Three, Univ. of Colorado	Fall 2004
Kent Goodrich	Co-director of the Actuarial Studies Certificate Program, Univ. of Colorado	2003 - 2004
Joshua Hacker	Assisted in developing teacher-training modules for St. Vrain Valley School District middle schools. This is in cooperation with CIRES & the local AMS chapter.	January 2004 - Ongoing
Tara Jensen	Web master for IEEE-Geoscience & Remote Sensing Society	Ongoing
Tenny Lindholm	Revised aviation weather section for the 2nd edition of "Handbook on Aviation Human Factors"	2004
Tom Warner	Taught Desert Meteorology, Univ. of Colorado	Aug - Dec 2003

David Yates	Taught Course: 'Hydrologic Modeling', Univ. of Colorado, Dept. of Civil Engineering	Spring 2004

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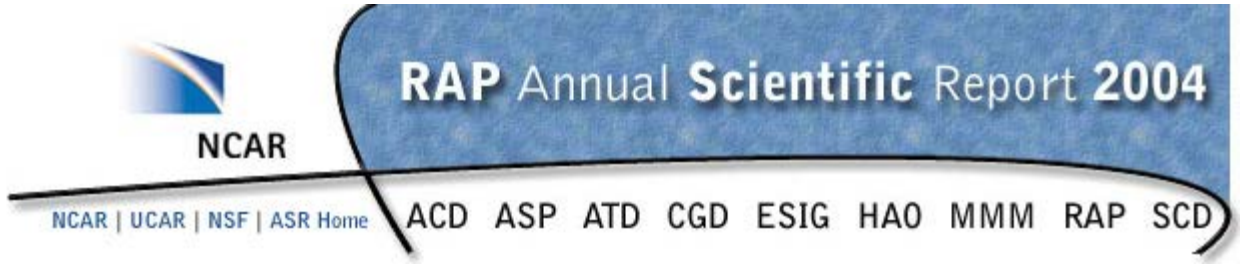

Awards and Honors

Staff Name	Description
Dan Breed	Distinguished Alumni Award - Sterling (IL) Schools Foundation
Bob Sharman	Turning Goals into Reality (TGIR) Goal 1, Revolutionize Aviation Award, June 2003 - NASA
Bob Sharman	Top 50 Research Leaders of the Year, Dec. 2003 - Scientific American
Bob Sharman	"Paying tribute to Larry Cornman, Robert Sharman, and Paul Polak" - Hon. Scott McInnis of Colorado, U. S. Congressional Record, Proceedings and debates of the 108th congress, first session, House of Representatives
John Williams	NASA Langley Research Center - Certificate of Appreciation: Exceptional contributions developing technologies that have significant potential for reducing turbulence-induced injuries aboard commercial transports
Guifu Zhang	Cross-Correlation Method for Estimating 3-D Wind Field; a patent #6721678 given by US patent office

RAP Publications 2004

[Refereed]
[Unrefereed]

Bold denotes University collaborators
* denotes non-NCAR or other collaborators

Refereed

Brandes, E., G. Zhang and J. Vivekanandan, 2004: Comparison of polarimetric radar drop size distribution retrieval algorithm, *J. Atmos. Ocean. Tech.*, **21(4)**, 576-590.

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Chen, F., 2004: Variability in Global Land Surface Energy Budgets During 1987-1988 Simulated by an Off-line Land Surface Model and a Comparison with NCEP/NCAR Reanalysis. *Climate Dynamics*. (In press)

Chen, S.-H, F. Vandenberghe, G. Petty and J. Bresch, 2004: Application of SSM/I Satellite Data to a Hurricane Simulation. *Q. J. R. Meteorol. Soc.*, **130**, 801.

Clark, T. L., J. L. Coen and D. Latham, 2004: Description of a Coupled Atmosphere-Fire Model. *Intl. J. Wildland Fire*, **13**, 49-63.

Coen, J. L., **S. Mahalingam** and **J. W. Daily**, 2004: Infrared imagery of crown-fire dynamics during FROSTFIRE. *J. Appl. Meteor.*, **43**, 1241-1259.

Coen, J. L., 2003: Book Review of "Burning Questions: America's fight with Nature's Fire, by David Carle", *The Environment,* **45**, 36.

Cortinas, J.V., Jr., B.C. Bernstein, **C.C. Robbins** and J.W. Strapp*, 2004: An analysis of freezing rain, freezing drizzle and ice pellets across the United States and Canada: 1976-1990. *Wea. Forecasting*, **19**, 377-390.

Crook, N.A. and J. Sun, 2004: Analysis and Forecasting of the Low-Level Wind During the Sydney 2000 Forecast Demonstration Project. *Weather and Forecasting*. **19(1)**, 151-167.

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Davis, C., **N. Atkins**, D. Bartels*, L. Bosart, M. Coniglio, G. Bryan, **W. Cotton**, D. Dowell, B. Jewett, R. Johns, D. Jorgensen*, J. Knievel, **K. Knupp**, W.C. Lee, **G. McFarquhar**, **J. Moore**, R. Przybylinski*, **R. Rauber**, **B. Smull,** R. Trapp, S. Trier, **R. Wakimoto**, M. Weisman and **C. Ziegler**, 2004: The Bow Echo and MCV Experiment (BAMEX): observations and opportunities. *Bull. Amer. Meteor. Soc.,* **85**, 1075-1093.

Doviak, R. J., G. Zhang, S. A. Cohn and W. Brown, 2004: Comparison of spaced-antenna wind estimators: Theoretical and simulation results, *Radio Science*, **39(1)**, Art. No. 1006.

Dowell, D.C., **F. Zhang**, L. J. Wicker*, C. Snyder and N.A. Crook, 2004: Wind and temperature retrieval in the 17 May 1981 Arcadia, Oklahoma Supercell: Ensemble Kalman Filter Experiments. *Mon. Wea. Rev*. **132**, 1982-2005.

Fox, N., R. Webb*, J. Bally*, **M. Sleigh**, C. Pierce*, D. Sills*, P. Joe*, J. Wilson and **C. Collier**, 2004: The impact of advanced nowcasting systems on severe weather warnings during the Sydney 2000 forecast demonstration project: 3 November 2000*. Wea. Forecasting, **19**, 97-114.*

Gilleland, E. and D. Nychka, 2004: Statistical Models for Monitoring and Regulating Ground-level Ozone. *Environmetrics.* (In press)

Knievel, J. C., **D. S. Nolan** and **J. P. Kossin**, 2004: Imbalance in a mesoscale vortex within a mid-latitude, continental mesoscale convective system. *J. Atmos. Sci.*, **61**, 1827-1832.

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Reeder, M.J., T.P. Lane, F.M. Guest, and D. Wratt*, 2003: Two southerly changes observed during the New Zealand Southern Alps experiment (SALPEX). *Aust. Met. Mag.*, **52**, 251-258.

Rife, D. L., C. A. Davis, Y. Liu and T. T. Warner, 2004: Predictability of low-level winds by mesoscale meteorological models. *Mon. Wea. Rev.*, **132,** 2553-2569.

Sharif, H. O., **F. L. Ogden**, **W. F. Krajewski** and **M. Xue**, 2004: Statistical analysis of radar rainfall error propagation, *J. Hydrometeorology.* **5(1)**, 199-212.

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People

Staff 2004

Visitors 2004

Staff

Director's Office

G. Brant Foote (director)
Richard Wagoner (deputy director)
Joanne Dunnebecke
Inger Gallo
Cindy Halley Gotway
Cheryl Hilliard

Engineering Systems Group (ESG)

Bruce Carmichael (manager of engineering)
Tenny Lindholm

Operational Systems Group (OSG)

Michael Dixon (group head)
Deirdre Brucker

Dara Houliston
Lisa Lundeen (casual)
Rose Lundeen
Rhonda McGaffic
William Mahoney
Mary Pronk
Diane Simpson
Jennifer Wilson
Lara Ziady

Applied Science Group (ASG)

*** Joint Appointment with MMM**
**** Joint Appointment with ATD**

Roy Rasmussen (group head) *
Jennifer Abernethey (student)
Joseph Alfieri (student assistant)
Richard Bateman
Ben Bernstein
George Bieberbach
Carter Borst (long-term visitor)
Patrick Boylan (student assistant)
Jamie Braid
Edward Brandes
Daniel Breed *
Barbara Brown
Roelof Bruintjes *
Randy Bullock
Michael Chapman
Fei Chen
Janice Coen *
Jeffrey Cole
Jeff Copeland
Larry Cornman
Andrew Crook *
Christopher Davis *
Tressa Fowler
Rodney Frehlich (long-term visitor)
Ming Ge
Danika Gilbert
Eric Gilleland
David Gochis
Kent Goodrich (long-term visitor)
Lisa Goodrich (casual)
Angel Gutierrez (casual)
Joshua Hacker
Julie Haggerty **
Andrea Hahmann
William Hall *
Benjamin Hendrickson
Paul Herzegh
Alan Hills *
Lacey Holland
Hsiao-ming Hsu
Kyoko Ikeda
Thomas Acierno (student assistant)
Celia Chen
Stephen Dowdy
Teresa Eads
O. Tres Hofmeister
Jacob Pratt (student assistant)
Kendall Southwick (student assistant)
Jeffrey Stolte
Anne-Marie Tarrant
Steven Webb
Kim Webster
Linda Zhang

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Todd Applewhite
Karen Arp
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Terri Betancourt
Gary Blackburn
Jennifer Boehnert (join with ESIG)
Al Bourgeois
Aaron Braeckel
Laurie Carson
Steven Carson
Marcel Casado
Julien Chastang
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Susan Dettling
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Niles Oien
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Paul Prestopnik
Nancy Rehak
Rebecca Ruttenberg

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David B. Johnson
Teddie Keller (long-term visitor)
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Jason Knieval
Scott Landolt
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Yubao Liu
Carol Makowski
Frank McDonough
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Carol Park
Marcia Politovich
Matthew Pocernich
Daran Rife
Rita Roberts
Conrad Roesch (student assistant)
Vidal Salazar
Thomas Saxen
David Serke
Robert Sharman
Rong-Shyang Sheu
Jennifer Simard (student assistant)
Jenny Sun *
Agnes Takacs
Robert Tardif (graduate research assistant)
Claudia Tebaldi (joint with ESIG, CGD)
Mukul Tewari
Gregory Thompson
Matthew Tryhane
Francois Vandenbergh
Jothiram Vivekanandan **
Charles Wade
Thomas Warner (long-term visitor)
John Williams
James Wilson **
Cory Wolff
Jamie Wolff
Mei Xu
David Yates
Stephan Zednik (student assistant)
Guifu Zhang
Ying Zhang

Troy Sandblom
Elena Schuler
Steve Sullivan
Shane Swartz
Scott Swerdlin
Andrew Weekley
Beth Chorbajian Weekley
Robert Weingruber
Adrian Wilksch
Wesley Wilson
Matthew Wood (student assistant)
Alan Yates
Jaimi Yee

Visitors

(Foreign visitors in **Bold)**

Visitor	Affiliation	Dates	Host
Dr. Alan Betts	Atmospheric Research	7-9 June 2004	Water Cycle

Shankar Mahalingam, Ph.D	Univ. of Calif.-Riverside	Intermittent in FY04	Wildland Fire Initiative
Tan Xiaoguang	Institute of Urban Meteorology (Beijing, China)	20 Nov. - 18 Dec. 2003	Auto-nowcasting
Chen Mingxuan	Institute of Urban Meteorology (Beijing, China)	20 Nov. - 18 Dec. 2003	Auto-nowcasting
Alan Seed	Bureau of Meteorology (Australia)	June 2004	USWRP
Gerhard & Ana Held	Instituto de Pesquisas Meteorologicas (Portugal)	Sept. 2004	USWRP
May Yuan, Ph.D	Univ. of Oklahoma	Sept. 2004	GIS Initiative
Andrew Reehorst	NASA Glenn Research Laboratory	Need Date	NIRSS Display Upgrade (NASA), FAA Aviation
Jeff C. Flo	Hong Kong Univ. of Science & Technology	16 Mar. - 15 Sept. 2004	Urban Land Use Modeling for Pearl River Delta Region
Alexis Lau	Hong Kong Univ. of Science & Technology	24-25 July 2004	Urban Land Use Modeling for Pearl River Delta Region
Barbara Casati	Univ. of Reading	17 Mar. - 14 April 2004	Verification Group
Chris Albrecht	Iowa State Univ.	21-23 July 2004	MDSS
Matt Alexander	E-470 Public Highway Authority (Colorado)	21-23 July 2004	MDSS
Roemer Alfelor	FHWA HQ/HOTO	21-23 July 2004	MDSS
Dennis Belter	Indiana DOT	21-23 July 2004	MDSS
Jim Block	Meteorologix	21-23 July 2004	MDSS
Brenda Boyce	Mixon/Hill, Inc.	21-23 July 2004	MDSS
Dennis Burkheimer	Iowa DOT	21-23 July 2004	MDSS
Bob Dreisewerd	SSI/Surface Systems, Inc. (St. Louis)	21-23 July 2004	MDSS
Tina Greenfield	Iowa State University	28 June 2004	MDSS and E-470
Xueliang Guo	Chinese Academy of Sciences	10 Aug - 10 Oct 2004	Precipitation Enhancement
Bob Hallowell	MIT/LL	21-23 July 2004	MDSS
Bob Hart	Meridian Environmental Technology	21-23 July 2004	MDSS
Amy Holman	NOAA/National Weather Service	21-23 July 2004	MDSS
Joe Holt	Tennessee DOT	21-23 July 2004	MDSS
Frank Kinder	Colorado DOT	21-23 July 2004	MDSS
Geoff Koenig	CRREL	21-23 July 2004	MDSS
Dennis Kroeger	Iowa State Univ.	21-23 July 2004	MDSS
Wayne Lupton	Colorado DOT	21-23 July 2004	MDSS
John Mewes	Meridian Environmental Technology	21-23 July 2004	MDSS
Wilf Nixon	Univ. of Iowa	21-23 July 2004	MDSS
Leon Osborne	Meridian Environmental Technology	21-23 July 2004	MDSS
Curt Pape	Minnesota DOT	21-23 July 2004	MDSS
Brooke Pearson	Vaisala	21-23 July 2004	MDSS

Rudy Persaud	FHWA/HRDO	21-23 July 2004	MDSS
Gary Phetteplace	CRREL	21-23 July 2004	MDSS
Paul Pisano	FHWA HQ/HOTO	21-23 July 2004	MDSS
James Pol	FHWA HQ	21-23 July 2004	MDSS
Gary Rasmussen	American Meteorological Society	21-23 July 2004	MDSS
Dan Roosevelt	Virginia DOT	21-23 July 2004	MDSS
Paul Schultz	FSL	21-23 July 2004	MDSS
Lee Smithson	AASHTO	21-23 July 2004	MDSS
Andy Stern	Mitretek	21-23 July 2004	MDSS
Jack Stickel	Alaska DOT	21-23 July 2004	MDSS
Ron Sznaider	Meteorologix	21-23 July 2004	MDSS
Micheli Watson	E-470 Public Highway Authority (Colorado)	21-23 July 2004	MDSS
Edward Argenta, Jr.	US Army, Dugway Proving Ground	4-5 May 2004	ATEC
Rich Babarsky	US Army, NGIC	4-5 May 2004	ATEC
Paul Benda	US Army, DARPA	4-5 May 2004	ATEC
Jim Bowers	US Army, Dugway Proving Ground	4-5 May 2004	ATEC
Michael Brown	Los Alamos National Laboratory	1-2 June 2004	ATEC
Antonio Castillo	US Army, White Sands Missile Range	4-5 May 2004	ATEC
Charles Clough	US Army, Aberdeen Proving Ground	4-5 May 2004	ATEC
Craig Egeland	US Army, Cold Regions Test Center	4-5 May 2004	ATEC
Ed Ellison	US Army, White Sands Missile Range	4-5 May 2004	ATEC
Frank Gallagher	US Army, Dugway Proving Ground	4-5 May 2004	ATEC
Scott Halvorson	US Army, Dugway Proving Ground	4-5 May 2004	ATEC
Cmdr. Stephanie Hamilton	US Army, DTRA	4-5 May 2004	ATEC
John Hannan	US Army, DTRA	4-5 May 2004	ATEC
Terry Huck	US Army, White Sands Missile Range	4-5 May 2004	ATEC
Glenn Lader	US Army, White Sands Missile Range	4-5 May 2004	ATEC
Robert Malone	US Army, Electronic Proving Ground	4-5 May 2004	ATEC
Ray Rigert	US Army, Ft. Delvoir/Night Vision	4-5 May 2004	ATEC
Arnie Villarreal	US Army, Dugway Proving Ground	4-5 May 2004	ATEC
Dean Weingarten	US Army, Yuma Proving Ground	4-5 May 2004	ATEC
Kelly Wink	US Army, Aberdeen Proving Ground	4-5 May 2004	ATEC

Henry Baron	FAA Headquarters	15-16 June 2004	JAWS
Tom Carty	FAA Technical Center	15-16 June 2004	JAWS
Rick Girard	FAA Alaska Region	15-16 June 2004	JAWS
Cynthia Grzywinski	FAA Technical Center	15-16 June 2004	JAWS
Dan Hedenberg	FAA Headquarters	15-16 June 2004	JAWS
David Jackson	FAA Headquarters	15-16 June 2004	JAWS
Frank Law	FAA Technical Center	15-16 June 2004	JAWS
Marcella Meador	FAA Operational Support	15-16 June 2004	JAWS
Mehdi Rashidifard	FAA Operational Support	15-16 June 2004	JAWS
Susan Strauman	FAA Technical Center	15-16 June 2004	JAWS
Kimo Villar	FAA Alaska Region	15-16 June 2004	JAWS
Rich Vliet	FAA Headquarters	15-16 June 2004	JAWS
Hank Williams	FAA Alaska Region	15-16 June 2004	JAWS
Vaughn Yates	FAA Headquarters	15-16 June 2004	JAWS
Ken Mitchell (Fei)	NCEP	23-24 Feb. 2004	Noah LSM Development
Michael Ek (Fei)	NCEP	22-23 June 2004	Noah LSM Development
Ying Lin	NCEP	12-16 July 2004	Verification Group

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A Message from SCD Director Al Kellie

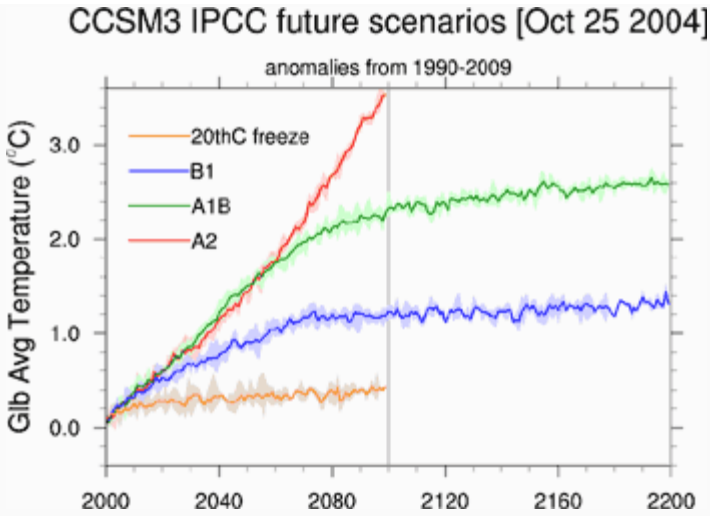
In Fiscal Year 2004, SCD defined its strategic plan for the next five years and met significant computer security challenges while continuing to provide integrated support services for researchers in the atmospheric, oceanic, and related sciences.

Two major accomplishments stand out for this year: bluesky's contribution to research for the Intergovernmental Panel on Climate Change (IPCC) and meeting cybersecurity challenges.

Climate Modeling for IPCC

Phase III of the current Advanced Research Computing System (ARCS) was placed in service in FY2004, increasing net computing capacity by two teraflops. Phase III of ARCS expanded the IBM Cluster 1600 system (bluesky) by fourteen 32-way p690 Symmetric Multi-Processor (SMP) servers. Bluesky is now comprised of 50 POWER4 38 Regatta-H Turbo frames, making it the single largest system of this type in the world.

Twelve of these new servers were initially dedicated to NCAR's participation in the Intergovernmental Panel on Climate Change (IPCC). This new supercomputing capability proved essential in completing the IPCC simulations with the high-resolution version of the new Community Climate Simulation Model (CCSM3). Long control simulations, numerous historical recreations, and a wide range of future scenarios were carried out with NCAR's flagship coupled climate model at much finer horizontal resolutions than has ever been possible before.



The graph shows average global temperature change scenarios that were computed during the IPCC runs on bluesky. The amber line (20thC freeze) shows the temperature trend associated with no change in current worldwide emissions of anthropogenic aerosols. The other three lines show model predictions for other aerosol emission scenarios.

Strong support by SCD staff allowed the CCSM group to run continuously throughout the experiment period, even during determined hacker attacks. The results of this experiment are now being analyzed by NCAR scientists, and the data are being distributed freely to the global climate change research community in time for the Fourth IPCC Assessment Report.

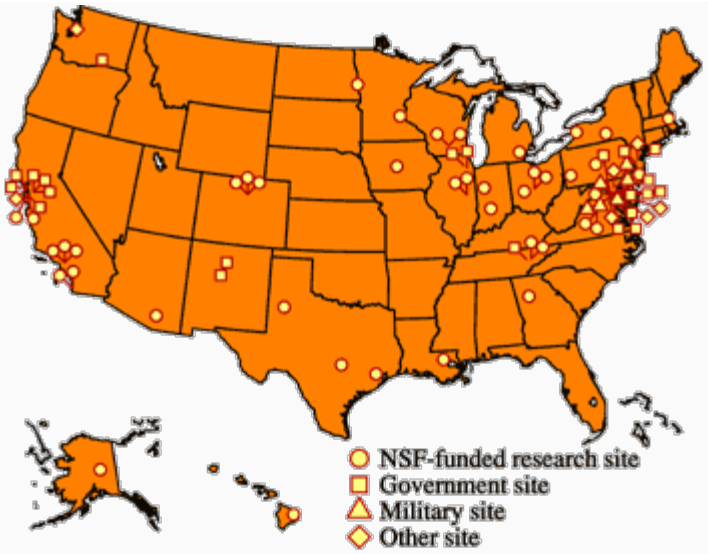
Bluesky contributed over 25 centuries of simulated climate to the IPCC effort -- more than half of all IPCC computing during this campaign. At the conclusion of the IPCC campaign in late FY2004, the 14 new p690 nodes were released to the community to augment SCD's computing capacity for all users. The current aggregate peak capacity of NCAR's supercomputing facility is now 12.1 teraflops distributed across six SMP computers.

Computing Security and Divisional Threat Response

In response to a major cybersecurity incident that involved multiple high-performance computing sites in March 2004, SCD rapidly developed and deployed a long-term solution for protecting the supercomputing and mass storage systems at NCAR. SCD now requires one-time password tokens, arbitrated via encryption devices issued to all users, to access these systems. Security procedures were updated and published to provide all users with guidelines and instructions for working within the secure supercomputing environment.

One of the problems encountered during the March 2004 incidents was a lack of effective communication among the affected institutions. SCD proposed a conference to bring together stakeholders from the nation's research and high-performance computing centers to prepare a coordinated response for future incidents.

With funding from the National Science Foundation (NSF), SCD planned, organized, and hosted a two-day Cybersecurity Summit near Washington D.C. Attended by over 120 cybersecurity experts from some of the nation's leading research institutions, the summit explored the competing needs of having an open, collaborative research environment while protecting the security and integrity of its computing and data assets.



The map shows the locations of the sites participating in the Cybersecurity Summit. This broad-based collaboration aims to coordinate strong response plans for threats against research computing and data.

Cybersecurity Summit 2004 was the first step in laying the foundation for responding to future large-scale security breaches and reducing the disruptive impact of such incidents on the nation's research agenda. These research institutions are increasing their cooperation on security policies, procedures, and incident response to better protect the nation's scientific computing and data resources.

Other areas of significant advancement in FY2004

The Mesa Lab standby generators were commissioned and put into service. These twin generators provide an eight-hour window of emergency power to the NCAR Computer Room as well as the Mesa Lab's life-safety systems in case of electrical outages.

SCD entered the era of Linux cluster computing with the acquisition in FY2004 of a 256-processor e1350 AMD Opteron cluster from IBM. With a peak of 1.1 teraflops, this system outperforms bluesky on a processor-for-processor basis by roughly 40%.

In the area of experimental computer technology, SCD, in collaboration with the University of Colorado, won a $1.2M 2004 MRI grant from the CISE directorate in NSF. This money will be used to acquire a 1024-processor, 5.6-teraflops Blue Gene/L MPP system in FY2005. This system will be used to study the suitability of a variety of scientific applications and algorithms to Blue Gene/L.

SCD released new versions of the MySCD portal that provides, for the first time, customizable GAU charging information directly to our users.

Our Earth System Grid web portal was released in the summer of 2004. Designed for general use by the climate modeling community, it has already played a significant role in the IPCC activities of CCSM by allowing easy access to the latest CCSM data. Users may browse the data catalogs hierarchically, perform searches on metadata, download full files, or subset the virtual aggregated datasets.

Our Network Engineering and Telecommunication Section (NETS) built the local-area networking infrastructure in UCAR's new Center Green Campus, bringing that campus into full compliance with UCAR networking infrastructure standards.

SCD's staff has accomplished many more activities this fiscal year. As you read through this Annual Scientific Report, you will gain a greater appreciation of the level of innovation and support that SCD is committed to provide to NCAR, UCAR, and the greater atmospheric sciences research community. Behind these annual accomplishments is a level of infrastructure support that is literally without peer anywhere in the country. NCAR, as a national discipline-specific center, benefits enormously from the dedication and talented work of SCD's staff who work behind the scenes to ensure a state-of-the-art, balanced, end-to-end computing environment.

As we look forward to implementing SCD's new strategic plan, we reflect here on the accomplishments of this past fiscal

year. As always, we seek to provide the finest in computing, research, data storage, networking, analysis, visualization resources, and user support to help advance the scientific understanding of our physical world.

I invite you to read the overview in the executive summary of SCD's FY2004 accomplishments and the details in SCD's FY2004 Annual Scientific Report.

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Executive Summary

SCD's mission is to serve the computing, data management and research needs of the atmospheric and related sciences. Consistent with this mission, SCD supports a robust, advanced computational infrastructure at NCAR that allows the scientific community to address both national and international research agendas. In anticipation of future needs, SCD also conducts applied research in partnership with NCAR's scientific community in the areas of visualization, networking, computer science, numerical methods and computational science.

Here we discuss our major FY 2004 activities and program highlights that collectively contribute to the advancement of NCAR science across many fronts.

High Performance Computing

In FY2004, Phase III of the current Advanced Research Computing System (ARCS) was delivered to NCAR. This was an expansion of the IBM 1600 cluster (Bluesky) by fourteen, 32-way p690 Symmetric Multi-Processor (SMP) servers, resulting in a net increase of two teraflops in computing capacity. Bluesky is now comprised of 50 POWER4 38 Regatta-H Turbo frames, making it the single largest system of this type in the world.

Working in partnership with the Intergovernmental Panel on Climate Change (IPCC), Bluesky contributed over 25 centuries of simulated climate—over half of all IPCC computing during this campaign. At the conclusion of the IPCC campaign in late FY 2004, a total of fourteen p690 nodes were subsequently released to the community to augment SCD's computing capacity for all users. SCD's current aggregate peak capacity is 12.1 teraflops distributed across six SMP computers.

In July we procured a Linux cluster machine (left) to determine the feasibility of deploying such systems as viable, cost effective supercomputing alternatives. The cluster (an IBM e1350) has 256 processors, each running at 2.2 GHz, and can achieve a peak of 1.1 teraflops. The system is being used to build, test, and evaluate models at NCAR, such as the Community Climate System Model (CCSM) and the Weather Research and Forecasting (WRF) model. Since many of NCAR's university partners who use these models have Linux-based systems, we anticipate that testing and developing these models on a similar system at NCAR will accelerate their distribution to the university community.

This diagram illustrates the configuration of the machine room, as of September 30, 2004.

Finally, we note briefly that SCD's supercomputing resources are comprised of two separate computational facilities: the Climate Simulation Laboratory (CSL) and the Community Computing facilities. Some of our systems (e.g., Bluesky and Blackforest) are shared between these two facilities. This distribution of resources continues to be a major feature of our commitment to both long-running, numerically intensive climate models and highly focused research objectives from our university constituents.

Computing Security and Divisional Threat Response

We collectively manage for NCAR a diverse computational and data storage environment containing high-end computers, mass storage subsystems, data archives, visualization, E-mail, DNS, authentication and web servers, and networks (including IP telephony). Aside from their significant monetary value, they comprise vital scientific research tools and business continuation systems used by the UCAR/NCAR organization and university communities.

In response to a major cybersecurity incident in early 2004, SCD expeditiously developed and deployed a long-term solution for the protection of the supercomputing and mass storage systems at NCAR. The use of one-time password tokens, arbitrated via encryption cards issued to all users, are now required to access these systems. Security procedures were updated and published to provide all users with guidelines and instructions on how to work within the secure supercomputing environment.

Further, with funding from the National Science Foundation (NSF), we convened and hosted a two-day Cybersecurity Summit in late September in Arlington, VA. The summit, attended by over 120 people, aimed at increasing cooperation on cybersecurity among the nation's research and high-performance computing institutions.

Data Archiving and Management: The Mass Storage System (MSS)

Often referred to as one of the "crown jewels" at NCAR, the MSS exceeded two petabytes (PB) of data storage in July 2004. The net growth rate of unique data in the MSS is approximately 30 terabytes per month. The MSS continues to provide a scalable and robust data storage system that meets the data storage requirements of our users.

Our MSS Storage Manager (a new file management server developed in-house that provides connectivity to fiber-channel devices) was enhanced to support StorageTek's 9940B tape drives. They provide more than a threefold increase in capacity over the current 9940A cartridges (60 GB per cartridge increasing to 200 GB per cartridge), and have increased the total capacity of the existing StorageTek robotic tape libraries (silos). They also provide a threefold increase in data transfer rates (from 10 MB/sec to 30 MB/sec).

To assist with capacity planning and performance tuning of the MSS, we developed a simulator that includes all the major hardware and software components of the MSS. The simulator enables the us to consider different design alternatives for new software and hardware components and estimate how the different designs will perform before the components are added to the actual system. Simulation studies were conducted in mid-2004 using an earlier version of this simulator to aid in configuring and sizing the Storage Manager disk cache system.

Initial deployment of 20 StorageTek 9940B tape drives was completed in FY2004. Managed by our new Storage Manager, these drives are servicing the files off-loaded from the disk cache and local system backup files. An additional twenty 9940B tape drives will be installed in early FY2005 and with the expansion of the disk cache. Migration of data (termed "data ooze") will begin in FY2005 to complete the replacement of the 9940A technology.

Computational Science Research

Our computational science staff conducts basic applied mathematical research aimed at developing software for novel, accurate, efficient, and scalable numerical dynamical cores for climate, weather, and turbulence applications.

In FY 2004 we participated in several software infrastructure development projects, each with strong research components:

1. The Spectral Tool Kit (STK) deployed the first software release of this new functionality and began packaging STK functions with the NCAR Command Language (NCL).

2. An NSF-ITR funded project, the Inverse Ocean Modeling (IOM) system for modular ocean data assimilation is composed of these principal activities: continued development and deployment of parallel communication infrastructure needed for IOM and the PEZ ocean model, design and implementation of an observation class for IOM, testing of different parallel execution modes for the IOM system component architecture, and collaboration with Martin Erwig's team at Oregon State University that is using software derived from the Haskell language.

In addition, SCD and the Pittsburgh Supercomputing Center (PSC) collaborated on the Network Path and Application Diagnosis project to help address next-generation Internet performance issues. We will investigate underlying causes of bulk transport protocol limitations and develop and test new mechanisms in high-performance networking environments such as the Extensible Terascale Facility and the Abilene Network of the Future.

Progress on a new NSF ITR award for extending progressive data access techniques to handle time-varying data and irregular data began this year. Staff have started to investigate Open Source user tools based on promising technologies explored under this award.

Development Activities

Work continued on the collaborative Earth System Modeling Framework (ESMF). A much-anticipated release of ESMF software Version 2.0 occurred in July 2004. The ESMF Version 2.0 release includes software for representing and manipulating components, states, fields, grids, and arrays, as well as a number of utilities such as time management, configuration, and logging. It runs on a wide variety of computing platforms, including SGI, IBM, Compaq, and Linux variants.

The Grid-BGC project completed a top-level user interface design, selected a GIS technology for handling maps and geographical information, began implementing Globus protocols; made implementation decisions regarding the software framework; completed "look-and-feel" designs for static and dynamic visualization tools; and performed data transfer and computational capacity testing on existing parallel hardware.

The Earth System Grid (ESG) moved into production mode for climate model research data with dedicated service for IPCC services in the area of coupled climate model data.

Finally, we completed work on the Web100 and NET100 projects.

Computing Center Operations and Infrastructure

Our Operations and Infrastructure Systems (OIS) section is committed to delivering secure, reliable, high-quality, customer-focused services and infrastructure around the clock, 365 days per year.

As part of this committment, in FY2004 we released new versions of the MySCD portal that provides, for the first time, customizable GAU charging information directly to our users. In addition, the SKIL database was upgraded to add "modify-and-delete" functionality.

Two collaborative projects are ongoing with the University of Colorado at Boulder:

1. The METIS event-based workflow system evaluation is nearly complete.
2. A group of CU students are modernizing the UCAR room reservation system.

The continued increase in electric power consumption (and the corresponding need to dissipate heat in the machine room) is beginning to impact the computing facility's infrastructure -- the computer room has reached its maximum cooling capacity. To address this situation, in FY2004 we dealt with near-term needs by augmenting the chilled water capability to match a maximum electrical load of 1.2 MW. We also developed short- and long-term plans to meet the demands of future computing systems. Multiple planning options were articulated, including the option of expanding the data center. The plans for a data center expansion have been presented to the NCAR directorate, the UCAR President's Council, and SCD's Advisory Panel. Presentations will also be made to the UCAR Board of Trustees in October 2004. This work will continue into FY2005.

Additionally, the Mesa Lab standby generators were commissioned and put into service. The twin generators provide an eight-hour window of emergency power to the NCAR Computer Room as well as the Mesa Lab's life-safety systems in case of electrical outages. Some field modifications have been made to simplify the generators' operation.

Other activities of note during FY2004:

- We have assumed after-hours support, setup, and distribution of our secure, one-time password tokens (CRYPTOCards) required by our strengthened security requirements.
- Tape media conversions continue with the move to 200 GB tapes.
- Early in FY2004, computer operators transitioned to a new rotating schedule format to more effectively cover the 7x24 requirements of the data center. This rotating format offers equitable opportunities for each operator to interact more fully with the rest of the division.

- Significant additional responsibilities were added throughout the year, including developing fully documented procedures for managing major SCD services, e.g., e-mail, DNS, Web and VPN services.

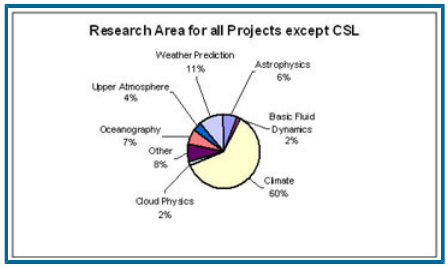
Network Engineering and Telecommunications

Our Network Engineering and Telecommunication Section (NETS) built the local-area networking infrastructure in the new Center Green Campus, bringing that campus into compliance with UCAR networking infrastructure standards. This work included building a fiber link along the bike path from Center Green to the Foothills Lab to interconnect the campuses with UCAR-owned fiber.

We also upgraded local, metropolitan and wide area network (LAN, MAN, and WAN) links to 10Gbps as required. Staff completed wireless service deployment throughout all office areas on all UCAR campuses and installed fiber optic links between our Jeffco and Mesa Lab campuses, replacing leased land services.

Finally, we continue to be an active participant in important regional, state, and municipal projects such as the Front Range GigaPOP, Quilt and Westnet projects.

Assistance and Support for NCAR's Diverse Research Community



Our User Support Section (USS) continued to provide high-level technical support to NCAR's research community via web-based resources, and consultant, phone, and E-mail contacts. A total of 1,529 researchers representing 169 institutions used SCD computing resources during FY2004. Of these 169 institutions, 102 are universities in the U.S.

(Click on the image at left for a larger version of the graphic.)

We helped users in transitioning models and large codes from the SGI Origin 03000 (Chinook) to the IBM 1600 cluster (Bluesky) and in transitioning data analysis jobs from the SGI 02000 (Dataproc) to our new SGI 03800 (Tempest). We worked collaboratively with other divisions to test, document, and resolve user issues for the new IBM Linux cluster (Lightning) that arrived in July 2004. There has also been an increase in training for specific groups of users, starting with Advanced Study Program ((ASP) fellows and SOARS protégés. We continue to provide on-going training on use of the TotalView debugger with a complex code—namely the Community Climate System Model (CCSM).

Revisions to current on-line user documentation as well as new guides for Lightning and Tempest were created and published on the SCD web site. Staff worked to create four new websites in support of SCD, NCAR and UCAR activities, including a secure site for the Cybersecurity Summit 2004. We also participated in a broad-based, UCAR-wide effort to redesign and deploy a new, umbrella web site for NCAR, UCAR, and UOP. The efforts of this Web Outreach, Redesign and Development (WORD) project created a database-driven infrastructure that will continue to transform our overall web presence into a more dynamic, interactive experience.

Finally, we contributed to the successful inauguration of new security procedures for over 1,000 users—following a security intrusion in mid-2004—-by issuing one-time password token cards (CrytoCards) and linking them to individual user's accounts.

Visualization and Enabling Technologies

We were pleased— via our Web Engineering Group (WEG)—to be an integral part of UCAR's Web Outreach, Redesign and Development (WORD) Project. This project involved over 25 staff members from throughout the organization (five from SCD) and was tasked with developing a new UCAR, NCAR, UOP umbrella web site bringing together news and resources from all three institutions into a unified web presence. The site was designed to engage a wide audience of scientists, educators, students and the public alike. The WORD group created a database-driven infrastructure that will continue to transform our web presence into a more dynamic, interactive experience. The new web site was launched in May 2004.

During 2004, we saw major progress in both content and infrastructure for the Community Data Portal (CDP) effort. The portal's metadata architecture was re-engineered to accommodate the new Thematic Realtime Environmental Distributed Data Services (THREDDS) v1.0 specification, which includes information for collection-level search and discovery of datasets. Accompanying that, the portal was equipped with a powerful new user interface for initiating complex searches on distributed metadata catalogs.

Our Earth System Grid web portal was released in the summer of 2004. Designed for general use by the Climate Modeling Community, the portal allows easy access to the latest CCSM (Community Climate System Model) v3 data. Users may browse the data catalogs hierarchically, perform searches on metadata, download full files or subset the virtual aggregated datasets.

This summer, SCD helped two students in the Significant Opportunities in Atmospheric Research and Science (SOARS) program give face-to-face presentations to their peers and mentors — even though they were thousands of miles away.

We continue to maintain and operate several Access Grid (AG) nodes in the division, including the main node in the Vislab as well as a portable node that can be moved, on short notice, to other local meeting facilities. We continued to support AG technology both on site and with our university partners; completing the acquisition and testing of an AG system at Howard University, and successfully integrating an AG system into SCD's conference room.

Our Web Engineering Group (WEG) continued its mission to consolidate web hosting at UCAR in 2004, adding four high-profile NCAR divisions and programs (ESIG—now ISSE, HIAPER, MMM, and HAO). The group completed its configuration of a new back-end cluster that provides core services and hosts dynamic websites. The WEG was instrumental in the WORD group launch of the new UCAR/NCAR/UOP website, creating a metadata management system called VAVOOM that automates the posting of news and other information to the site.

Research Data Support and Services

Our Data Support Section (DSS) manages and curates important research data archives (RDA) containing observational and analysis reference datasets that support a broad range of meteorological and oceanographic research. The archive content continues to grow through systematic additions to the modern collections, by data received from special projects, and from data rescued for historical time periods. The archive—currently over 30 terabytes (TB) in size—is also enhanced by capturing and improving documentation and associated metadata, enforcing a systematic organization, applying data quality assurance and verification checks, and developing access software for multiple computing platforms.

Research efforts have been made easier by providing on-line access to more current data. For example, three main data streams—the Unidata Internet Data Distribution (IDD), the National Center for Environmental Prediction (NCEP) operational observations and final global analysis, and the NCEP/NCAR Reanalysis—have the most recent 90 days and annual time periods maintained on-line. These new services will aid global and mesoscale modeling and time series studies that need readily available, up-to-date data.

The International Comprehensive Ocean-Atmosphere Data Set (ICOADS) issued an update adding 1998-2002 data to the archive that begins in 1784. ICOADS is a two-decade long collaboration with the NOAA Climate Diagnostic Center and NOAA National Climatic Data Center. The observations and monthly summary statistics are now available online and are freely distributed worldwide.

We continue to provide a crucial service in the area of atmospheric data re-analyses. The National Center for Environmental Prediction (NCEP) now runs NCEP/NCAR and NCEP/DOE re-analyses in an operational mode and these products will continue to be archived here within SCD. The European Centre for Medium-range Weather Forecasting (ECMWF) Re-analysis 40 (ERA-40) computation is finished and it provides a T159 (approximately 1.1° resolution) global analysis, four times per day, on 60 vertical levels for the years1957-2002. The complete archive will be available both on-line and from the MSS through data servers and web interfaces. We also received, processed and delivered the new NCEP North America Regional Reanalysis (NARR) in FY 2004. NARR covers the North America domain with a 32 km horizontal resolution eight times per day, with 45 vertical levels for the years 1979-2003.

We have also been capturing and storing dataset and data file metadata in systematically organized ASCII files for the past 20 years. The content of the RDA has been made more visible by extracting basic metadata from the ASCII files and writing a Dublin Core compliant form that has been compiled into Thematic Realtime Environmental Distributed Data

Services (THREDDS) catalogues and hosted on the UCAR Community Data Portal (CDP). This is a first step toward improved data discovery of the RDA within the context of all UCAR data holdings.

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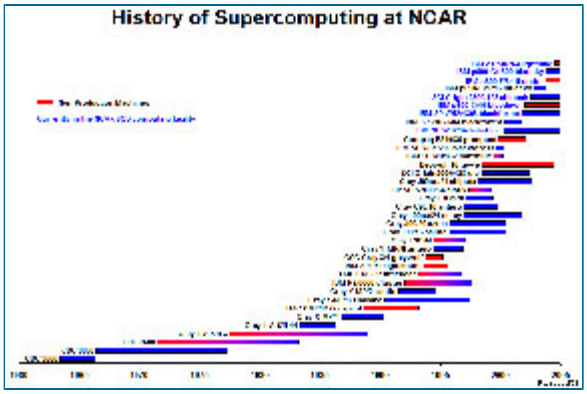
SCD Achievements

High Performance Computing

Maintaining NCAR's production supercomputing environment

The production supercomputer environment managed by SCD for NCAR has evolved over the years. During the last 20 years, SCD has brought NCAR's science into the multiprocessing supercomputer world. Prior to the introduction of the 4-CPU Cray X-MP in October 1986, all modeling was performed with serial codes. Since then, the focus has been on redeveloping codes to harness the power of multiple CPUs in a single system and, most recently, in multiple systems.



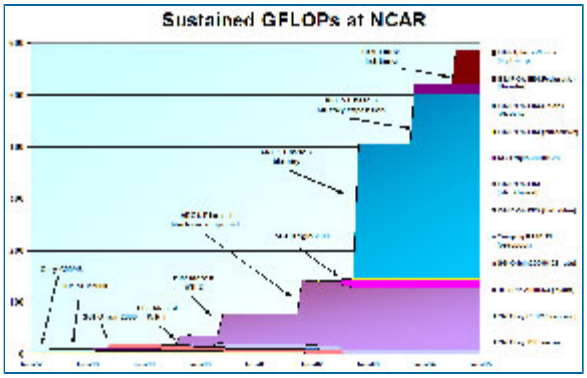
(Click on the image for a larger version.)

Supercomputing systems deployed at NCAR

During the last 20 years, SCD has deployed a series of Parallel Vector Processor (PVP) systems ranging from a 2-CPU Cray Y-MP to a pair of 24-CPU Cray J90se systems. Massively Parallel Processing (MPP) systems included the Cray T3D with 128 processors and the Thinking Machines CM2 and CM5 systems. Most recently, Distributed Shared Memory (DSM) systems have been deployed; these include the Hewlett-Packard SPP-2000, SGI Origin2000, Compaq ES40 cluster, SGI Origin3800, IBM SP POWER3 and POWER4 systems, and now Linux clusters.

The diagram at left shows the systems that SCD has deployed for NCAR's use since its inception. The systems shown with blue bars are those deployed for production purposes, those shown in red were (are) considered experimental systems.

In 1986, with the first multiprocessor system (the Cray X-MP/4) on NCAR's floor, SCD could deliver on average approximately 0.25 GFLOPS of sustainable computing capacity to NCAR's science. In the roughly 20 years since, that sustained computing capacity has grown significantly to over 587 GFLOPS, with a peak capacity of 12.1 teraflops (TFLOPS). The image at right illustrates this trend. (Click on image for a larger version.)



FY2004 production system overview

In FY2004, Phase III of the current Advanced Research Computing System (ARCS) was delivered to NCAR. This was an expansion of the IBM cluster (bluesky) by 14, 32-way p690 SMP servers with each server based on the POWER4 micro-

processor and operating at a clock frequency of 1.3 GHz.

Each server included 64 GB of memory. The system expansion also included 10.5 TB of formatted disk storage, which was added to the existing disk subsystem, thereby increasing bluesky's total disk capacity to 31 TB. Of the 14 servers, only 12 were added to bluesky, the remaining two servers are temporarily being used for a special SCD testbed project. At end-FY2004, bluesky is comprised of 50 POWER4 38 Regatta-H Turbo frames, making it the single largest system of this type in the world.

The 12 additional 32-way P690 SMP servers were used to support CCSM for contributions to the IPCC process, as reported in SCD's Annual Budget Review. The installation of the blueksy system and its subsequent augmentation has doubled the capacities of both the Climate Simulation Laboratory and Community computing.

Further, there were several major system software upgrades performed on all supercomputers.

Supercomputer systems maintained during FY2004

Distributed Shared Memory (DSM) systems:

- SGI Origin2100 (chinookfe), with 8 processors, was used in the Climate Simulation Laboratory.
- SGI Origin3800 (chinook), with 128 processors, was used in the Climate Simulation Laboratory.
- SGI Origin2000 (dataproc), with 16 processors, was used by both Climate Simulation Laboratory and Community users.
- SGI Origin2000 (mouache), with 4 processors, was used as a test platform by SCD for evaluation of new Irix systems, libraries, and compilers prior to their installation on the production SGI platforms; all interested users now have access to mouache.
- IBM SP (babyblue), with 64 processors, was shared by the Climate Simulation Laboratory and the Community.
- IBM SP (blackforest), with 1,308 processors, was shared by the Climate Simulation Laboratory and the Community.
- IBM NightHawk2 (dave), with 16 processors, was shared by the Climate Simulation Laboratory and the Community.
- IBM p690 Regatta (bluedawn), with 16 processors, was used as a test and development platform for the integration of the IBM POWER4 Cluster 1600.
- IBM Cluster 1600 (bluesky), with 1,600 processors, was shared by the Climate Simulation Laboratory and the Community.

New supercomputer systems added during FY2004

DSM systems:

As an element of its five-year strategic plan to aggressively evaluate and deploy potentially more cost-effective new computing technologies, SCD acquired a large-scale Linux-based supercomputer cluster. Following a competitive procurement process, IBM was selected to deliver a 256-processor e1350 Linux cluster. The system, called lightning, was delivered in July 2004 and uses 2.2 GHz AMD Opteron processors, has a peak computational capacity of 1.14 teraflops, 0.5 terabytes of memory, and 7 terabytes of disk. The CAM and POP benchmarks demonstrated that lightning will outperform bluesky by a factor of 1.3 or more on a per-processor basis. This system brought the total computational capacity at NCAR to 12.1 teraflops.

Production system performance and utilization statistics

At the end of FY2004, the production supercomputer environment managed by SCD for NCAR included five IBM supercomputers and four SGI supercomputers. The following tables provide average utilization and performance statistics for the production supercomputer systems SCD operated in FY2004.

In addition, SCD publishes monthly usage reports at http://www.scd.ucar.edu/dbsg/dbs/. These reports provide summary information on system usage, project allocations, and General Accounting Unit (GAU) use.

End—FY2004 production supercomputer systems

The SCD supercomputer resources are comprised of two separate computational facilities: the Climate Simulation Laboratory (CSL) and Community Computing facilities. Some systems, such as the IBM SP systems, the dave system,

and the dataproc system are shared between these two facilities. The following sections describe the supercomputing systems available in these two facilities.

CSL facility:

The Climate Simulation Laboratory facility provided the following supercomputing resources at the end of FY2004:

Climate Simulation Lab facility, FY2004 configuration					
	System	# CPUs	GB memory	Peak GFLOPS	Notes
Dedicated:	IBM SP (blackforest)	560	280	840.0	1,120 total system batch CPUs; 560 dedicated to CSL
Dedicated:	IBM SP (bluesky)	704	1408	3660.8	1,408 total system batch CPUs; 704 dedicated to CSL
Dedicated:	SGI Origin3800 (chinook)	124	64	124.0	124 CPUs dedicated to CSL
Dedicated:	SGI Origin2100 (chinookfe)	8	8	4.0	Front-end system for chinook
Shared:	IBM SP (babyblue)	48	24	72.0	Shared new-release test platform; available for user use
Shared:	SGI Origin2000 (dataproc)	16	32	8.0	Shared with Community for data analysis and post-processing applications
Shared:	IBM NightHawk2 (dave)	16	32	24.0	Shared with Community for data analysis and post-processing applications

Community Computing facility:

The Community Computing facility provided the following supercomputing resources available at the end of FY2004:

Community Computing facility, FY2004 configuration					
	System	# CPUs	GB memory	Peak GFLOPS	Notes
Dedicated:	IBM SP (blackforest)	560	280	840.0	1,120 total system batch CPUs; 560 dedicated to Community
Dedicated:	IBM SP (bluesky)	704	1408	3660.8	1,408 total system batch CPUs; 704 dedicated to Community

Shared:	IBM SP (babyblue)	48	24	72.0	Shared new-release test platform; available for user use
Shared:	SGI Origin2000 (dataproc)	16	16	8.0	Shared with CSL for data analysis and post-processing applications
Shared	IBM NightHawk2 (dave)	16	32	24.0	Shared with CSL for data analysis and post-processing applications

Key maintenance activities

During FY2004, SCD provided ongoing maintenance activities to ensure the integrity and reliability of existing computational systems and improved the quality of service to the NCAR user community. Some of the key areas were:

Maintain supercomputer operating systems
SCD stayed apprised of major software releases from IBM and carefully scheduled upgrades to the production systems and product set software based on the judged stability of those upgrades in the NCAR production environment. SCD also continued to provide major system support for the SGI Origin3800 and Origin2000 systems.

Maintain stability and reliability of systems
One of the most significant attributes of the NCAR computational environment is its overall stability and reliability. For instance, the NCAR Mass Storage System has a reputation for reliability, and SCD has in the last year deployed a number of high-availability fileserver systems. This reliability and stability does not come easily; it stems from a combination of choosing reliable, stable vendor products and using proven, fail-safe system administration and maintenance techniques. SCD will continue to focus on ensuring, in whatever ways possible, highly stable and reliable systems and systems operations.

System monitoring
Over the years, SCD has developed a large number of system monitoring procedures, techniques, and tools. SCD continued to enhance and utilize its collective experience to maintain the stability of the existing production systems through this proactive monitoring. In addition, SCD continued to enhance its monitoring tools, techniques, and procedures, and SCD automated a number of procedures for detecting system failure or trouble. This automation was integrated with commercial alphanumeric paging technology to provide more rapid alert mechanisms to SCD operations and systems staff and thus reduce the amount of time that systems are unavailable to the NCAR user community when they do fail.

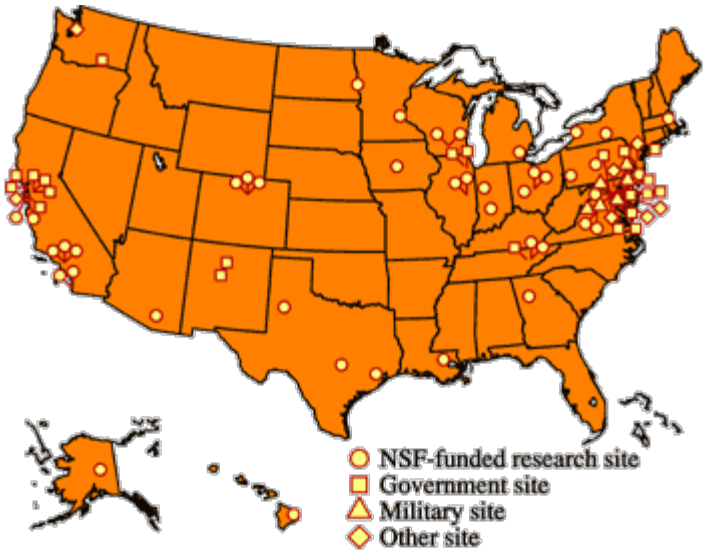
Computer Security and Divisional Threat Response

SCD manages a diverse computational and data storage environment containing high-end computers, mass storage subsystems, data archives, visualization, e-mail, DNS, authentication and web servers, and networks (including IP telephony). Not only are these systems valuable monetarily, they comprise vital scientific research tools and business continuation systems used by the UCAR/NCAR organization and university communities.

In response to a major cybersecurity incident that involved multiple high-performance computing sites in March 2004, SCD rapidly developed and deployed a long-term solution for protecting the supercomputing and mass storage systems at NCAR. SCD now requires one-time password tokens, arbitrated via encryption devices issued to all users, to access these systems. Security procedures were updated and published to provide all users with guidelines and instructions for working within the secure supercomputing environment.

One of the problems encountered during the March 2004 incidents was a lack of effective communication among the affected institutions. SCD proposed a conference to bring together stakeholders from the nation's research and high-performance computing centers to prepare a coordinated response for future incidents.

With funding from the National Science Foundation (NSF), SCD planned, organized, and hosted a two-day Cybersecurity Summit near Washington D.C. Attended by over 120 cybersecurity experts from some of the nation's leading research institutions, the summit explored the competing needs of having an open, collaborative research environment while protecting the security and integrity of its computing and data assets.



The map shows the locations of the sites participating in the Cybersecurity Summit. This broad-based collaboration aims to coordinate strong response plans for threats against research computing and data.

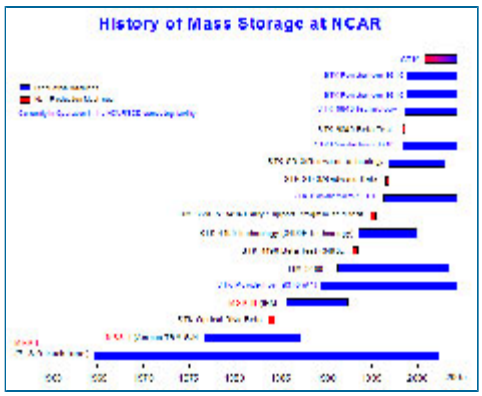
Cybersecurity Summit 2004 was the first step in laying the foundation for responding to future large-scale security breaches and reducing the disruptive impact of such incidents on the nation's research agenda. These research institutions are increasing their cooperation on security policies, procedures, and incident response to better protect the nation's scientific computing and data resources.

Data Archiving and Management: The Mass Storage System (MSS)

The NCAR Mass Storage System (MSS) is a large-scale data archive that stores data used and generated by climate models and other programs executed on NCAR's supercomputers and compute servers. At the end of FY2004, the NCAR MSS managed stored data exceeding 25 million files of over 1,247 unique terabytes (TB), and the total holdings exceeded 2,149 TB (2.1 petabytes) when including duplicate copies. The net growth rate of unique data in the MSS was approximately 30 TB per month.

On average, 160,000 cartridges are being mounted each month, approximately 1% (1,000) of these by operators and 99% in the StorageTek Powderhorn Automated Cartridge Subsystems (ACS). The StorageTek Powderhorn ACS systems (also called "silos") use robotics to mount and dismount cartridges. On a daily basis, the MSS handles approximately 41,000 requests resulting in the movement of over 3,900 GB of data. During FY2004, data transfers servicing user requests to and from the MSS exceeded 1,400 TB.

While some of the data stored on the NCAR MSS originate from field experiments and observations, the bulk of the data is generated by global climate-simulation models and other earth-science models that run on supercomputers. SCD therefore faces an increasing demand to archive the data generated by increasingly more powerful supercomputers. As supercomputers become larger and faster, they generate more data to be archived. Ever-greater demands for archiving data will result from the growing use of coupled atmospheric/oceanic simulation models.



MSS history

The NCAR Mass Storage System has evolved over the last 18 years. Prior to late 1989, mass storage at NCAR was comprised strictly of offline, manual-mount media. In November 1989, the first STK Powderhorn "silo" was acquired, commencing a new era of mass storage at NCAR. The following figure illustrates the various technologies that have been used to store critical datasets throughout NCAR's history.

(Click on the image at left for a larger version.)

During FY2003, the NCAR Mass Storage System grew from 20,340,049 files with a total of 880 unique TB to 25,121,621 files with a total of 1,247 unique TB. Total holdings grew from 1,500 TB (1.5 PB) to over 2,149 TB (2.149 PB) This was an average net growth rate of 30 unique TB (60 total TB) per month during FY2004.

The MSS Today

MSS Access Methods

During FY2004, the technology used to access MSS data continued to undergo substantial change. A migration is underway from the use of the older, non-commodity, High Performance Parallel Interface (HiPPI) technology to the use of Gigabit Ethernet (GigE) and Fibre Channel (FC) technologies.

The HiPPI technology provides direct storage-device access via the High-Performance Data Fabric (HPDF). The data fabric consists of HiPPI channel interfaces to host computers, non-blocking HiPPI switches capable of supporting multiple bi-directional 100 MB/sec data transfers, and protocol converters that connect the HiPPI data fabric to the IBM-style device control units. To utilize the HPDF, SCD staff wrote a file transport type of interface to enable users to copy files between their host systems and the MSS. At the end of FY2004, the HPDF data fabric supports 12 independent file transfer operations between the tape devices and the compute servers sustaining 10 MB/sec each, for an aggregate total of 120 MB/sec.

HiPPI technology continues to be deployed only in a niche market. It has not shown signs of spreading into the commodity marketplace, and as a result the cost of HiPPI technology has remained high and the number of HiPPI vendors is small. The lack of availability of and support for HiPPI technology is becoming a critical issue to the continued operation of the MSS.

To alleviate these issues, SCD staff wrote the UNIX-based Storage Manager (STMGR), which replaces the HPDF as the method used to access data by host systems. STMGR isolates the client host systems from directly accessing the storage devices, simplifying the code SCD has to write and maintain for each type of host operating system. It also eliminates the need for HiPPI channel interfaces and device drivers on the client hosts. In place of HiPPI, commodity TCP/IP networking is used to access STMGR from the client host systems. Client host systems can use any available network interface at any speed to access files on the MSS. Currently, when using GigE, data rates in the range of 30-60 MB/sec are easily achievable with recent computer hardware. Using high-speed Ethernet as the client system interconnect means that future deployment of higher-speed GigE will automatically raise the capacity of the client system interconnect.

The use of UNIX systems for STMGR allows SCD to deploy the latest storage hardware and software technologies to manage MSS data. STMGR server systems initially use a FC Storage Area Network (SAN) to access RAID and tape drives via a high-reliability switch. Fibre Channel is currently available in versions that support either approximately 100 MB/sec or 200 MB/sec bidirectionally. Multiple FC connections may be made between STMGR servers and storage devices, and aggregate I/O rates approaching 1 GB/sec are possible with commodity components on a single STMGR server. The use of FC RAID plus journalling file systems allows STMGR to improve the robustness and flexibility of the disk cache. Also, MSS administrators can have STMGR reallocate resources between disk cache partitions or add space to disk cache partitions on the fly without interruption to MSS clients.

Near the end of FY2003, STMGR was placed into production as a replacement for the old IBM 3390 disk farm. The old disk farm could store approximately 180 GB, was used to buffer files that were smaller than 15,000,000 bytes long, and supported an aggregate transfer rate of 12 MB/sec. During the initial deployment, the STMGR disk cache stores approximately 500 GB and supports an aggregate transfer rate approaching 120 MB/sec. During FY2004, the STMGR disk cache was increased to approximately 8 TB to buffer files up to 50 MB in size. In FY2005, the STMGR disk cache will grow to approximately 60 TB, will buffer files of all sizes, and will support an aggregate transfer rate approaching 400 MB/sec. A disk cache of this size will permit newly written files to reside in the cache longer, which will reduce the number of tape mounts and tape I/O. STMGR will also, with further improvements in MSS software, allow better tape utilization by allowing files with differing storage requirements to be segregated on separate tape media. Both of these improvements will reduce the total number of tape drives that will be required to support the aggregate data rates between the MSS and the client host systems.

Also during FY2004, the use of HiPPI was reduced for newly written tape files when STMGR assumed the role of providing tape access. HiPPI can then be decommissioned in FY2005 once all data has oozed off the StorageTek 9840A media. New tape devices, such as the StorageTek T9940B Fibre-Channel-attached drive, store up to 200 GB and support I/O rates in the neighborhood of 30 MB/sec. This will be an improvement of 3 times in both storage density and transfer rate over the current tape devices. These improvements will allow the MSS to expand into the multi-petabyte range while reducing the latency to access MSS files.

MSS Storage Hierarchy

The NCAR MSS currently uses two levels of storage: online and offline. The most frequently accessed data are kept on the fastest storage media, which is the online storage devices: 8 TB of Fibre Channel RAID storage, and five StorageTek Powderhorn ACSes. The Powderhorn ACSes use StorageTek 9840A and 9940A, as well as StorageTek 9940A technology. Currently, the NCAR MSS has five ACSes providing a total online capacity of approximately 2 petabytes. The total capacity of the online archive will exceed 6 petabytes utilizing 9940B 200 GB cartridges.

Expansion of the MSS storage hierarchy is planned over the next five years with the introduction of new tape technologies, new ACSes, and with the integration of a multi-terabyte disk farm cache. Simulations of the MSS workload indicated that a 60-TB disk farm cache can reduce the amount of tape readback activity by as much as 60%. The disk farm cache would not only reduce the number of tape drives required in the system but also provide a much-improved response time to read and write requests. In addition, the MSS Group will continue to evaluate hardware and software solutions being developed by vendors throughout FY2005 and how they might be integrated into the NCAR MSS.

MSS Import/Export Capability

Another important capability of the NCAR MSS is the ability to import and export data to and from external portable media. Importing data involves copying data from portable media to the MSS data archive, while exporting data involves copying data from the MSS data archive to portable media. Import/export allow users to bring data to NCAR with them, as well as take data away. Import also allows data from field experiments to be copied to the NCAR MSS archive.

Options to exchange data with smaller satellite storage systems are being investigated. Using this technique, data generated at NCAR could be transferred to remote sites for further analysis. The NCAR SCD storage model would thus be geographically distributed, rather than centrally located and administered.

In addition to 3480 and 3490E cartridge tapes, the NCAR MSS also offers import/export to single and double-density 8mm Exabyte cartridge tapes. The deployment of an MSS-IV Import/Export server in FY2000 provided the ability to support many more device types, such as CD-ROM, DAT, and newer Exabyte media, to name a few.

MSS Accomplishments for 2004

Disk farm cache simulator

To aid capacity planning and performance tuning of the MSS, a simulator that includes all the major hardware and software components of the MSS was developed in 2003. The simulator enables the MSS group to consider different design alternatives for new software and hardware components and estimate how the different designs will perform before the components are added to the actual system. Simulation studies were conducted in 2004 using an earlier version of this simulator (that only simulated the disk cache component of the MSS) to aid in configuring and sizing the STMGR disk cache system.

In addition, simulator output was combined with MSS warehouse information to help measure the effectiveness of external data caches which were deployed to avoid rereading data from the MSS, thus avoiding the abuse of a data archive as a file server. The external cache deployment resulted in as much as a 60% drop in such re-reads.

StorageTek 9940B Technology

Initial deployment of 20 StorageTek 9940B tape drives was completed in FY2004. Managed by the STMGR, these drives are servicing the files offloaded from the disk cache and local system backup files. An additional 20 9940B tape drives will be installed in early FY2005, and with the expansion of the disk cache, a data ooze will be started in FY2005 to replace the 9940A technology.

User Education

As a result of the SCD-held user forum on computing issues, MSSG compiled for SCD's Consulting Office a short list of do's and don'ts regarding the NCAR Mass Store to help guide users toward efficient and proper use of the MSS.

New MSS Hosts

The IBM eSeries Linux Cluster, named lightning, was provided with Mass Store connectivity in 2004.

MSS Growth

NCAR Mass Storage System growth during FY2004 increased over FY2003. Average net growth rate during FY2003 was 27 TB per month, whereas the average net growth rate during FY2004 was 30 TB per month. This increase in the growth rate can be attributed to several factors, such as new MSS hosts coming online, increased amounts of local disk storage on several machines (which increases the size and number of MSS backup files), the IPCC initiative, and 14 computing nodes added to the IBM POWER4 cluster (bluesky). Further increases in the net growth rate are expected in FY2005 with the addition of two Linux clusters in early FY2005. Projecting this growth into the future, it is not difficult to realize that new storage paradigms and user education will be required, since without this the growth in just three to five years will be untenable.

The following table compares year-end statistics for FY2000 - FY2004.

Mass Storage System Growth Statistics					
	eFY2000	**eFY2001**	**eFY2002**	**eFY2003**	**eFY2004**
Total storage unique bytes (TB):	273	379	519	880	1,500
Total files (millions):	8.3	10.9	14.4	20.3	25
Net growth (unique bytes TB per month) at eFY:	5.2	10	13.3	27	30
Data read/written (TB per month):	25	37	49	83	118
Data migrated internally (TB per month):	25	74	68	83	90
Manual tape mounts (number per month):	18,000	10,000	11,000	6,800	1,000
Robotic tape mounts (number per month):	54,000	95,000	110,000	123,200	160,000
Offline cartridge count:	142,000	126,000	70,000	20,000	24,000
Sustained GFLOPS on NCAR computing floor:	~75	~75	~140	~388	~500

Future Plans for the MSS

Key issues to be addressed over the next four years include:

- Managing data growth and integrating new storage technologies to keep pace with the projected growth in computing power, finding ways to reduce the MSS growth.
- Providing web-based MSS tools and interfaces to handle the unique problems of large-scale MSS file management and folding at least some of these into the SCD Portal.
- Develop Quality of Service metrics from warehoused and other data to measure and report system performance.
- Explore possibilities for collaborative research topics pertinent to the management and performance of large-scale data systems.

- Implementing a multi-terabyte "internal" disk farm cache to be positioned in front of the MSS tape archive to improve overall response time and reduce tape traffic substantially.
- Integrating multiple "external" disk caches to further reduce the load on the MSS and pave the way for a global, shared front-end fileserver.
- Deployment of a new Metadata Server to replace the Master File Directory (MFD). The new Metadata Server will use a commercial database with the capability of scaling beyond the limitations of the current MFD.
- Warehouse ongoing MSS performance data for subsequent accounting, analysis, and reporting.
- Investigating solutions to address disaster recovery.
- Use the newly developed MSS simulator to aid in capacity planning and performance tuning of the system.

Computational Science Research

CSS's mission is to help realize the end-to-end scientific simulation environment envisioned by the NCAR Strategic Plan. To this end CSS's role is to benchmark and evaluate computer technology, learn to extract performance from it, pioneer new and efficient numerical methods, create software frameworks to facilitate scientific advancement, particularly through interdisciplinary collaborations, and share the resultant software and findings with the community through open source software, publications, talks, and websites.

Applied Computer Science Research Activities

In 2004, CSS-applied computer science efforts have centered on three activities: studying experimental, massively parallel architectures such as Blue Gene/L; benchmarking and evaluating Linux clusters as part of an SCD procurement; and porting applications to Linux-Itanium systems as part of the Gelato Federation.

Blue Gene/L Application Research

IBM has developed a novel, low power, densely packaged, massively parallel computer system called Blue Gene/L. Each node of Blue Gene/L consists of dual PowerPC 440 cores running at 700 MHz. Each core is capable of two floating multiply-adds per clock cycle, and 1,024 nodes can be packed into a single 19-inch rack. Thus a single rack of Blue Gene/L processors has a peak speed of 5.6 teraflops. This is achieved while consuming about 15 kW of electrical power, a tiny fraction of that consumed by conventional massively parallel systems. Apart from its low power and dense packaging, Blue Gene/L has several interesting architectural characteristics, for example a dedicated tree reduction and synchronization network, as well as a toroidal interconnect.

Figure 1: 512 nodes (1,024 processors) of an IBM BlueGene/L system (photograph courtesy of IBM Research).

In 2004, scientists in CSS, in collaboration with researchers from CU-Denver and CU-Boulder, submitted a proposal to the NSF's Major Research Infrastructure program. The objective was to acquire a 1,024-node Blue Gene/L system to study the performance of scalable applications on it, and to evaluate its production capabilities. This proposal was recently funded by the NSF, and SCD is currently in negotiations with IBM to obtain a Blue Gene/L supercomputer for evaluation. The system will be used for high-resolution studies of moist physical processes, employing the cloud-resolving convection parameterization (CRCP). Because of its scalability, the primitive equations dynamical core for these studies of CRCP physics will be the section's prototype spectral element model, HOMME. Throughout the past year, members of CSS, working closely with IBM computer scientists, have been benchmarking a 512-node Blue Gene/L prototype located at IBM's T.J. Watson Research Center. The benchmarks have been chosen to measure the system's performance on key algorithms drawn from our proposed atmospheric science projects. All-to-all, point-to-point, and global reduction communication benchmarks have been used to measure the capabilities of the Blue Gene/L's networks, and prototype CRCP physics packages have been ported and optimized.

Benchmarking, Porting and Performance Modeling Activities

CSS has also been extensively involved in evaluating and benchmarking clusters for the recent procurement by SCD of a 256-processor Linux-based system. This procurement resulted in the acquisition of an Opteron/Myrinet Linux cluster, which achieved performance levels 1.3-1.4 times higher than an equivalent number of IBM 1.3-GHz POWER4 processors. In 2004, CSS performed extensive testing and evaluation of the IBM "Federation" interconnect.

CSS has continued to expand its engagement with computer science students. Dr. Henry Tufo in CSS has played a key role in exploiting this opportunity by leveraging his joint appointment as a Computer Science professor at the University of Colorado to involve four graduate students in NCAR research problems. Students of Dr. Tufo are working in the areas of application porting and tuning, Linux cluster system administration, and Grid computing applications. CSS staff also provided technical support to computer science students in a course taught by John Halley at the University of San Diego, in which NCAR applications were ported to a variety of platforms.

Gelato Membership

The Itanium very long instruction word (VLIW) architecture represents an important departure from the traditional superscalar RISC microprocessor and CISC-like Pentium architectures used in the geosciences departments at most universities today. Since the VLIW relies on the compiler rather than on-chip circuitry to extract parallelism from the instruction stream, developing robust optimizing compilers for Itanium is critical. As Itanium microprocessors become plentiful in the geosciences community, access to reliable compilers, ported modeling applications, and open-source high-performance mathematical libraries optimized for this architecture enable scientific progress on Itanium Linux

systems.

In the past year, CSS's role as a member of the Gelato Federation, an organization devoted to the advancement of the Linux-Itanium technical solution, has been to "beta test" the Intel Fortran and C++ compilers on the Intel Itanium and Itanium-2 processors by porting and tuning a variety of applications, such as CAM2 and MM5 to this platform. In this capacity, CSS has closely collaborated with SGI to port CCSM to the Altix (Itanium-based) shared-memory architecture. As a result, CCSM has recently been validated and has successfully demonstrated exact restart capability on this platform.

Applied Mathematics Research Activities

The research activities of the Computational Science Section (CSS) at NCAR are focused on three broad goals. First, work sponsored by the Department of Energy's Climate Change Prediction Program (CCPP) is developing a new generation of accurate, efficient, and scalable general circulation models, based on high-order methods and suitable for use by the atmospheric research community. To this end, CSS has conducted applied mathematical research, tested novel numerical algorithms using the standard test cases of the atmospheric science research community, and has created efficient software implementations of these algorithms.

CSS has also been working to integrate two physics packages into these models: the physics in the Community Atmospheric Model Version 2 (CAM2), recently used for IPCC simulations as a component of the Community Climate System Model (CCSM) (Blackmon, et al. 2001), and a Cloud Resolving Convective Parameterization (CRCP) sub-grid scale physics scheme acquired through a collaboration with the Cloud Dynamics Group in the MMM division at NCAR.

New Semi-Implicit Implementation

In 2004, CSS completed re-implementing a semi-implicit time step for the spectral element primitive equations. As before, the 3D governing primitive equations were specified in curvilinear coordinates on the cubed sphere combined with a hybrid pressure vertical coordinate. The new non-staggered formulation eliminates the interpolation for nonlinear terms that caused problems for the staggered semi-implicit during year seven of our research. The new dry dynamical core, based on a non-staggered weak formulation, has been validated using the standard 1,200-day Held Suarez test problem.

The semi-implicit solver of this model is based on vertical eigenmode decomposition and an iterative conjugate-gradient elliptic solver. In tests, the performance of the solver has been greatly improved using a simple preconditioner proportional to the determinant of the metric tensor. The vertical eigenmode with the largest velocity is the last to converge and effectively controls the rate of integration. To be useful, the longer time-step allowed by the semi-implicit method must overcome the additional cost of the Helmholtz solver. Preliminary tests indicate that the semi-implicit integration rate is at least three times faster than the explicit spectral element dynamical core on a single processor. Scalability tests of the new formulation are planned for later in 2004.

Adaptive Mesh Refinement of Non-conforming Spectral Elements

Year 2's success rests on the outstanding work of Amik St-Cyr and John Dennis, two very promising young scientists at NCAR. In the past year they successfully developed and implemented a multi-level AMR version of the section's spectral element dynamical core. This is a fully parallel code based on the geometrically non-conforming SEM of Kruse and Fischer combined with a novel tree management strategy for AMR on the cubed-sphere called HAMR (HOMME AMR). Time-stepping restrictions caused by refinement are partially alleviated by employing the novel nonlinear operator integration factor splitting (OIFS) scheme of Thomas and St-Cyr. (As an added benefit, the resulting 3D equations are well-posed under AMR as OIFS does not require local time-stepping.) Our refinement/de-refinement technology is based on the error estimator work for spectral element methods of C. Mavriplis. Though validation testing is not complete the current release of the code has been validated on several of the shallow water test cases of Williamson, in particular test case 5. Other highlights of year 2 include numerous journal publications, conference presentations, and the involvement of several CU graduate students in the project.

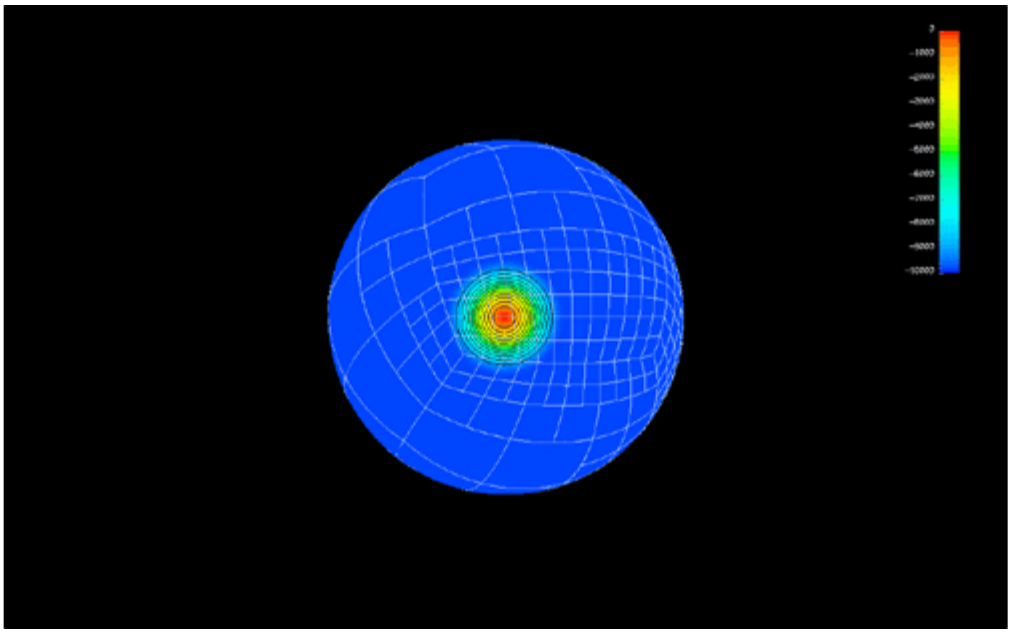


Figure 2: Adaptively refined non-conformal spectral elements tracking a cosine bell test shape in shallow water equations.

After investigating the currently available packages to support AMR, the decision was made in September 2003 to build our own package to support AMR on the cubed-sphere. Using the static non-conforming code developed in year 1 as a guide, an entirely new AMR implementation was developed for HOMME. The HOMME AMR implementation (HAMR) is based on the TFS communication library of Tufo. TFS is a scalable direct stiffness summation package with low setup cost. It uses unique global IDs to pair shared degrees of freedom in a distributed environment. HAMR is designed around the concept of a distributed graph, while a lightweight bit-shifting tree algorithm is used to maintain inheritance properties among the spectral elements. The topology of the cube-sphere necessitated that a minimum of six separate trees, one tree for each face of the cube, be maintained along with the connectivity information between each tree. Because of the unavoidable need for graph management, it was decided that all spectral element connectivity information be maintained in graph form (versus tree form). This decision allows for an arbitrary select of the underling base grid. The distributed graph is updated each time a spectral element is refined or coarsened. Local graph query functions are used to set the proper global degree of freedoms for the TFS library. HAMR has been demonstrated in parallel to support both refinement and coarsening for multiple levels of refinement and achieves load-balancing via element migration.

In 2003, St-Cyr and Thomas developed a novel time-stepping scheme to ameliorate the time-step restrictions encountered under AMR and to maintain well-posedness of the 3D equation set. Merging the OIFS time-stepping required major revisions to the Krylov solvers, as generation of the preconditioning matrices on the fly is non trivial. In addition, HOMME implementation was generalized to remove unnecessary edge rotations. In the earlier version, a special treatment of vector quantities was necessary when on an edge of the cubed sphere. This change was necessary to use TFS library for the direct stiffness summations. The inter-element trace matching is generalized, and the masks necessary to eliminate doubled corner contributions are generated automatically.

As stated earlier, the OIFS time-stepping approach needs more aggressive preconditioning techniques. Martin J. Gander is collaborating with the team to determine whether an optimized Schwarz preconditioner can be used in the P_N - P_N (non-staggered) version of HOMME. Recent results obtained by Gander and St-Cyr include a proof that changing the preconditioning matrices in the Dryja-Widlund form of the additive Schwarz procedure leads to the optimized iterates. This result will help the community in accepting these novel preconditioning techniques.

Integration of Spectral Element Dynamics with CAM Physics

In 2004, CSS began Integrating HOMME explicit dynamics with CAM physics from version cam_2_0_2_dev69. The API between the dynamics and the CAM physics and the necessary CAM program management units was identified. Inconsistencies and incompatibilities with respect to the grid structures were identified and resolved. Most issues related to the initialization of an "Aqua Planet" [Hyashi86] experiment have also been resolved.

Integration of Cloud Resolving Convective Parameterization (CRCP) with CAM Physics

In FY2004, work began interfacing a Cloud-Resolving Convection Parameterization (CRCP; a.k.a. super parameterization; Grabowski Smolarkiewicz 1999; Grabowski 2001, 2003) with the HOMME dynamics. CRCP is a novel

technique for representing clouds in atmospheric models. The idea is to embed a 2D cloud-resolving model in each column of a large-scale model to represent small-scale and mesoscale processes. Khairoutdinov and Randall (2001) have tested this approach in the Community Climate System Model (CCSM). A stretched vertical coordinate has recently been implemented in the CRCP code, facilitating direct coupling to a pressure vertical coordinate.

Conservative Advection using Discontinuous Galerkin Method

The Discontinuous Galerkin (DG) Method is a hybrid of finite-element and finite-volume methods, and it provides a class of high-order accurate conservative algorithms for solving nonlinear hyperbolic systems. This method is known for being highly parallelizable and the for being able to capture discontinuity of the exact solution without producing spurious oscillations.

In FY2004, a DG conservative transport scheme has been developed on the cubed-sphere (Nair 2004). This scheme has been further extended to a nonlinear flux-form shallow water model (SW) in curvilinear coordinates on the cubed-sphere. The spatial discretization employs a modal basis set consisting of Legendre polynomials. Fluxes along the element boundaries (internal interfaces) are approximated by a Lax-Friedrichs scheme. A third-order total variation diminishing Runge-Kutta scheme is applied for time integration, without any filter or limiter. The model has been evaluated using the standard SW test suite proposed by Williamson et al. (1992). The DG scheme shows exponential convergence for shallow water test case 2 (flow over a mountain). The DG solutions to the shallow water test cases are comparable to that of a standard spectral-element model. Even with high-order spatial discretization, the solutions do not exhibit spurious oscillations for the flow over a mountain test case. However, a spectral-element model or a global spectral model produces spurious oscillations for this particular test.

The model conserves mass to the machine precision. Although the scheme does not formally conserve the global invariants such as total energy and potential enstrophy, these quantities are better preserved than in existing finite-volume models. Currently, the DG transport scheme is being implemented in the NCAR/SCD High-Order Multiscale Modeling Environment (HOMME).

Radial Basis Functions (RBFs)

CSS has been focusing on two areas of research within RBFs. The first is examining the interpolation properties for oscillatory Bessel RBFs: these are an entirely new group of RBFs with interesting properties. For example, it has been shown very recently that pseudospectral (PS) approximations are just a subclass of RBF approximations in the flat basis function limit, i.e. as the parameter that controls the shape of the RBF goes to zero. Not only do oscillatory Bessel RBFs possess unconditional nonsingularity of the interpolation matrix for any scattered node distribution, but they are the only class of RBFs immune to divergence of the interpolant in the limit that the shape parameter goes zero. To further explore the relationship between PS and RBF approximations, it is important to understand the accuracy of oscillatory Bessel RBF interpolation in multi-dimensions. Dr. Natasha Flyer in CSS has proven in one-dimensional space that an oscillatory Bessel RBF expansion on an infinite lattice will exactly reproduce an n-dimensional polynomial of any order. She has gone on to provide an extension of the proof to arbitrary n-dimensional space. This is a great leap forward in RBF theory, as this is the only class of RBF functions known to possess this property. Dr. Flyer is working with Dr. Elisabeth Larsson of Uppsala University to extend this result to scattered node locations rather than a lattice.

The second RBF research area is to develop a theory applicable to spherical geometries. The importance of this research is to develop a new grid-free approach using RBFs to solve time-dependent PDEs in spherical domains. Such an approach is singularity free (due to its independence of any surface-based coordinate system), spectrally accurate for arbitrary node locations on the sphere, and naturally permits local mesh refinement. No other discretization method currently in use in spherical geometries can attest to these properties.

Modeling Solar Coronal Mass Ejections

The CSS collaboration with HAO studying Coronal Mass Ejection involves three related efforts. The first project is to extend recent results related to magnetic-field confinement in the solar corona. The second project, with Mei Zhang of the Chinese Astronomical Observatory, is to show that there is an upper bound on the amount by which the total magnetic energy in the force-free field for a dipole field configuration can exceed the Aly limit, which is defined by the amount of energy needed to completely open the solar magnetic field (i.e. have one end of a line of force anchored to the sun and the other running out to infinity). Dr. Flyer in CSS has been able to show numerically that not only does such a bound exist, but that it is 8.33%. This number has been guessed by some physicists in the field, but never before verified either numerically or analytically. The last project is to solve the hydromagnetic equations describing magnetic fields in realistic three-dimensional geometry, both in the force-free state and in force balance with plasma pressure and gravity. The general 3-D case is far more demanding computationally, featuring four coupled PDEs in three space dimensions, and is the subject of a recent CSS proposal submitted to NASA. This will be a cross-collaborative effort with HAO, CU-Boulder, and University of Wisconsin-Madison.

Shallow Water Flows Develop Singularities on the Sphere

In 2004, research demonstrating that certain shallow water test cases on a non-rotating sphere develop singularities was completed, and a paper on this topic has been accepted for publication [Swarztrauber 2004].

Development Activities

CSS development activities are aimed at providing modeling frameworks and mathematical libraries that support the research community's efforts to create portable and efficient models and scalable and efficient post-processing tools.

Earth System Modeling Framework

The Earth System Modeling Framework (ESMF) is building software infrastructure for climate, weather, and data assimilation applications. Collaborators include NCAR SCD, CGD, and MMM, NOAA GFDL, NOAA NCEP, MIT, the University of Michigan, DOE ANL, DOE LANL, and NASA/GSFC GMAO. The project is organized around a series of 11 milestones, the first five of which were submitted during FY2002 and FY2003.

The sixth and seventh ESMF milestones, submitted during FY2004, marked the public release of Version 2.0 of the ESMF software, the demonstration of three interoperability experiments using the framework, and the Third ESMF Community Meeting held at NCAR in Boulder, Colorado on July 15, 2004. The day-long Community meeting included a discussion of features in the release, a brief tutorial on adopting ESMF, and presentations describing how ESMF has been used to create applications from existing components developed at GFDL, MIT, NCEP, NASA and NCAR. ESMF Version 2.0 code and documentation can be downloaded from the ESMF website, http://www.esmf.ucar.edu/

The ESMF Partners and active collaborators list expanded to include groups at the DOD Naval Research Laboratory and the DOD Air Force Weather Agency, as well as existing partners at the Goddard Institute for Space Studies, UCLA, the Center for Ocean-Land-Atmosphere Studies, and the NASA GSFC Land Information Systems project. ESMF continues to coordinate with the European Programme for Integrated Earth System Modeling (PRISM) and the DOE Common Component Architecture (CCA) projects.

Spectral Toolkit Development

Work developing high-performance portable, highly efficient, open source numerical libraries for use by the mathematical and geosciences communities made steady progress in first part of FY2004, but this effort slowed later in the year due to staff hour cutbacks in this area to support CRCP physics integration activities.

In particular, development of the Spectral Toolkit library continued with the completion of the multithreaded spherical harmonic transform. Also developed were new distributed memory (MPI-based) 2D and 3D FFTs, using a generic pairwise generic transpose algorithm developed for the library. To date, completed components of the Spectral Toolkit include:

- General mixed radix real and complex FFTs that are highly portable and among the fastest available.
- Complex number class and operators that enable very efficient native complex arithmetic comparable to Fortran.
- Multithreaded 2D and 3D real and complex FFTs scalable on both dual processor workstations and large enterprise-class servers.
- Distributed 2D and 3D real and complex FFTs that enable scalable transforms on clusters using unique generic pair-wise transpose.
- Multithreaded spherical harmonic transform that uses recurrence relations for spherical harmonics for small memory footprint, along with cache-blocked matrix multiplication for efficient multiple-instance transforms.
- Associated Legendre function accurate evaluation at arbitrary points for generating spherical harmonic or spectral element reference points.
- Gaussian quadrature very accurate Gauss-Legendre quadrature that provides high-resolution grids without requiring quad precision, also includes Gauss-Lobatto points and weights for spectral element grids.
- Multidimensional generic array allocation that provides very efficient multidimensional array support comparable to Fortran, including triangular arrays for storing spherical harmonic coefficients.

Development Activities

Work continued on the collaborative Earth System Modeling Framework (ESMF). A much anticipated release of ESMF software Version 2.0 occurred in July 2004. The ESMF Version 2.0 release includes software for representing and manipulating components, states, fields, grids, and arrays, as well as a number of utilities such as time management, configuration, and logging. It runs on a wide variety of computing platforms, including SGI, IBM, Compaq, and Linux

variants.

The Grid-BGC project completed a top-level user interface design, selected a GIS technology for handling maps and geographical information, began implementing Globus protocols, made implementation decisions regarding the software framework, completed "look-and-feel" designs for static and dynamic visualization tools, and performed data transfer and computational capacity testing on existing parallel hardware.

The Earth System Grid (ESG) moved into production mode for climate model research data with dedicated service for IPCC services in the area of coupled climate model data.

SCD completed work on the Web100 and NET100 projects.

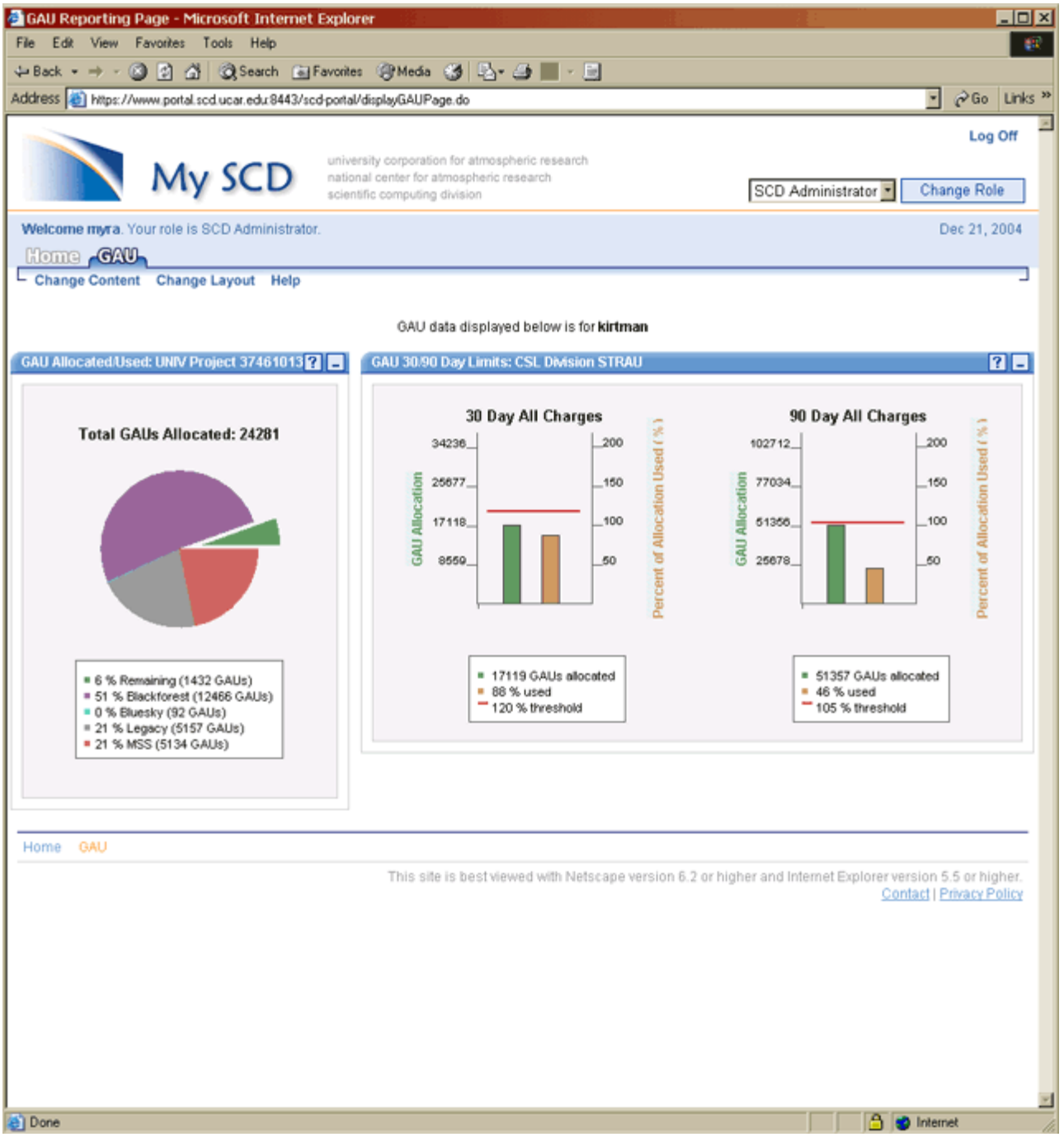
Computing Center Operations and Infrastructure

Applications

Released new versions of the MySCD portal which provides, for the first time, customizable GAU charging information directly to the users. SKIL was upgraded to include modify/delete functionality. Two collaborative projects are ongoing with the University of Colorado: the METIS event-based workflow system evaluation is nearly complete, and a group of students are modernizing the room reservation system.

MySCD Portal version 2.0 Release

The new version of the MySCD portal was released. This particular release was delayed as a result of security changes. These security changes required that the Portal system be retooled to support one-time passwords. The September release adds significant functionality that for the first time allows users of SCD's computational resources to get a summary view of their allocation usage including total percentage charges for computational and mass storage usage.


GAU Reporting Page - Microsoft Internet Explorer
File Edit View Favorites Tools Help
Back Search Favorites Media
Address https://www.portal.scd.ucar.edu:8443/scd-portal/displayGAUPage.do
Go Links
My SCD
university corporation for atmospheric research
national center for atmospheric research
scientific computing division
Log Off
SCD Administrator
Change Role
Welcome myra. Your role is SCD Administrator.
Dec 21, 2004
Home GAU
Change Content Change Layout Help
GAU data displayed below is for kirtman
GAU Allocated/Used: UNIV Project 37461013
Total GAUs Allocated: 24281
6 % Remaining (1432 GAUs)
51 % Blackforest (12466 GAUs)
0 % Bluesky (92 GAUs)
21 % Legacy (5157 GAUs)
21 % MSS (5134 GAUs)
GAU 30/90 Day Limits: CSL Division STRAU
30 Day All Charges
GAU Allocation
34236
25677
17118
8559
200
150
100
50
Percent of Allocation Used (%)
17119 GAUs allocated
88 % used
120 % threshold
90 Day All Charges
102712
77034
51356
25678
51357 GAUs allocated
46 % used
105 % threshold
Home GAU
This site is best viewed with Netscape version 6.2 or higher and Internet Explorer version 5.5 or higher.
Contact | Privacy Policy
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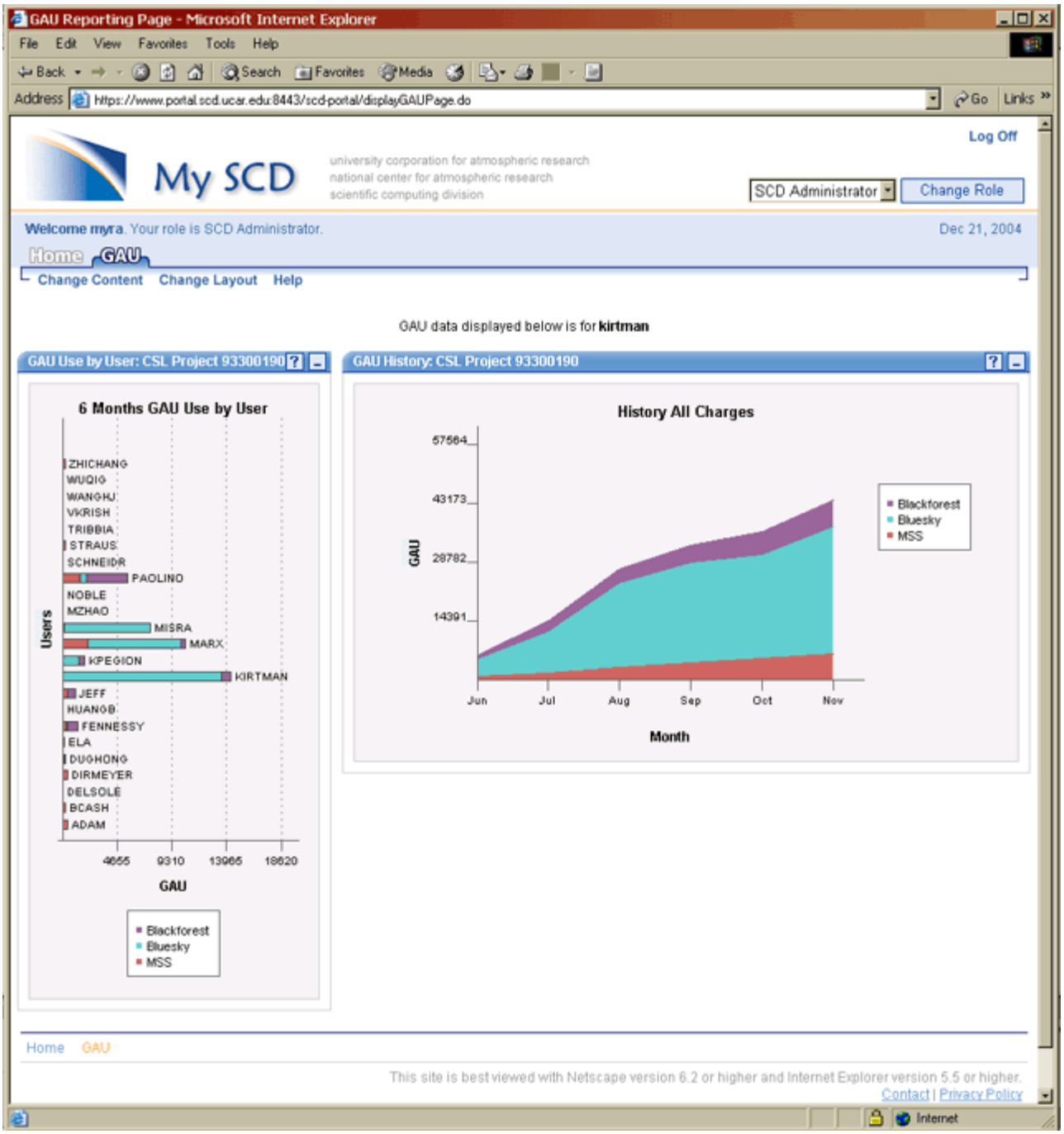


Additional accomplishments for applications:

- Remedy 5.1.12 upgrade
- SKIL release 2.0: addition of modify/delete functionality
- Metis Workflow System: completed analysis and evaluation of the final Metis system in the NCAR environment
- Room Reservation System: a senior capstone project with the University to develop a next-generation reservation system

Computer Room Infrastructure

SCD is developing both short and long-term plans to meet the demands of future computing systems. Multiple options are being developed that include building a second data center to expand, this work will continue into FY2005. The Mesa Lab standby generators were commissioned and put into service, and some field modifications will be made to simplify their operation. The computer room has reached its maximum cooling capacity; FY2004 focused on a design and procurement process to upgrade the chilled water systems.

The standby power generation system was installed and commissioned in March 2004. The shakedown and

familiarization with the systems continued well into the summer with some modifications to the control sequence as the result of lessons learned.

Additional accomplishments for infrastructure:

- Chilled water expansion project: design was completed and the construction phase will begin in early FY2005
- Data center expansion investigation: an extensive investigation is in progress to best meet the infrastructure needs of the organization that are being driven by the scientific demand for simulation capabilities. Options being investigated include:
    - Lease
    - Build
    - Collocate
    - Upgrade air handling units
    - Install Linux cluster

Computer Room Operations

Supported, set up, and distributed CryptoCards as part of a new responsibility associated with strengthened security requirements. Media conversions continue with the move to 200-GB media. Rotating schedules have been a success with much more exposure of all operators to the rest of SCD staff.

Operations stepped into a new support role that came about as part of new security requirements. During the March timeframe, the implementation of one-time passwords resulted in a new need to distribute and support CryptoCards.

Enterprise Services

Network and system security dominated the year. Several significant changes, including the introduction of one-time passwords, were completed very quickly to secure the supercomputing assets. Storage area networks were investigated along with several significant upgrades to production systems for data provisioning and web access.

During March a new security perimeter was quickly established, and the Distributed Systems Group (DSG) designed, implemented, and rolled out a one-time password solution to protect supercomputing assets from intrusion attempts. These efforts were instrumental in returning the supercomputer systems to the network for community use in a three-week period. Since then, there have been a number of attempts that have been successfully turned away.

In addition to the security work, a Storage Area Network (SAN) testbed was put together. A cost-effective solution is under investigation that will utilize Serial ATA technologies and a SAN solution that works in a heterogeneous environment. At this early point, Linux and Sun systems have been successfully integrated into the SAN.

Additional accomplishments for enterprise services:

- Server upgrades and additions:
  - Web cluster
  - DSS (huron)
  - Database server
- Windows desktops:
  - AD migration to CIT AD or SCDAD
  - Automated virus updates and patches
  - Veritas for backup solution

Network Engineering and Telecommunications

The Network Engineering and Telecommunications Section (NETS) is responsible for all engineering, installation, operation, maintenance, strategy, planning, and research regarding the state-of-the-art data networking and telecommunications facilities for NCAR/UCAR. Support of these facilities requires NETS staff to:

- Troubleshoot network hardware and software
- Update network configurations
- Monitor network performance, load, and errors
- Expand networks to meet increased numbers of users, increased bandwidth requirements, and new standards
- Design, engineer, and construct new cabling plant and wireless networking systems
- Support over 167 logical networks, approximately 200 monitored network devices, and over 4,400 network-attached devices at NCAR/UCAR
- Support Remote Access System (RAS)
- Design, engineer, and maintain UPS infrastructure
- Provide network-based security
- Support telecommunications and voicemail
- Provide telephone operator and directory services
- Support all SCD internal networking needs
- Maintain network documentation and databases
- Track and coordinate all network project activities via a work-request/work-tracking system
- Manage networking equipment inventory
- Develop and manage network budget
- Manage and engineer the Front Range GigaPOP (FRGP) and the Boulder Point of Presence (BPOP)
- Help manage the Boulder Research and Administration network (BRAN)
- Lead, participate and support the networking portion of advanced projects in high-performance network research and development that are a product of outside or interagency funding, including international networking project support, Web100, NPAD, Cisco Large Packet Grant, Net100, National LambdaRail (NLR), and the Quilt
- Evaluate new networking technologies and equipment
- Consult with network users about configuration and performance issues with network applications, network hosts, and network connections
- Provide high-performance networking testbeds
- Provide high-performance networking measurement tools
- Tune network performance

In summary, NETS provides a vital service to the atmospheric research communities by linking scientists and supercomputing resources (including mass storage systems and other data processing resources) at NCAR to other resources and scientists throughout the university research community. Such high-performance networking activities are essential to the effective use of NCAR/UCAR's scientific resources, and they foster the overall advancement of scientific inquiry.

The primary NETS accomplishments in 2004 include:

- Participating in the National LambdaRail (NLR) Project
- FL0 and CG1 design

Dark Fiber Expansion
- Participating in The Quilt Project
- CyRDAS Report

These projects along with the rest of the NETS 2004 accomplishments are described in this Annual Scientific Report.

Networking research projects and technology tracking

Networking research projects
NETS is a principal collaborator in several nationally recognized research and development networking and data communications technology projects. NETS hosts and presents at national and regional meetings on a variety of networking projects. NETS was awarded an STI award for the Network Path and Applications Diagnosis (NPAD) project proposals in collaboration with the Pittsburgh Supercomputing Center (PSC), and NETS contributed to the NIH BRIN Lariat project. NETS assisted in the submittal of the NSF Chronopolis proposal and NSF IRNC proposal.

Steering Committee for Cyberinfrastructure Research and Development in the Atmospheric Sciences (CyRDAS)
Marla Meehl served on NSF's The Steering Committee (SC) for Cyberinfrastructure Research and Development in the Atmospheric Sciences (CyRDAS). This committee was responsible for assessing the opportunities for advances in atmospheric science research that are made possible by current or anticipated advances in information technology and computer science, the opportunities for advances in science that might result from collaborative research between atmospheric scientists and computer scientists, ways in which cyberinfrastructure can contribute to formal and informal education in atmospheric science and the cyberinfrastructure needs of the NSF-funded atmospheric science research community. The committee also made recommendations on strategies for NSF that will help the academic research community exploit the opportunities identified in the assessments above. Finally, the CyRDAS Steering Committee developed an implementation plan for a distributed cyberinfrastructure that will meet the needs of the academic atmospheric science research community and which includes the flexibility to grow smoothly as that research advances and CI needs grow.

The Hybrid Optical and Packet Infrastructure Project (HOPI)
When Internet2 was first organized in October 1996, one defining mission was to provide scalable, sustainable, high-performance networking in support of the research universities of the United States. The resulting infrastructure, comprised of campus, regional, and national components, is a successful and robust packet switched network. In the next few years, however, it must evolve to take advantage of new infrastructures, and the HOPI testbed will examine future network architectures. In planning on the Internet2 networking architecture needed beginning 2006, HOPI is considering a hybrid of shared IP packet switching and dynamically provisioned optical lambdas. The term HOPI (for hybrid optical and packet infrastructure) is used to denote both the effort to plan this future hybrid and a testbed facility that will be built to test various aspects of candidate hybrid designs. A white paper describes a plan for the HOPI testbed facility. The goal of that facility is "to provide a facility for experimenting with future network infrastructures leading to the next generation Internet2 architecture." The eventual hybrid will require a rich set of wide-area lambdas together with switches capable of very high capacity and dynamic provisioning, all at the national backbone level.

Web100 project
The Web100 project is funded by the National Science Foundation (NSF) as a collaborative project developing end-host TCP performance measurement and enhancement tools, which help end-hosts automatically and transparently achieve high TCP data rates (>100 Mbps) over the high-performance research networks. Software and tools have been developed for the Linux operating system in an open manner so they can readily be ported to other operating systems. Such ports are currently in progress. The Web100 principal partners are the National Center for Atmospheric Research (NCAR), the Pittsburgh Supercomputing Center (PSC), and the National Center for Supercomputing Applications (NCSA).

The Web100 project has achieved significant progress on several of its key project milestones during the past year. By releasing the Web100 software to the general user community, numerous individuals and groups have incorporated the software into a wide and diverse set of useful applications. In addition, the Web100 TCP Extensions MIB is on the Internet Engineering Task Force (IETF) standards track and is expected to be submitted for last call by the end of this calendar year. Most importantly, the Web100 software is currently being officially incorporated into the Linux 2.6 kernel development release for use as library functions in all Linux distributions. Microsoft has reported incorporating much of the Web100 software functionality into the next release of their .NET server software, and a BSD port of the Web100 software is also underway. This project was completed in August 2004.

Net100 project
The Net100 project is creating software extensions that allow computer operating systems to dynamically adjust to the available network bandwidth for large data flows. Net100 has just completed the final year of a three-year grant from the

Mathematical, Information, and Computational Sciences (MICS) program in the Office of Science at the U.S. Department of Energy (DOE). The project is a collaboration between the Pittsburgh Supercomputing Center (PSC), the National Center for Atmospheric Research (NCAR), Lawrence Berkeley National Laboratory (LBNL), and Oak Ridge National Laboratory (ORNL). During this past year considerable additions have been made to the wide-area daemon (WAD) extension algorithms. The WAD code has also been extensively used and tested by several groups of external users, providing useful feedback to the Net100 team. The Net100 project has also implemented algorithms previously only run in simulations, providing useful theoretical feedback to the algorithm's author for additional modifications along its Internet Engineering Task Force (IETF) standardization process.

Network Path and Applications Diagnosis (NPAD)
A key missing piece of the end-to-end performance puzzle is that the current set of diagnostic strategies do not adequately account for the effects of path delay. The project team is developing extensions to existing diagnostic tools which will effectively take path delay into consideration, compensate for a variety of delay times, and test the effects of these new diagnostic tools with network users and operators, using actual high-performance applications. Due to recent insights gained from the Web100 and Net100 projects, we can show that the missing piece of the performance diagnostic puzzle is that the symptoms of most application and network defects scale with increasing path delay. For example, a minor defect in a campus LAN might have an insignificant or negligible effect on an application running on a 1-ms path across campus. However, that same defect has a greater impact on performance when running on a long path across the continent. In this project, we are developing new diagnostic techniques, which include a suite of diagnostic tools and strategies for their use to test applications locally with a 100-ms virtual path, and then test each successive segment of the actual path extended with a virtual path to a total path delay of 100 ms. Such testing is expected to expose otherwise hidden flaws and impediments that contribute to delay, since each component of the path and application can be tested in a context equivalent to an ideal end-to-end path, while ruling out other potential flaws.

Cisco University Research Program Funding - Investigating Large Maximum Transmission Units (MTU)
Over the last decade, we have witnessed a tremendous increase in raw network capacity. Today, we are seeing the ubiquitous deployment of cross-country 10 Gbps optical networks and early standards efforts in support of 40 Gbps and 100 Gbps networking technology. As a result, long fat pipes (elephants) [RFC1323] are no longer a rarity -- in fact they are becoming the norm. For example, NSF funded the 40 Gbps Distributed Terascale Facility (DTF) [RB02], UCAID has built a sonet-based 9.6 Gbps Abilene Network of the Future [Int02], and contractual negotiations have been completed on a dark fiber lambda network called the National LamdaRail. However, it is not clear whether these network capacity increases will actually result in comparable increases in application performance due to a number of specific underlying technical issues and limitations. It is well known that bulk transport application performance has not kept up with network capacity increases. We believe that application performance has fallen by about two orders of magnitude relative to the raw performance of the underlying technologies. In this proposal, we intend to identify, investigate, and address technical issues specifically associated with the underlying network infrastructure and application performance for next-generation Internet networks.

NOAA High Performance Computing and Communications (HPCC) Program
NOAA has asked NCAR to participate with their proposal to the NOAA High Performance Computing and Communications (HPCC) Program, with no funds proposed for NCAR. NOAA and NCAR are making excellent advances in supercomputing and planning for the development of enterprise network architecture. However, NOAA and NCAR currently do not have a distributed network test facility for evaluating new network technologies, other than in local environments, although the benefits of such a facility are numerous. NOAA and NCAR would be well served by developing a way to test and integrate new network technologies to gain vital experience for promoting NOAA and NCAR research and operations. We propose to develop an optical network testbed using Dense Wavelength Division Multiplexing (DWDM) by leveraging NOAA and NCAR's existing investment in a metropolitan fiber optic network. This network testbed will provide a platform for integrating DWDM technology, and for determining how DWDM will best serve NOAA and NCAR research and operations, but it will also address other important challenges. The optimization of data flows and server input/output at 10 Gbps will require study, testing and tuning, and the question of how to secure data flows at this rate will also be addressed. The proposed DWDM network testbed will include a pair of optical network switches with Gigabit Ethernet (GbE), 10 GbE, and DWDM components to be procured and located at NOAA Boulder and at NCAR. An optical tap will also be part of the testbed to allow passive monitoring of all data flows. In addition, four 64-bit computer systems will be procured to transmit, receive, monitor, and secure the data flows. Two systems will be located at NOAA and two at NCAR. NCAR will cosponsor 5% of Pete Sakosky's time and provide a rack of computer room space for this project. This proposal was submitted and is pending approval.

Access Grid
NETS participated in the network configuration, testing, and optimization of the SCD Access Grid. NETS will continue to participate in the deployment of operational Access Grids.

Earth System Grid project
NETS provided network-engineering support to the DOE ESG II project.

Network technology tracking and transfer
NETS tracks networking technology via networking conferences, training classes, vendor meetings, beta tests, technology demonstration testing, email lists, networking journals, attending user conferences, and by meeting and exchanging information with universities and other laboratories. NETS staff continued to utilize all of these technology-tracking avenues during FY2004. New technologies are integrated into the production UCAR networks on an ongoing basis after a technology has met our capacity, performance, connectivity, reliability, usability, and other maintainability requirements.

Local Area Network (LAN) projects

NETS supports both NCAR/UCAR network needs as well as the special networking needs of SCD itself. Therefore, all LAN projects are further subdivided as being either NCAR/UCAR LAN projects or SCD LAN projects.

NCAR/UCAR LAN projects

UCAR network infrastructure recabling projects
The common goal of all UCAR recabling projects is to provide each workspace with a standard set of dedicated data communications links. The overall plan calls for each workspace to be provisioned with a standard Telecommunications Outlet (TO) that connects with four Category 6 (CAT6) twisted-pair cables and two pairs of multi-mode optical fiber. Additionally, intra-building (trunk) cabling must be installed to concentrate all workspace cables to intermediate and central locations.

Concurrent with recabling, each network device is delivered 100 Mbps of dedicated bandwidth via a dedicated Ethernet packet-switch port. Such dedicated-port access offers substantial networking performance improvement over shared-media Ethernet access.

NETS designed permanent network infrastructure for the CG1 and FL0 buildings. NETS assisted in the extensive relocation and related cabling for FL4 staff. NETS recabled the FL2-FL3 interbuilding cabling due to FL0 construction.

NETS also participated in the following projects: CG bike path design, Jeffco hanger networking design and implementation, UNAVCO move and lease completion, and the Nextel cellular repeater design and implementation.

Network monitoring project

NETS continues to use HP Openview, flowscan, Prognosis and Cricket as its principal tools for network monitoring and statistics gathering.

Additionally, NETS has installed certain specialized network monitors at the request of two national network-measuring organizations, namely MOAT and Internet2. NLANR's MOAT organization has placed an OC3MON monitor at NCAR's Mesa Lab and installed an OC12MON in the Front Range GigaPOP equipment racks located in CU Denver's computer room. MOAT has also placed an AMP monitor at both the Mesa Lab and the FRGP as well. On behalf of UCAID's Abilene network, Internet2. (ANS) has placed a Surveyor network monitor at both the Mesa Lab and at the FRGP.

Local serial-access project
NETS supports several terminal servers for providing serial console access to various computer and networking equipment. Serial support is also provided for the very few serial terminals remaining at UCAR.

NETS CSAC support project
The NCAR/UCAR Computer Security Advisory Committee (CSAC) is chartered by the SCD Director to assess the state of computer and network security at NCAR/UCAR, and to make recommendations to assist NCAR and UCAR management in setting policies related to the security of computers and other devices attached to the NCAR/UCAR network. CSAC membership is composed of technical representatives located throughout the various NCAR/UCAR organizations.

NETS is involved with CSAC since nearly all security policies involve various types of network-connected devices located between the networks belonging to the external world and the UCAR networks that are being protected from the external world. These network-attached devices can operate as filters and/or authentication devices operating at one or more OSI (Open Systems Interconnection) layers, usually at the Network/Router Layer (Layer 3) and higher. Based on CSAC recommendations, NETS continues to implement significant new gateway router filters to improve network security for UCAR. Extensive testing and extensive coordination throughout UCAR is required to implement the recommended security filters. NETS also cooperates on wireless, RAS, and VPN security measures.

VLAN Splitting Project/Layer 2/3 Design
NETS is in the process of re-engineering our backbone to provide higher reliability and redundancy to network-based services. Previously, NETS allowed single subnets and VLANs to span across all campuses. This was a manageable design when NCAR was located in only two main campuses. The design offered increased convenience for users in being able to request any subnet to be activated anywhere at the Mesa Lab or Foothills Lab campuses.

NETS was driven to reevaluate this design with the addition of the third major campus, Center Green, and a desire of increased reliability for VoIP and business continuity. The old design did not include any redundant links, which would create network loops that needed to be dealt with using the spanning tree protocol. However, with the addition of the CG campus, NETS has built redundant links so the ML, FL and CG campuses are all connected in a triangle. While the spanning tree protocol works adequately in a simple, loop-free network, it is quite poor at handling redundant links and the loops they form. To take full advantage of the entire mesh of links between the campuses, it is necessary to use a more intelligent protocol at a higher layer.

At the IP layer, NETS has been using OSPF for a number of years. It is fully capable of handling the current topology, not only detecting and routing around link failures in a matter of a few seconds, but properly routing traffic over the shortest path between campuses. Presently, NETS has the new backbone fully deployed and is in the process of restricting subnets to a single campus. Completion of the project's final stage is expected before the end of the year.

Multicast support activities project
Multicasting is a technology in which a single outbound stream of data can be made to arrive at multiple destinations. The data stream is multiplied in a tree-wise fashion using both software and hardware to effect the multiplication. Multicasting technology is particularly useful for video conferencing and audio conferencing applications. NETS continues to support and enhance multicast services for UCAR.

UPS project
NETS has continued installing UPS (Uninterruptible Power Supply) units into all new telecommunication closets so all networking equipment will receive short-term standby power in the event of any short-term power failure. UPS units also help filter out damaging power spikes. Upgrading, expanding and maintaining these devices is an ongoing process.

In addition, SCD installed a generator at the Mesa Lab and NETS has tied their equipment into this in the computer room and in areas where safety and security support is critical. NETS is also in the process of tying their UPSs at FL into the facilities generator to provide additional business continuity.

Grounding
NETS is in the process of grounding all communications closets and NETS hardware to eliminate static issues causing hardware and phone failures. This is a technically difficult and time-consuming project.

Wireless
NETS supports wireless network access in all public areas and conference rooms, and is in the process of deploying wireless access in all office areas as well. NETS also designed, tested and installed a long-distance, high-speed, wireless link between CG2 and FL4 and the Mesa Lab and Foothills Lab. These links provide backup to wired links.

Voice over IP (VoIP)
VoIP in its full implementation is the complete merging of data, voice and video networks. Traditional separate voice systems such as PBXs, telephone cabling infrastructure, and proprietary telephone handsets are replaced with computer-based call managers, IP telephones, and IP-based voicemail devices that are Ethernet attached just like any other networked device. With a VoIP system, the same cabling infrastructure that is used for traditional network devices can also be used for VoIP devices. Such a combination simplifies the overall cabling infrastructure and lowers total costs of installation and maintenance. Additional, ongoing cost savings are realized through simplified moves, adds, and changes made possible through a VoIP-based system. The same network monitoring system can be used to monitor both VoIP and data network devices.

The VoIP project was completed January 2004.

SCD LAN projects

In addition to its overall NCAR/UCAR networking responsibilities, NETS has additional special support responsibilities specific to SCD. NETS handles or consults on most of the host-based SCD networking, including all supercomputing networking. NETS is also responsible within SCD for several other tasks including:

- Special cabling fabrication and installation

Networking and system testbeds
- External and local conference networking and system support
- Special-grant project networking needs
- Security

Ongoing SCD network support project
NETS is responsible for most aspects of daily operation of the SCD LANs and host-based networking. Among these responsibilities are monitoring, managing, tuning, troubleshooting, upgrading, reconfiguring, and expanding SCD LANs and host-based networking. NETS works closely with the system administrators of all SCD network-connected systems.

Supercomputing network support project
NETS supports almost all aspects of networking for all SCD supercomputers. This includes hardware, software, and routing configuration support for Gigabit Ethernet and Fast Ethernet interfaces. IP routing configuration support is also provided for the supercomputer connections.

ML 29 move and upgrade
NETS has been asked to relocate their equipment in the SCD Computer Room 29. In this process, we will also upgrade the 6509 Ethernet switches to Sup720s to provide full backplane capabilities and support 10 Gbps in the future. The design and planning for this project is complete.

Metropolitan Area Network (MAN) projects

Boulder Point-Of-Presence (BPOP)
The Boulder Point-of-Presence, or BPOP, is a collaboration of institutions in the Boulder area. BPOP members cooperate to provide access to wide-area network services. The BPOP members are: NCAR, University of Colorado at Boulder (UCB), NOAA, Colorado State University, the City of Boulder, and the County of Boulder. BPOP equipment consists of a router, an ATM switch and an Ethernet switch. The router, Ethernet switch, and ATM switch are located at the UCB Telecommunications Center.

The BPOP offers two primary services to its members: access to ICG Dedicated Internet Service and access to the FRGP. Access to ICG is provided via an OC12 (upgraded this year from OC3) link connected to BRAN fiber. A Gigabit Ethernet connection to the FRGP is provided over dark fiber. This link is shared by NCAR, NOAA, CSU, and the City/County of Boulder. UCB has its own OC-12 link to the FRGP. CSU also has its own OC3 to the FRGP. UCB and the BPOP also back up each other's links to the FRGP in Denver.

- **BEAR Project - BPOP Enhancement And Relocation project or Moving the BPOP to CU**
  Scot Colburn spearheaded the BEAR project to enhance robustness and redundancy in the UCAR and Boulder networks. NCAR's ML and FL sites are at remote ends of the BRAN fiber path, making these sites vulnerable to isolation should a BRAN fiber cut occur. A wireless link is in place to connect the two sites in case of such a cut, but NCAR's Internet connection depended on a border router at Mesa Lab not being isolated. Moving NCAR's border router to a location on the ring portion of BRAN created an opportunity for redundant Internet connections and a design where Internet access is invulnerable to BRAN fiber cuts. Co-locating NCAR network hardware on the BRAN ring involved finding and negotiating appropriate space in a building located on the ring, and it turned out that CU's Telecom building best fit the bill with a combination of well-secured and well-organized space having good power and cooling capacity. Fortunately, NCAR and CU have a history of working successfully together on projects such as BRAN. In addition to negotiating equipment space with CU, co-locating the necessary hardware involved scheduling, cutting into and re-terminating the NCAR portion of the BRAN fiber inside CU Telecom, which was done without incident. With BEAR complete, the BPOP members that use NCAR for Internet service or Internet backup connect to a network designed to be invulnerable to fiber cuts. Drivers for involved parties included:
    - NCAR sites receive reliable and robust Internet access. NOAA receives reliable and robust Internet access over NCAR's ML-FL wireless link. CSU GigE becomes less vulnerable to BRAN cuts. CoB gets more reliable Internet access and is invulnerable to BRAN cuts with a second GigE.
    - CU already has 622 Mbps to FRGP but backup FRGP access over NCAR's fiber path becomes more reliable via collocated switch.

  The BEAR project was completed this year.

- **BRAN project**
  BRAN is the Boulder Research and Administration Network, which is an eleven-mile fiber network in Boulder built and operated by the four BRAN partners to privately interconnect their Boulder-area facilities. The BRAN partners

include:

- City of Boulder
- University of Colorado at Boulder
- National Center for Atmospheric Research
- NOAA-Boulder and NIST-Boulder

UCAR has greatly reduced intra-Boulder circuit costs by utilizing BRAN fiber. Active BRAN circuits involving UCAR facilities include ML-FL, ML-FL Security, City-UCB, NOAA-ML, CU-ICG, CSU-UCB, CU-ML, UCB-FRGP (via Level3), CG-ML. BRAN carries voice and data traffic. NETS continues to actively participate in the BRAN management committee and the BRAN technical committee.

Remote-working and home-access project
Remote access continues to be provided by four digital T1 PRI lines connected to a Cisco AS5300 Remote Access Server (RAS). Each T1 PRI line provides twenty-three 56-Kbps channels that can support analog or ISDN dial-in access. Long-distance access via direct 1-800 lines is overlaid on one of the PRI lines. Telnet, PPP, and ARAP access are supported on the Cisco RAS device.

Dark fiber efforts
NETS led the effort to interconnect BRAN to ICG fiber at the Boulder ICG POP. This was a long-term goal of BRAN and has allowed added flexibility in planning and expansion of BRAN to include fiber paths from Boulder to Denver, Boulder to Fort Collins, adding the Center Green campus, the OC12 (622 Mbps) ICG path for Commodity Internet services, and the ICG Primary Rate Interface (PRI) telecommunication and RAS services provided to UCAR. These efforts allow for future strategic directions to be taken for the expansion of dark fiber, additional cost-effective ICG services, distributed storage area networks (SANS), and business continuity goals.

NETS is in the process of installing fiber to the Jeffco site. NETS also worked with the University of Wyoming to secure fiber from Laramie to the FRGP and to provide a northern protect fiber ring in Colorado and Wyoming. NETS is working to secure a private diverse fiber ring in downtown Denver to protect the FRGP access locations. NETS is working on the Western Lights project to investigate fiber paths in the western US including Utah to provide a protect path to the FRGP. NETS has also had discussions of fiber to other FRGP members such as Colorado School of Mines, University of Colorado at Colorado Springs, University of Northern Colorado and Denver University.

Wide Area Network (WAN) projects

Front Range GigaPOP (FRGP)
The Front Range GigaPOP (FRGP) is a consortium of universities, non-profit corporations, and government agencies that cooperate in an aggregation point called the FRGP to share Wide Area Networking (WAN) services connecting to the Commodity Internet, Abilene/Internet2, and to each other. UCAR operates the Front Range GigaPOP under contract to the other members. The primary FRGP networking facilities are located in the Auraria Campus computer room of the University of Colorado at Denver and in the Level3 Denver POP located at 1850 Pearl Street in Denver. The current partners are (* = new this year):

- CSM - Colorado School of Mines
- CSU - Colorado State University system
- DU - Denver University
- FLC - Fort Lewis College
- *Ithaka (provider of online scientific journal articles)
- NCAR - National Center for Atmospheric Research
- NOAA - National Oceanic and Atmospheric Administration
- State - State of Colorado
- UCB - University of Colorado at Boulder
- UCCS - University of Colorado at Colorado Springs
- UCD - University of Colorado at Denver
- UCHSC - University of Colorado Health Sciences Center
- *University of Utah
- UW - University of Wyoming

There are several GigaPOPs similar to the FRGP throughout the U.S., and a number of advantages are gained by sharing services through such GigaPOPs:

- Costs for WAN services are reduced for each partner

- Expertise among partners can be shared
- A higher level of services can be purchased than the individual institutions could afford
- There is more buying power among a consortium
- There are great economies of scale
- Quilt membership and their negotiated discounts with Commodity Internet providers are available only to GigaPOPs

UCAR has provided the engineering and Network Operations Center (NOC) support for the FRGP, with the service costs incurred by UCAR being shared by all FRGP members. NETS believes that the greater service and bandwidth obtained through the FRGP are important enough for UCAR to operate the FRGP by providing engineering and NOC services, and the FRGP has agreed that NETS has the most qualified engineering and NOC staff to provide the very best engineering and NOC services for the FRGP.

The FRGP is a critical service for UCAR staff as well as all of the other FRGP partners, and the FRGP has proved to be an extremely successful technical project as well as an excellent collaboration with the Colorado, Wyoming, and Utah research and education community.

NETS made many significant improvements to the FRGP during 2004. These include:

1. WilTel Commodity Internet Service at GigE.
2. Qwest Commodity Internet Service at GigE.
3. A peering agreement was created and approved, and we signed Comcast and the FRII as our peering partners at no cost to UCAR or the FRGP.
4. FRGP formed a consortium with Utah and signed NLR, LLC Participation Agreement.
5. NETS is developing an FRGP/BPOP redundancy plan called DREAM.
6. The FRGP is developing a northern fiber ring for redundancy.
7. New 5-year FRGP agreements were developed and executed.

The Quilt
The Quilt is a project whose participants are nonprofit advanced regional network organizations dedicated to advancing research and education in the United States by:

1. Providing a broad range of advanced networking services to their constituents, including network engineering, management, and operation; regional connectivity and exchange; and promotion and coordination of regional activities

2. Facilitating innovative and successful projects and productive working relationships

The Quilt's specific purposes and objectives are to:

1. Provide advanced network services to the broadest possible research and educational community

2. Promote end-to-end continuity, consistency, reliability, interoperability, efficiency and cost-effectiveness in the development and delivery of advanced network services by means which, at the same time, foster innovation and reflect the diversity of its members

3. Represent our common interests to backbone network service providers, industry, government, standard-setting organizations, and other organizations involved in or influencing the development and delivery of advanced network services

The FRGP joined The Quilt in June 2001, and NETS represents the FRGP on the Quilt Steering Committee and the Quilt Executive Committee. NETS actively serves on the Network Facilities Project, the Regional Fiber Project, the Peering Project and the hiring committee. The FRGP continued to take advantage of Quilt discounted pricing for Commodity Internet services, which significantly decreased prices paid by FRGP for Commodity Internet services this past year.

National LambdaRail (NLR)
National LambdaRail, Inc. (NLR) is a consortium of leading U.S. research universities and private-sector technology companies building and operating an optical multi 10 Gbps LAN-PHY network across the country. NLR's fundamental mission is to provide an enabling network infrastructure for new forms and methods for research in science, engineering, health care, and education as well as for research and development of new Internet technologies, protocols, applications and services. As evidence of the commitment to this mission, NLR will devote 50 percent wave allocation to network research. NLR puts the control, the power, and the promise of experimental network infrastructure in the hands of our

nation's scientists and researchers. NLR aims to re-energize innovative research and development into next-generation network technologies, protocols, services, and applications.

NETS has played a leading role in developing NLR throughout the year. NETS also worked to build an FRGP/Utah consortium to join NLR.

vBNS+
The vBNS+ network is a production ATM network owned and operated by MCI. The vBNS+ interconnects the NSF supercomputing centers, universities, and other customers. UCAR remains connected to the vBNS+, and NETS has continued its support of the vBNS+, as long as MCI continues to provide this service to UCAR.

Internet2/Abilene
Internet2 operates the Abilene network, a SONET 192 (9.6 Gbps) national backbone supporting high-performance connectivity and Internet innovation within the U.S. research university community. The set of advanced services supported include IPv6 and multicast. As of October 2004, Abilene had 44 connected entities serving 228 institutions. UCAR joined UCAID and attached to Abilene via the FRGP in FY2000.

Other network projects

Projects listed in this section are ones that don't neatly fit into the Research, LAN, MAN, or WAN project classification scheme.

Telecommunications
NETS is responsible for all voice communications at UCAR. Responsibilities include engineering, maintenance, configuration, and operation of the telecommunications cabling plant, the VoIP system, and telephone handsets. Telephone directories and UCAR telephone reception are also NETS responsibilities. The PBX was decommissioned and removed this year. See the VoIP subsection of the LAN section above for more information on work in this area.

Westnet
Westnet is an affinity group that grew out of the NSFnet regional network called Westnet. NETS' long-term participation continued, and NETS continues in its leadership role. NETS is a member of the Westnet Steering Committee and leads the effort to plan and run bi-annual meetings that include technical presentations from members and vendors. Westnet provides powerful political and technical contacts with Rocky Mountain area universities that are UCAR members and that share common information technology concerns. The current Westnet members include:

- CU-Boulder
- CU-Denver
- Colorado State University
- University of Denver
- University of Wyoming
- University of Utah
- Utah State University
- Brigham Young University
- Arizona State University
- University of Arizona
- University of New Mexico
- New Mexico State University
- New Mexico TechNet
- Idaho State University
- Boise State University
- South Dakota School of Mines and Technology
- UCAR

Project-tracking system
The project-tracking system continued in full production in FY2004. NETS work requests and projects are opened, tracked, and closed with this project-tracking system. The use of project-tracking tools is necessary because of the vast number and variety of projects. It would be unwieldy to manually track even just the personnel assignments for these hundreds of projects, much less track progress details of so many projects. In 2004, NETS completed more than 934 work requests and 30 projects.

Property-tracking system
NETS used the Remedy-based asset manager system to track its small property equipment. NETS is also responsible

for tracking all large NETS equipment, including the VoIP phone system. Presently, NETS tracks approximately 360 equipment items. (See: NETS Inventory).

Business continuity
It is UCAR's policy to develop and maintain a corporate-wide contingency program, known as the Business Continuity Plan (BCP). This plan aims to provide the corporation with every opportunity to withstand a catastrophic event, be it accidental, man-made, or natural, and resume total operations in an efficient and effective manner. It is expected that, with the BCP in place, management will be able to provide the swift and decisive leadership that will be necessary for a successful recovery. Also, because of the guidance provided by the BCP, it is expected that employees will be able to carry out their tasks and responsibilities efficiently and effectively. NETS actively contributes related material to this document and process.

Documentation
NETS has an ongoing effort to create and maintain documentation in support of project management and network support.

NETS NCAB project
The Network Coordination and Advisory Board (NCAB) consists of appointed technical representatives from the NCAR divisions and UCAR. The purpose of NCAB is to advise NETS concerning network strategy, planning, policy, expansion, and management issues for all of NCAR and UCAR. The work of NCAB continues to be indispensable to the success of networking at UCAR. NCAB meets monthly.

Strategic plan
At the request of UCAR management, NETS formulated a comprehensive strategic plan outlining technical and budgetary requirements for UCAR networking for the next several years. This document was completed this year and received NCAB and ITC approval.

Conferences
NETS continues to provide networking support for classes, demonstrations, meetings, and conferences throughout NCAR/UCAR. This work involves the design, construction, configuration, and operation of the network components required for these activities. NETS also sponsored and hosted the following events in 2004:

- January 2004 Westnet Meeting
- June 2004 Westnet Meeting
- October 2003 CyRDAS Focus Group Meeting
- The Quilt Fiber Workshops
- I2 IPv6 Reception
- CyBerSecurity Summit Organizing Committee

Outreach support

NETS personnel attended and presented at several conferences, meetings, and training sessions, preparing numerous trip reports and presentations. See Education and Outreach for more detail.

Committee support

NETS representatives have attended and supported the following NCAR/UCAR committees:

- The Network Coordination Advisory Board (NCAB)
- The Computer Security Advisory Committee (CSAC)
- Advisory Committee for Central Infrastructure Service (ACCIS) - Jim Van Dyke chair
- Information Technology Council (ITC)

SCD committees:

- The SCD Executive Committee
- The Computer Room Planning Committee (CRPC)
- The Machine Dependencies Committee
- The SCD Security Policy Committee (SSPC)

External committees:

The Quilt Executive Committee
- The Quilt Steering Committee
- The Westnet Steering Committee
- The Front Range GigaPOP Management Committee (FMC)
- The Front Range GigaPOP Technical Committee (FTC)
- The BRAN Technical Committee
- The BRAN Management Committee
- The CyRDAS Committee
- The NLR Board of Directors
- NLR Engineering Committee
- HOPI Design Team

Assistance and Support for NCAR's Diverse Research Community

SCD's User Support Section (USS) provides leading-edge software expertise for the climate, atmospheric, and oceanic research communities to facilitate their high-performance computing endeavors at NCAR. The section furnishes a variety of services to users, both local and remote, that enable them to pursue their research within SCD's end-to-end high-performance computing environment. USS has direct contact with NCAR's user community, and with a staff of 26, represents a continuing divisional investment in focused user support services tailored to their specific needs.

Consulting Services and User Support

Consulting staff assisted users in transitioning models and large codes from chinook to bluesky and in transitioning data analysis jobs from dataproc to tempest. This work occurred during the June-September timeframe. SCD also carried out two important computing campaigns:

1. CGD's IPCC campaign running models 7x24 on 18 nodes of bluesky
2. The High Resolution WRF Real Time campaign April 15-July 31

SCD also ran memory-affinity experiments on bluesky before the IPCC campaign that showed a 7-10% speedup in throughput with this feature, and accordingly decided to adopt it for the production environment.

Online Documentation

USS staff has developed hardware and software documentation for the following computers:

- lightning - our new IBM Linux cluster
- tempest - our 128-processor SGI 3800 data analysis server

User guides for these two machines have been developed and placed online. The lightning documentation will be augmented as SCD gains experience with the Linux cluster.

Staff also revised and redesigned two primary guides to all user information about NCAR computers:

- NCAR computers: Complete user information
- SCD user documentation catalog

In addition, we produced online documentation for Fishpack90, a new version of our popular math software library for our users.

Security and related issues

To support new security requirements for the NCAR computing environment, staff worked with UCAR and NCAR security stakeholders and published new SCD supercomputing Security web pages, providing guidelines, instructions, and procedures for user passwords and for using the new CrytpoCARD one-time password tokens.

Web-based services and activities

The SCD website was instrumented with targeted search tools that give users new, more effective ways to access specific computing information.

We also designed and developed four new websites in support of SCD, NCAR, and UCAR activities:

COMSCI: Staff developed this site to support a UCAR-wide staff-based initiative to increase the communication skills of NCAR and UCAR scientists and technical staff.

CSAC: Staff redesigned this web interface and redeployed content for UCAR's Computer Security Advisory Committee.

SCICOMP12: Staff designed and launched a new website as part of SCD's successful bid to host the 12th annual meeting of SCICOMP, an international organization of scientific/technical users of IBM systems. (For further information on SCICOMP, please see: http://www.spscicomp.org/).

Cybersecurity Summit 2004 (restricted URL): Staff created a promotional web site to advertise an NSF-sponsored conference on security issues as they affect federal laboratories. SCD coordinated and managed all aspects of this very successful, two-day conference, held from September 27-28, 2004, in Washington D.C.

Staff also participated in the design and troubleshooting of the new MySCD Portal web interface. The portal is a user-customizable, database-driven web site that provides SCD users with information they require on running jobs, mass storage allocations, project status and more.

Finally, staff were part of a 25-member, cross-divisional effort to create a database-driven infrastructure that transformed our web presence into a more dynamic, interactive experience. (See: http://www.ucar.edu/) The Web Outreach, Redesign, and Development (WORD) project resulted in a new web presence for all of UCAR, NCAR, and UOP. The new site was launched in spring 2004.

Testing hardware and software

USS staff performed consistency testing for all operating systems, compilers and other major product upgrades. Consistency testing involves a set of programs and models that are run before and after the upgrades. Both sets of results are then compared to verify upgrades. Staff developed stress tests for the new batch system Load Sharing Facility (LSF) deployed on lightning, and ran various benchmark programs during lightning's Acceptance Test Period. The machine successfully passed the 168-hour mark in September. USS has also developed a portable, statistics-based node analyzer for cluster computers, for the purpose of locating slow nodes and processors on the cluster.

Training

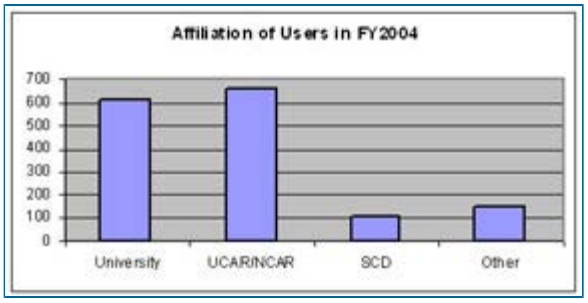
We substantially increased our user training efforts in FY2004 by providing an introduction to Unix to the SOARS protégés, and a class in supercomputer optimization to the Advanced Studies Program (ASP) Fellows. Both of these classes were delivered in June. USS staff provided introductory training and discussion of supercomputing security following the intrusion incidents of March-April, when the security environment at UCAR radically changed. This training was delivered to NCAR divisions ACD, ATD, CGD, HAO, MMM, and also at COLA in Maryland, during the May-June timeframe. During October, SCD provided user training for the lightning Linux cluster, including LSF training and an overview of hardware and architecture.

Software applications development and maintenance

USS staff maintain the NCO and IDL products on its SCD data analysis machines dave and tempest. These are products that have been specifically requested by a large number of users. Staff developed and released the Fishpack90 software library for solving elliptical partial differential equations, which provides corrections to the older Fishpack library that had several FORTRAN language problems that manifested themselves more severely on modern compilers.

Resource Allocations and Accounting

USS staff manage and maintain all users' resource and project accounting databases, implement allocations for use of computing resources, and assist users with mass storage file management.



A total of 1,529 people representing 169 institutions used SCD computing resources during FY2004. Of these 169 institutions, 102 are universities in the U.S. University projects used over 300,000 GAUs in FY2004. (One GAU is equivalent to 4 hours on one processor on the IBM POWER4 computer bluesky or 10 hours on the IBM POWER3 computer blackforest. (Click on the images for larger versions).

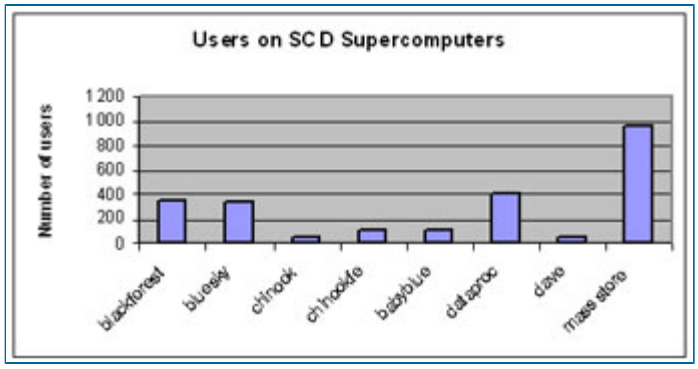
University Allocations

All of the large university allocations are for projects funded by NSF awards in the atmospheric and related sciences area. SCD's Advisory Panel met in April 2004 and September 2004 to review these large requests and to advise the SCD and NCAR Directors. There were 39 large requests from university researchers during FY2004 totaling 1.3 million GAUs. The largest request approved was 100,000 GAUs while the median request was for 10,000 GAUs. At the September panel meeting, there were requests for 2.4 times the available resources. In the end, with so many high-quality proposals, the panel over-allocated university resources by 20%. The SCD job scheduler isolates the three allocation groups: university, NCAR and CSL so that overuse by one group will not slow turnaround by another group. Allocations of up to 1,800 GAUs are made available to NSF-supported researchers without panel review, usually within three days of their application. During FY2004 NSF-supported projects from 62 institutions received SCD computational resources. (See Table 1).

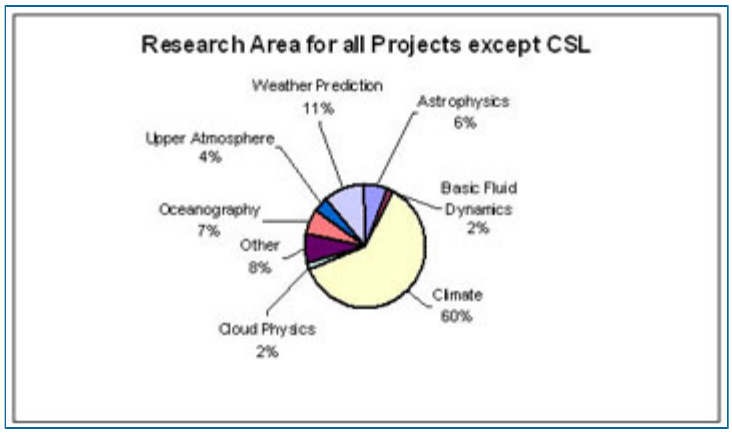
During FY2004 SCD provided over 11,000 GAUs of computational resources to 48 graduate students, and 40 postdocs in the atmospheric and related sciences who do not have NSF awards. Graduate students and postdocs may request allocations of up to 600 GAUs. Faculty members who have received their Ph.D. within the past five years and do not have an NSF grant may request allocations up to 1,500 GAUs. A list of the 29 institutions receiving graduate student and postdoctoral researcher support in FY2004 is given in Table 2.

Very small allocations (10-20 GAUs) are given to geoscience researchers at U.S. universities for data access.

In total, SCD made 216 allocations in FY2004 for data access, graduate students, postdocs, new faculty, and NSF-supported projects requests of <1,800 GAUs. This is an increase of 20% over last fiscal year.

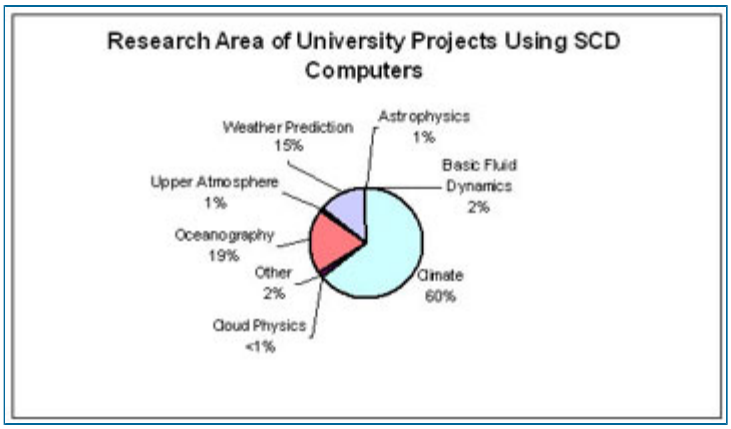


Distribution of Research Areas

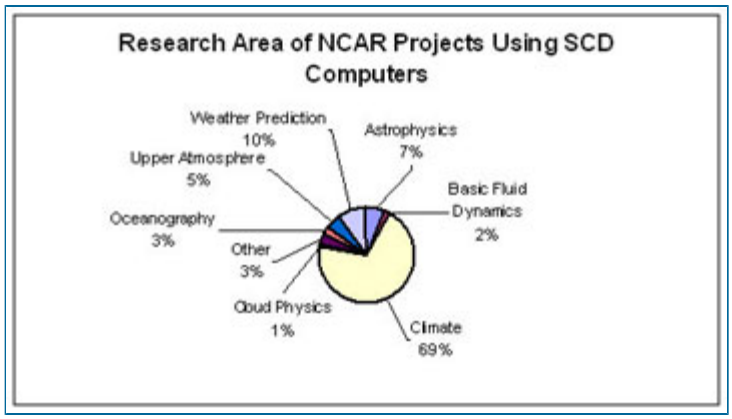


In FY2004, community use (defined as university and NCAR projects) was dominated by climate-related research. This included the completion of IPCC experiments run by NCAR using 12 upgraded nodes of bluesky (SCD's most powerful computer) that were funded for this research. Starting in October 2004, these nodes will be reallocated to the university, NCAR and CSL communities. (Click on image at left for a larger version).

University use is also dominated by climate (60%), with oceanography coming in a strong second (19%). (Click on image at right for larger view).



NCAR Allocations



NCAR researchers are allocated approximately 50% of the computational resources, the same amount as the university community. In FY2004, NCAR researchers used a larger share of the computing resources when there was no university work waiting to be run. (Click on image at left for a larger view.)

Climate Simulation Laboratory Allocations

Since 1994, in collaboration with the NSF Atmospheric Sciences, Ocean Sciences, and Mathematical and Physical Sciences Divisions, NCAR has operated a special-use dedicated climate system modeling computing facility known as the Climate Simulation Laboratory (CSL). The CSL provides high performance computing, data storage, and data analysis systems to support large, long-running simulations of the earth's climate system that need to be completed in a short calendar period.

The laboratory is open to all principal investigators funded or supported by a U.S. university or U.S. federal or U.S. private not-for-profit laboratory agency, including their international collaborators, who are performing research in support of the multi-agency Climate Change Science Program. Allocation of the CSL resources is done via a peer review process that includes a panel of experts in climate and/or large, long-running simulations. Large, collective group efforts, preferably interdisciplinary teams that address broadly posed sets of questions, such as the Intergovernmental Panel on Climate Change (IPCC) issues, are particularly encouraged to apply.

A new Announcement of Opportunity for the Climate Simulation Laboratory (CSL) computational resources was released in April 2004. The CSL Allocation Panel (CSLAP) met in July 2004 to review these proposals. The CSLAP allocated over 2 million GAUs of computing resources effective September 1, 2004 and continuing for 16 months to 12 projects. The projects receiving CSL allocations are shown at: http://www.scd.ucar.edu/csl/alloc.2004.html

During FY2004, 209 CSL researchers used SCD's computational resources (see http://www.scd.ucar.edu/csl/cslcomp.html) and consumed over 1.45 million GAUs. The largest project was the Community Climate System Model, which used over 1.1 million GAUs. In addition, SCD provided many computer hours of standby time for CSL projects when extra time was available. CSL projects were used heavily by both university and NCAR scientists. The accomplishments of the CSL researchers with their use of SCD computing resources are detailed at: http://www.scd.ucar.edu/csl/cslcpuchg0404.html

Accounting activities

In FY2004 our Data Base Services Group (DBSG) supported the following six databases using Oracle software:

- Database to track computer resource use and project contract information

- Database used as a back end for the SCD trouble ticket system and MySCD portal web pages, for SCD asset management and GLOBE school data
- Database for tracking mass store file information including mass store computer accounting
- New database created to support Enact project management software
- Test database for the portal project
- Test database for the SCD trouble ticket system

During FY2004, database processes were moved to a larger database server machine with twice the processors and twice the memory. DBSG installed Oracle 9i and upgraded the Oracle database software for the Remedy trouble ticket, asset management system, and the GLOBE school data to 9i.

DBSG participated in the evaluation of the LSF accounting software and began working with SSG on the use of the LSF accounting software to streamline computer accounting processing on SCD's high performance computers, beginning with the SCD's new Linux cluster.

DBSG created and/or modified scripts, programs, and the database to:

- Provide web reports and graphs of NCAR computer resource use for various time periods on a regular basis including job accounting information for each job run on bluesky and blackforest
- Provide reports and graphs and generate web pages in preparation for the SCD Advisory Panel meetings twice a year and the CSL panel meeting
- Track assignments of one-time password electronic cards used in securing access to NCAR high performance computers
- From mid-March through June, DBSG focused almost 100% of their time on developing and implementing new security procedures for SCD's high-performance computers in concert with the other groups in SCD. This included:
    - Taking requests, assigning, and working with SCD's OIS section to distribute 1,149 CRYPTOCards to users of SCD's high performance computers and 78 CRYPTOCards to system administrators and others in the institution so they could investigate moving to the CRYPTOCard system of one-time passwords
    - Reassigning passwords for all of SCD's high-performance computers and associated systems for each user
    - Processing requests for central authentication passwords which all university users of SCD's high performance computers now need
    - Adding three phone lines for the Database Services contact number so that DBSG could respond to the very high volume of questions regarding CRYPTOCards, passwords, removal/reactivation of user accounts as well as other new security procedures and policies

Transitioning Users During Equipment Upgrades

USS typically has early access to SCD equipment upgrade plans and uses this information to inform users on what will change and how to move their work to other equipment. In general, and depending on the type of upgrade or decommissioning, we:

- Announce equipment upgrades in advance, as far as advantageously possible, to our computing community. These changes are posted via the SCD News, the SCD Daily Bulletin, and in SCD local web pages. In certain cases, USS broadcasts email to its various user populations. Last spring, USS taught security changes via seminars presented to selected UCAR divisions and COLA.
- Develop and advertise strategies to help users anticipate change, outline the impact to their workflow, and show how to minimize the impact. USS uses the same advertisement mechanisms as above for this purpose. When new supercomputer upgrades are commissioned, SCD provides new user guides for the system.
- Work one-on-one as necessary to assist with any code conversion required for the transition.
- During a decommissioning process, USS archives user home directories to prevent loss of work and to expedite retrieval of files required for future work.

Visualization and Enabling Technologies

SCD's Visualization and Enabling Technologies Section (VETS) has a primary focus of advancing the knowledge development process. Our activities span the development and delivery of software tools for analysis and visualization, the provisioning of advancing visualization and collaboration environments, web engineering for all of UCAR, R&D endeavors in collaboratories, the development of a new generation of knowledge and data management and access, Grid R&D, novel visualization capabilities, and a sizable outreach effort.

VETS grew to 23 staff members in FY2004, which includes student contributors and new positions coming from external funds. We were awarded continued NCAR funding for a Cyberinfrastructure Strategic Initiative (CSI), and this covers two additional staff positions. The CSI has been a fine success, with excellent milestones reaching across all areas of endeavor. The Web Outreach Redesign and Development (WORD) project has delivered a beautiful and highly usable new web environment for NCAR, UCAR, and UOP. The Community Data Portal (CDP) in conjunction with its companion project, the Earth System Grid (ESG), is now serving internal science projects and serving a broad range of data to our community. We continued our efforts to deploy AccessGrid (AG) collaboration technology, integrated another SCD divisional system, and supported some exciting new applications of the technology.

We wrote and contributed to a number of proposals this year, particularly in the area of knowledge and data systems. We made a successful bid for a 2-year renewal on our Earth System Grid project, and the proposal was awarded high marks. ESG is now in production, serving CCSM, PCM, and IPCC data to a community of more than 100 registered users. Toward the end of FY2004, we also received notice that NSF intended to fully fund our bid to their NSF Middleware Initiative (NMI) program named "A Virtual Solar-Terrestrial Observatory." We will be collaborating with PI Fox in HAO on this exciting foray into semantic knowledge systems.

Building on the excellent success and community impact of our NCAR Command Language (NCL) application, we made a new foray into frameworks for geoscientific analysis and visualization: PyNGL. PyNGL is a Python interface to a refactored instance of our software, and it opens up myriad opportunities for expanding capability and leveraging open source efforts. After a successful recruiting campaign, we also made excellent progress on our new NSF ITR-funded VAPoR effort, which promises to deliver new tools for visually exploring and analyzing very large turbulence datasets.

VETS continued a very strong outreach program, providing dozens of presentations in our Visualization Lab. We continued our program where UCAR's Public Visitors Program (PVP) prepares and delivers highly visual presentations to visiting educational groups, and the results thus far have been very positive. Through teamwork, we are able to accommodate a much greater number of visitors with only a modest impact on SCD technical staff. We had a strong presence at the SC2003 conference and showed off a number of our new projects, including ESMF. In addition, we are engaging in research on cognitive issues in visualization with ASP and DLESE via a shared staff member.

Responding to recent NSF reviews of SCD, NCAR, and UCAR, we have continued an aggressive effort to define and gather metrics of performance. We are generating good data for web services, visualization services, visualization and analysis software, and ESG. In FY2005 we will bring metrics for the CDP online. Across all of these areas, we expect to be able to have a much more complete understanding of the value and impact of our many activities and to use that information to prioritize our efforts.

FY2005 promises to be an exciting year where we begin building major bridges across a superb portfolio of related projects: CDP, ESG, the NASA-sponsored GridBGC project, our AccessGrid efforts, VSTO, NCL, PyNGL, VAPoR, and our VizServer project. Considered as a whole, they not only represent a substantial impactful contribution to our community but also offer a splendid platform for building common Collaboratory infrastructure.

Cyberinfrastructure Strategic Initiative (CSI)

CSI Overview

The Cyberinfrastructure Strategic Initiative (CSI) was funded to dramatically advance our organizational web presence, our institutional web-based data presence, and the integration of collaboration technologies into the fabric of our day-to-day interactions. In FY2003 we completed our initial statement of work on AccessGrid (AG) environments, and NCAR/UCAR now has a large collection of AG nodes spread throughout the organization. During FY2004, we made excellent progress on our other two goals, which are manifested in the Web Outreach Redesign and Development (WORD) and Community Data Portal (CDP) efforts. Across all of these areas, the Strategic Initiative has accomplished one of its core missions: to fundamentally change how we share information among ourselves and with the world, how we manage and share scientific data, how we collaborate, and the scope of our future opportunities. The accomplishments of the WORD and CDP efforts are detailed below.

Web Outreach, Redesign and Development (WORD) Project

The WORD group launched a new UCAR, NCAR, UOP umbrella website in May 2004, bringing together news, research, and resources from all three institutions into a unified website designed to engage scientists, educators, students, and the public alike. The 25-member team of employee volunteers from across divisions created a staffing strategy that will support the ongoing maintenance of a significantly more dynamic top-level web presence without the need to hire additional staff.

The new site organizes information thematically, presenting a more natural interface for non-employees who previously

had to browse through our organizational hierarchy to find items of interest. The site more actively features NCAR's research and key resources with five automatically rotating items on the home page compared with the previous site's one feature. A brand new "Our Research" section consisting of over 50 pages was the project's largest content creation undertaking and provides an excellent introduction to the major issues in atmospheric science.

The site is careful to meet the highly individualized needs of scientists, educators, students, and the public, as well as UCAR members and employees with "especially for" pages for each of these audiences as well as "Our Research" topic pages that link to a universe of related information throughout our web presence for each audience.

Figure 1: Snapshot of the new WORD-developed "umbrella" site for our organization

Underpinning the new web presence is a completely new software architecture called VAVOOM that keeps the site current by storing metadata about news and other high-value information objects in a database and delivering them to the appropriate pages automatically. VAVOOM will continue to transform our overall web presence in the months and years to come with centralized catalogs of scientific publications, posters, instruments, applications, and other key information that has traditionally been scattered throughout individual division and program websites.

The WORD project and team is ongoing. The larger team continues as a UCAR web content advisory group that will reconvene occasionally to discuss institution-wide issues. A team of two WORD co-chairs and a Managing Editor steers the ongoing work of the WORD production team and convenes new subgroups when necessary to accomplish objectives. For example, a Laboratories subgroup was formed to launch five new NCAR laboratory websites in less than two months, bringing together all the appropriate divisional web developers for the task. The WORD team will continue to perform this integrative function across the three institutions and their divisions and programs.

You may visit the new umbrella website at http://www.ucar.edu/ The WORD team also maintains a project intranet site at http://word.ucar.edu/

The Community Data Portal (CDP)

The NCAR Community Data Portal or CDP (http://cdp.ucar.edu/) is an NCAR Strategic Initiative aimed at developing a central institutional gateway to the large and diversified data holdings of UCAR, NCAR, and UOP. The ultimate goal is to provide a state-of-the-art data portal with a broad spectrum of functionality ranging from data search and discovery to catalogs and metadata browsing, and from high performance and reliable data download to analysis and visualization.

Building on a conversion to a new THREDDS schema, we added a substantial number of new datasets to the CDP during FY2004:

- ACD/BAI MEGAN data
- ACD model evaluation data: several ACD field campaigns including TRACE-P, SOLVE, ACCENT, CRYSTAL-FACE, and POLARIS
- ATD IHOP 2002 field campaign
- CGD/CAS top-level data catalogs: ECMWF data, satellite data, climate indices, NCEP data, and surface data
- CU/ENLIL heliospheric model data
- VEMAP data (Vegetation/Ecosystem Modeling and Analysis Project)

During 2004 the following major technical tasks were accomplished:

- The underlying metadata architecture of the portal was upgraded to conform to the newly released THREDDS v1.0 specification, which includes geosciences-specific tags for search and discovery of datasets.
- A new, powerful search functionality was implemented that allows the user to perform structured queries on the content of the enriched THREDDS metadata. The search interface is complemented by "power-browsing" capabilities.
- High-level data services for aggregation and subsetting of NetCDF data were developed in collaboration with the Earth System Grid project and were deployed on the CDP web portal for the WACCM and MEGAN (Model of Emissions of Gases and Aerosols from Nature) model data.
- Other important developments include a package for storing and analyzing detailed portal usage metrics, and for managing the portal data cache for connection to the NCAR MSS via the Storage Resource Manager (Grid-enabled middleware from the ESG collaborators at LBNL).

Two very important collaborations were initiated and are currently actively pursued:

- CDP and other SCD staff are working to establish NCAR as an early DCPC (Data Collection or Production Center) contributing to the first prototype GISC (Global Information System Centre) developed as part of the long-term data and information strategy promoted by FWIS (Future WMO Information Systems).
- The CDP and GIS NCAR strategic initiatives are collaborating to share technologies and data holdings between the two portals, and to provide high-level interoperability between the specific areas of functionality.

Finally, a new Advisory Panel was established for the CDP, and the first meeting and review of the effort was undertaken during summer 2004.

Data and Knowledge Systems R&D

The Earth System Grid

The Earth System Grid (ESG) is a DOE-funded project focused on building a DataGrid for climate research that facilitates management and access to terascale climate model data across high-performance broadband networks. ESG is a collaboration of NCAR (SCD, CGD, and HAO), Argonne National Labs (ANL), Oak Ridge National Labs (ORNL), Lawrence Livermore National Labs (LLNL) Program for Climate Model Diagnosis and Interpretation (PCMDI), the University of Southern California Information Sciences Institute (USC/ISI), and Lawrence Berkeley National Laboratory (LBNL). This broad collaboration builds on one of the more exciting recent developments in computational science: Grid Technologies and the Data Grid. The Data Grid is a next-generation framework for distributed data access in the high-performance computing arena, and it addresses security, transport, cataloging, replica management, and access to secondary storage. The diagram below gives a general idea of the basic topology of our Grid and partner organizations.

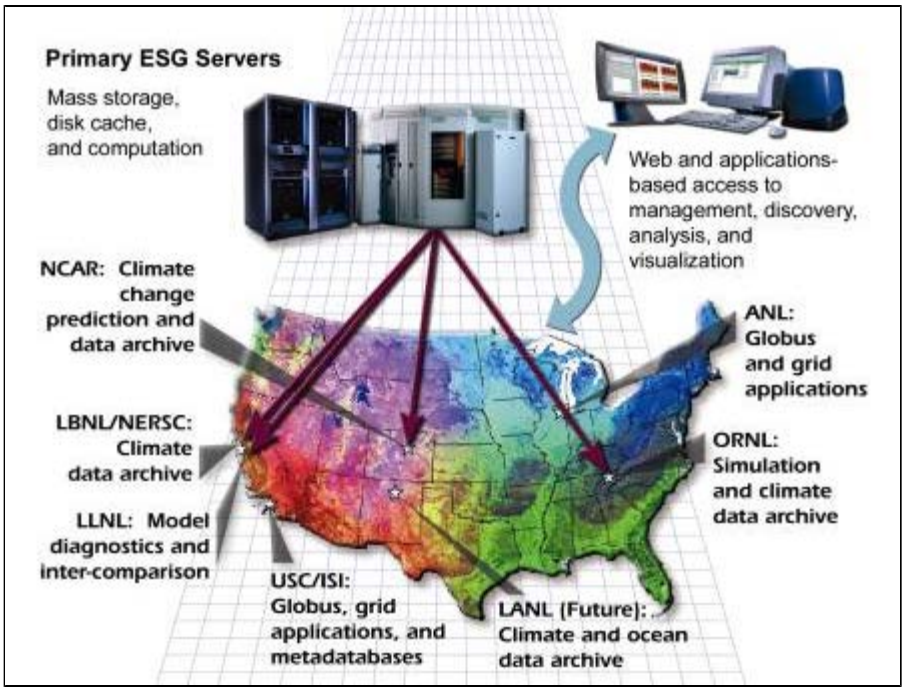


Figure 2: Project and data topology for ESG

ESG realized enormous progress in FY2004 and released a production version of the Earth System Grid web portal in summer 2004, coincident with the release of CCSM V3 and the subsequent CCSM Workshop. When the CCSM V3 announcement was made, new datasets for control scenarios were available for use by the Climate Modeling Community. Since then we have been publishing new model results constantly. The portal allows easy access to the latest CCSM (Community Climate System Model) v3 data, including simulation runs for IPCC scenarios, as well as to almost all of PCM (Parallel Climate Model) data holdings. Users may browse the data catalogs hierarchically, perform searches on metadata, download full files or subset the virtual aggregated datasets. The portal currently indexes 49 TB of data located at NCAR and other national data centers (e.g. ORNL, NERSC), and serves a community of approximately 100 registered scientists and researchers. More than 100 GB of data have been downloaded since the portal release in July 2004. The following image shows a shapshot of the ESG portal interface:

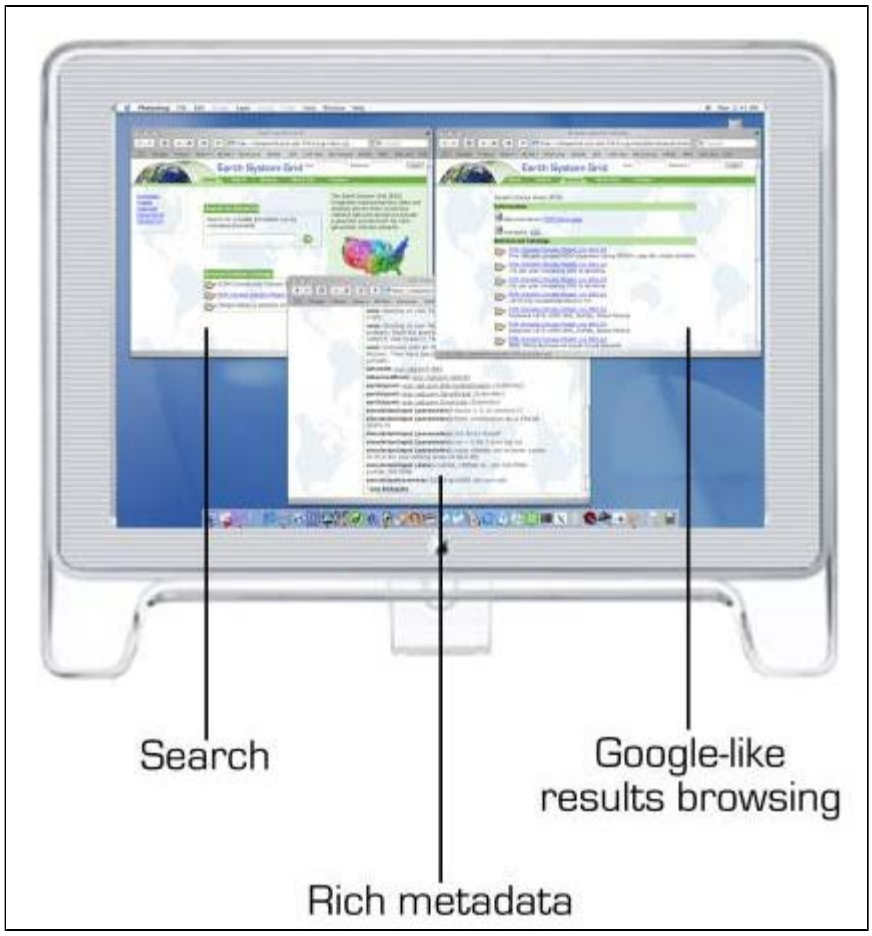


Figure 3: Earth System Grid Web Portal

Our multidisciplinary team had many accomplishments during the year, and we summarize a few of these below.

- Authored a successful bid for two years of continuation funding, including an increment to support adding Los Alamos National Lab to ESG. LANL will provide high-resolution ocean simulations to our Grid.
- Developed a robust, powerful dataset publication service and deployed it. CGD ESG contributors published 49 TB of distributed data composed of more than 100,000 files. We have supported a steady data publication process since our July release.
- Developed a new authentication and authorization system that allows us to conveniently register users and assign permissions such that they can access data according to DOE and CCSM Scientific Steering Committee policy. This was a collaborative effort between Argonne and NCAR.
- Developed and deployed a new metadata system based on the emerging U.K. OGSA-DAI (Open Grid Services Architecture. Data Access and Integration) package. We found that the early version that was available was not capable of handling the tens of thousands of files we have with CCSM, so we had to construct a workaround service. This was a good learning experience and provided valuable feedback to the OGSA-DAI developers, and we'll test-drive a new version in FY2005.
- Developed and released a production version of our Grid Web Portal, as per above.
- Developed an alpha version of our Virtual Data Services architecture, which combines Aggregation Services and OPeNDAP-g. This will be fully tested and released early in FY2005.
- Began design and development of our new DataMover-lite (DML) client.
- Began development and integration work of the IPCC Working Group 1 ESG Portal which will be housed at LLNL/PCMDI to support their commitment of delivering this data to the world.
- Provided various demonstrations at SC2003.

Our primary goals for FY2005 include continued data publication, usability studies and portal enhancement, improved metrics gathering and reporting, enhanced security infrastructure, and the production release of the IPCC WG1 site at LLNL/PCMDI.

CDP

See the Community Data Portal (CDP) section above.

GridBGC (Grid Biogeochemistry)

NCAR and CU were awarded a three-year grant through NASA's Advanced Information Science and Technology (AIST) program, one of 11 awards made nationally. The effort is aimed at developing a new modeling system that encompasses the remote execution of a biogeochemical model (a future component of CCSM), the Grid-mediated movement of initialization and output data, and associated web portals and analysis tools. This is a close collaboration among CGD (PI and scientist), SCD CSS and VETS, and CU's Computer Science Department.

During 2004 formal development work began on the project. During the first phase of the project, the system and software requirements were developed using several techniques. The primary technique used was interactions with the PI acting as user surrogate. During the process, several graphical user interface prototypes were developed to visualize the user experience in a concrete form. The requirements were refined based on feedback received during the process into a baseline document that the implementation could begin from.

After the baseline requirements were established, formal development began on the implementation. The initial implementation work had two primary focus areas. The CU staff developed the grid-based job management services and integrated Data Mover for data transfer between systems. The second area of development was the implementation of the graphical user interface. The user interface is being developed as web based portal using Java/Struts technology. After a skeletal implementation of the GUI is complete, it will be released to select beta testers for review. The results and feedback gained from the evaluation will be integrated into the application as development continues. The project website is http://www.gridbgc.ucar.edu/

The Virtual Solar-Terrestrial Observatory

Toward the end of FY2004, we were pleased to receive notice from NSF that they had ranked our Virtual Solar-Terrestrial Observatory proposal very highly, and intended to fully fund the proposed three-year project. A collaborative effort led by HAO and to be funded by the NSF Middleware Initiative (NMI) program, this forward-looking effort is aimed at developing the next-generation knowledge environments for this realm of science. It builds on our earlier Knowledge Environment for the Geosciences (KEG) work, the Earth System Grid, and the Community Data Portal. HAO and SCD will be collaborating with a range of ongoing efforts like CISM and CEDAR and our partners at Stanford's Knowledge Systems Lab.

Proposals and Strategic Opportunity Development

In addition, we prepared a number of other proposals this year in the areas of data and knowledge systems, including Chronopolis, a joint endeavor with the San Diego Supercomputing Center (SDSC). Chronopolis is still under review at NSF.

Data Analysis and Visualization R&D

NCL: Community Software for Data Analysis and Visualization

The NCAR Command Language (NCL) is an internally developed scripting language that provides robust file handling, data analysis, and publication-quality two-dimensional visualizations. The visualizations of NCL are based on those produced by NCAR Graphics, a collection of low-level C and Fortran routines for generating a wide variety of two- and three-dimensional visualizations.

The use of NCL continues to grow in the scientific community, as evidenced by the number of people visiting the two main NCL websites, the increasing number and complexity of questions being posted to the NCL email list, the unsolicited positive feedback we get from our users, and the growing interest in NCL's lab-based workshops. Seven of these workshops were held in FY2004, of which four were local, and three were at the Stennis Space Center, Purdue University, and the National Ocean Service. Since 2000, 23 workshops have been held with over 260 users in attendance. Continuing with other metrics, the estimated number of downloads of NCL from the web has increased 300% in the last four years, and the number of email subscribers has increased by 70% since 2003. As a side note, NCAR Graphics has been open source under the GNU Public License (GPL) since 2000, and it is averaging about 400-500 downloads a month.

Graduate students, professors, and researchers use NCL in areas of atmospheric science, mechanical engineering, geography, geology, geophysics, electrical engineering, earth sciences, biogeochemistry, and physics. It is used for data analysis and visualization of a wide variety of model runs, in teaching graduate-level atmospheric-science-related courses, for automatic generation of web pages, for use in real-time web sites, for converting file formats, and for publication-quality graphics in journals, presentations, and dissertations. NCL users hail from around the globe including Australia, Argentina, Brazil, Canada, China, Denmark, England, France, Germany, Greece, India, Italy, Japan, Korea, Norway, Portugal, Senegal, South Africa, Switzerland, Taiwan, United States, Vietnam, and Yugoslavia.

In FY2004, algorithms for contouring unique grids and triangular meshes were added to NCL. This functionality is considered by many scientists to be the most significant feature added to the software since its initial release in 1995. Some of these unique grids and meshes include:

- A grid from the High-Order Multiscale Modeling Environment (HOMME)
- A geodesic grid from Colorado State University's atmospheric general circulation model
- An adaptive grid from the Department of Atmospheric, Oceanic, and Space Sciences at the University of Michigan
- A grid from the International Satellite Cloud Climatology Project (ISCCP) in the World Climate Research Program at NASA
- A global ocean mesh (ORCA) from an Ocean General Circulation modeling system at the Laboratoire d'Oceanographie Dynamique et de Climatologie
- A triangular mesh from the Chesapeake Community Model Program Quoddy model
- A triangular mesh from a shelf-scale model run by an oceanography division at the Naval Research Laboratory
- A grid from the ARPEGE Atmospheric General Circulation Model developed by the French climate community
- A Parallel Ocean Program (POP) grid from Los Alamos National Laboratory, being used in the Community Climate System Model
- A satellite swath grid from UCLA

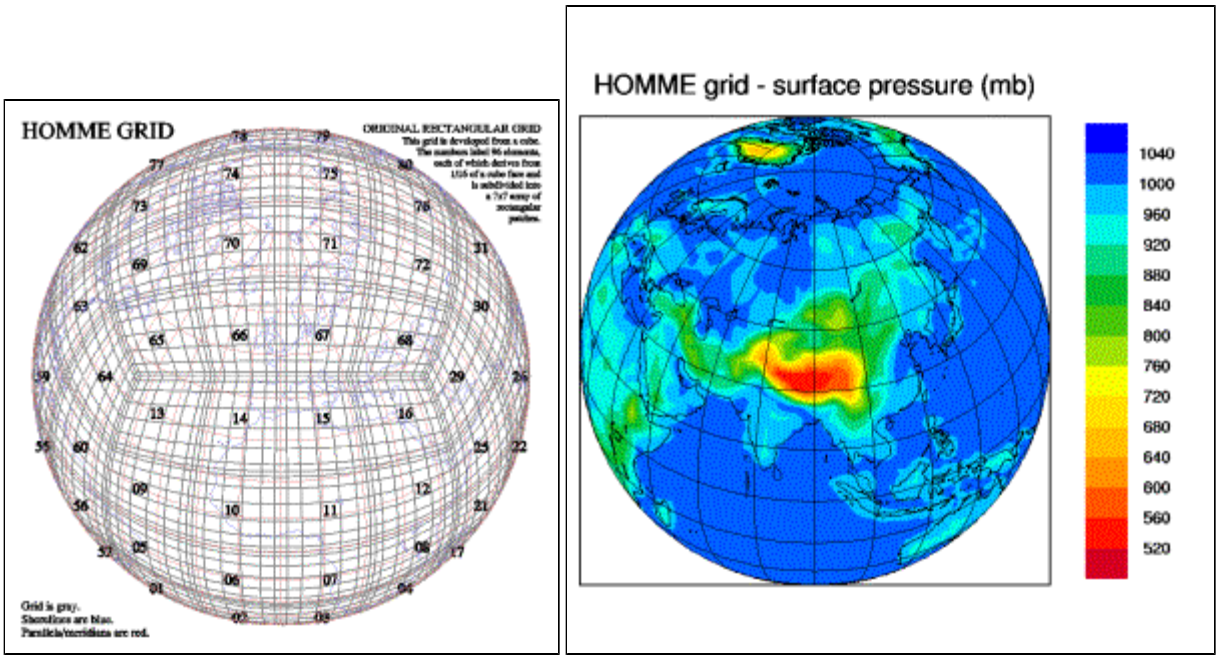
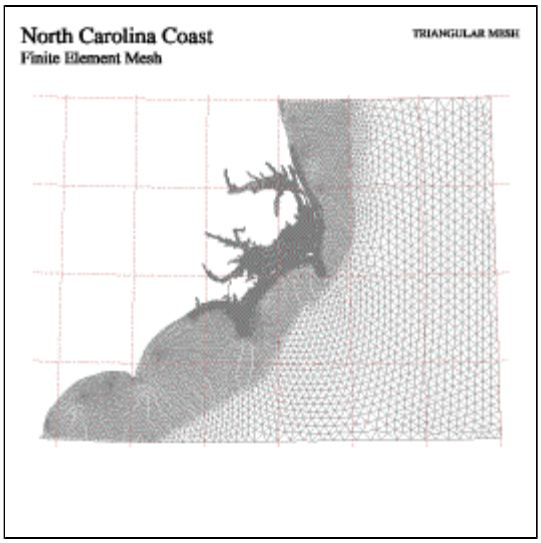


Figure 4: NCL/PyNGL rendering of the HOMME grid



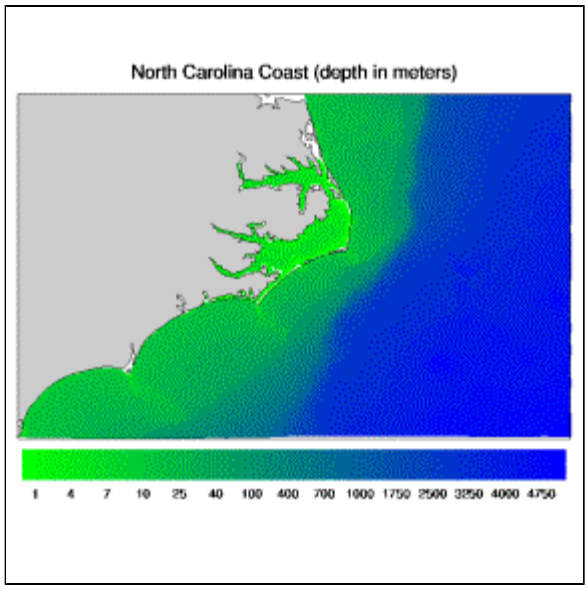


Figure 5: Visualizations of finite element mesh

In addition to enhancements, bug fixes, and general code maintenance, many other major features and updates were added to NCL in FY2004. In the area of data I/O, many updates have been made to NCL's GRIB reader, making it one of the most powerful GRIB readers available. Several functions for writing Vis5D files were added and NCL's OpenDAP capabilities were extended, giving users more file I/O capabilities, and the ability to pull over subsets of data served on the web.

NCL continues to be available on a wide variety of UNIX systems, and in FY2004, it was ported and tested on several new systems including FreeBSD, a variety of 64-bit Linux systems, and a MacOS X system using new compilers. These ports additionally provided invaluable testing and feedback for systems staff and users testing new platforms.

In FY2005, efforts are either underway or planned for adding vector and streamline visualization drivers for the special grids and meshes mentioned above, releasing a new command line interface for NCL, adding an HDF5/HDF-EOS5 reader, and researching a potential replacement for our outdated display model. A new display model will open the door for importing raster images into NCL, for saving visualizations to other raster formats (like PNG), and for getting new capabilities with colors that our current model can't handle.

Toward Frameworks for Analysis and Visualization - PyNGL

An alpha and a beta version of PyNGL (Python interface to the NCL Graphics Library) was released in FY2004. Python is a mainstream object-oriented programming language often compared to Tcl, Perl, and Java, and is gaining popularity in the atmospheric sciences community. PyNGL is a Python module that gives Python users easy access to the same high-quality two-dimensional visualizations available in NCL. This endeavor will make the functionality of NCL available to a much wider audience, and has opened the door to several potential collaborations and projects.

In FY2005, we plan to release the first version of PyNGL to the scientific user community. To supplement the visualization module, progress has been made toward creating a module of NCL's powerful I/O capabilities and providing Python wrappers to many of NCL's unique climatological functions. In addition, augmenting PyNGL with three-dimensional capabilities by coupling it with a Python module like VTK will be researched.

PyNGL is a pivotal step in our larger strategy to develop generalized frameworks for geoscientific analysis and visualization. By refactoring the computational and data I/O engines underneath NCL and providing Python integration, we not only offer a high-impact new software application, but we also position ourselves to be able to leverage the open source movement and couple in diverse functionality from other development efforts. These include data management, Grid environments, and interactive 3D visualization, and we have already begun to engage in some exploratory efforts.

VAPoR

The VAPoR project is an NSF ITR-funded, Open Source software development effort focused on improving the ability of earth sciences fluid flow researchers -- particularly those working in the area of numerically simulated turbulence -- to explore and analyze terascale-sized datasets. This project is one component of a larger time-varying data research-and-development effort whose collaborators include NCAR, U.C. Davis, and Ohio State University. With NCAR leading software development, and our university collaborators taking the lead on research, a mutually beneficial relationship has arisen; NCAR provides a steady supply of interesting research challenges to our university partners, who in turn provide solutions to some of our toughest visualization problems. One goal we are meeting with this partnership is reducing the lag between the time when visualization research results are first published and when they become available in end-user applications.

Much progress was made on the VAPoR development effort in FY2004. An international steering committee was assembled with representation from within and outside of NCAR. The steering committee worked actively with development staff to produce a rigorous Software Requirements Specification (SRS), detailing all of the needs of our target user group: working scientists. Following the creation of the SRS, developers crafted a Graphical User Interface design to accommodate the needs outlined in the SRS. A working GUI mockup was developed thereafter. Advanced GUI features present in the prototype, such as undo/redo capability and context-help, are but one example of steps taken to maximize the software's usability -- one of the forefront goals of the project deemed necessary for making it a success. We also hosted a U.C. Davis grad student this summer, whose activities focused on integrating his research results on stretched grid volume rendering into the application. Early in CY2005 we anticipate releasing a first alpha release of the software to steering committee members. A general release of the software is expected later in the year.

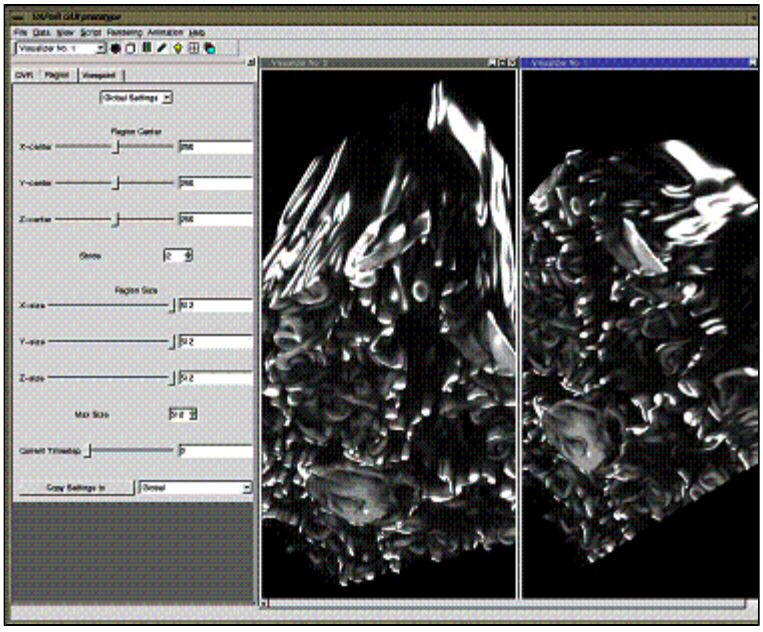


Figure 6: Screen snapshot of prototype VAPoR application

Visualization Lab and Services

Computational Facilities

VETS operates a state-of-the-art visual supercomputing facility, offering powerful interactive visual computing platforms,

batch platforms for data postprocessing tasks, and a shared, high-performance Storage Area Network (SAN) for containing large working sets of data. FY2004 brought few significant changes to the Vislab, with no major equipment upgrades performed. Much of the systems activity in FY2004 was undertaken in response to a heightened security status, following an NCAR-wide security breach. Though no Vislab systems were compromised, numerous proactive changes were effected in response to the threat. Measures taken included:

- Revising and developing new security policies encompassing user authentication, inactive accounts, provision of services, post-upgrade/install procedures, and attack response, to name a few
- Deployment of PAM-based user authentication for services and interactive logins
- One Time Password (OTP) authentication for root access
- OS and application revisions on all platforms

Not all Vislab activities were aimed at security improvements. Vislab technical staff fruitfully invested time in exploring, and in some instances deploying, commodity-based technologies offering significant price/performance advantages in a couple of key areas. RAID storage systems comprised of inexpensive ATA drives were investigated and successfully deployed in support of Vislab as well as non-Vislab related projects. Much effort was also spent evaluating and experimenting with commodity-based graphics/visualization systems. This research led to acquisition of two commodity clusters that will serve as replacements for aging, expensive SGI technology (see Experimental Visualization Cluster).

Access Grid Facilities

VETS continues to maintain and operate several Access Grid Nodes in the Division, including the main node in the Vislab and a portable node that can be moved on short notice to other, local meeting facilities. Staff maintained a testing platform for new AG functionality and supported experiments with new videoconferencing tools and environments in the context of scientific collaboration and visualization. The AG staff continues to track and implement new Access Grid updates and functionality, and they provide consulting and tutorials to new users on a per-request basis. VETS also provided consultation and planning for the integration of the divisional Access Grid and the A/V systems in the SCD conference room, and they helped coordinate the remodel between the NCAR Multi-Media Group, and a third-party contractor.

Events and Metrics

VETS continues to provide support for meetings and demonstrations in the Vislab. Including the ongoing partnership with the Public Visitor Program which provides outreach to public and school groups. VETS supports demos to government and scientific visitors, video conferencing for researchers and software developers, and meeting space for review teams and advisory panels.

The following table lists the number of events and participants that were recorded this fiscal year:

	AG Meetings	Vislab Demos	Vislab Meetings
No. of Events	66	88	13
No. of Participants	240	1,489	155

Experimental Visualization Cluster

The performance of commodity graphics chips has increased at a rate exceeding Moore's law for the last several years, and inexpensive gaming chips now offer performance far surpassing traditional high-end graphics systems. With the advent of programmable Graphics Processing Units (GPUs), the capabilities offered by these platforms is unprecedented. However, due to the limited memories of 32-bit PCs, tackling large data problems with these systems required clustering machines together; an exercise often fraught with frustration due to limited software availability for these distributed memory systems.

The emergence of 64-bit PC processors in FY2004 has changed the visualization system landscape once again; it is now possible to build an inexpensive, powerful graphics platform with a large memory and a simple programming environment. Vislab staff have been evaluating commodity systems for several years and concluded that with these recent processor developments the time was right to enter the commodity visualization system space. A pair of

inexpensive 64-bit graphics workstations was acquired at the end of FY2004 to replace the Vislab's aging SGI visual supercomputers. This marks a strategic step for the Vislab as we move away from costly proprietary systems.

Vizserver and Metrics

The VizServer project provides an advanced image-delivery service permitting users from inside and outside the NCAR campus to access centralized, visual supercomputing services from the convenience of their own office. This capability is essential to interactive visual analysis work as it enables the spontaneous access needed to support visual data exploration. This service, initiated in FY2003, entered into production mode in FY2004 with relatively modest activity. Two major software upgrades were performed and steps were taken to improve the security of the system, which supports users outside of the NCAR firewall. Vislab staff also began exploring alternatives to the proprietary, SGI-only image-delivery service currently employed, looking at promising new technologies with better platform portability, including support for our new 64-bit commodity graphics cluster.

For FY2004, monthly average usage metrics for the VizServer system include: 7 unique sessions and 160 total sessions.

Collaboration Environments R&D

VETS staff completed the deployment of a Collaboration Environment at Howard University and continued participation in the Scientific Workplaces of the Future project as a testing partner for new collaboration technologies.

Howard University AG

NCAR sponsored the acquisition, deployment, and testing of an Access Grid node at Howard University, a historically African-American university in the Washington DC area with a growing and vibrant atmospheric sciences program. The installation was made in the new computer lab of the Howard University Program in Atmospheric Sciences (HUPAS) and completed in early 2004 providing HU with new videoconferencing and research collaboration capabilities.

Vislab Staff worked with IT personnel at Howard University and a third-party Access Grid supplier, InSORS, to coordinate the planning, purchase and deployment of this system, which included projection systems, microphones, video cameras, computer system, and audio gear.

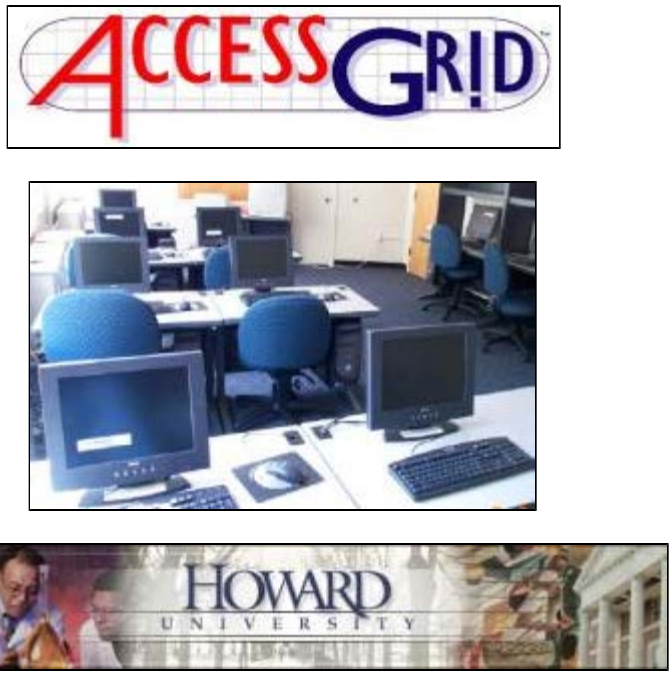


Figure 7: Howard University's new AccessGrid facility

Scientific Workspaces of the Future

VETS continued to participate as an unfunded partner with the Scientific Workplaces of the Future (SWOF) Project. Staff met on a biweekly basis over the Access Grid with partners from Boston University, ANL, EVL, NCSA, and LANL to discuss new tools and innovations for application in Access Grid environments.

VETS provided testing and feedback for new functionality including the ANL Shared Movie Player, ScView, Rasmol, and audio/video tracking software.

Enterprise Web Services

Web Facilities

The Web Engineering Group (WEG) completed its migration of numerous services to a new high-performance backend cluster in FY2004. The new cluster will meet the needs of our increasingly dynamic and computing-intensive websites, applications, and services. A new test cluster, expected to be finished in 2004, is still under development due to the impact of UCAR security issues this year. The test cluster will enable developers to test their sites in a production-like environment before going live. In FY2005, we will replace our front-end cluster, interactive sessions server, and install a remote desktop administration server to increase system administrator productivity. This will complete our new architecture.

Web Tools and Services

The WEG was an integral part of the WORD group's launch of the new UCAR-NCAR-UOP umbrella website. The WEG created the underlying software and hosting architecture for the site. This innovative architecture, called Vavoom, which an NSF review panel recommended the WEG share with other institutions, applies the metadata cataloging approach that has been so successful in the arena of scientific datasets to create centralized catalogs of high-value information objects scattered throughout the UCAR web presence. The Java-based architecture enables division and program web developers who host their site with the WEG to utilize the metadata holdings in their own sites. It also caches data to maximize performance and minimize server load. The potential for this architecture to transform our overall web presence is significant, and we are just now beginning to see its effects.

The People Search web application developed by the WEG has been a resounding success and was enhanced this year with failover capability. The application now enables employees and system administrators to modify profile information as well.

A new system aggregates all our web logs for improved log management. We began beta testing a new web traffic analyzer service that provides web developers with the ability to drill down into statistics to get very specific metrics for their sites.

Web Outreach, Advocacy, and Community Building

The WEG gained several new high-profile customers in FY2004, continuing its mission to centralize web-hosting services for the institution. These included ESIG, GLOBE, HAO, HIAPER, and MMM. In the interest of improved customer service transparency, the WEG began publishing its work request queue on the WEG website.

The WEG was presented with the unique opportunity to host the Space Science Institute's MarsQuest Online website for the Mars Land Rover missions. We worked with several institutions to put together a hosting solution to meet the high traffic and database replication needs of this site. The WEG cluster served over 44 million page views for MarsQuest this year, with over 20 million in July alone.

The Web Advisory Group, which advises the WEG, completed its implementation plan, identifying several key priorities for the overall institution. These are a test cluster (already under development), search engine optimization (already underway), next-generation authentication and access control, metadata directories and catalogs (already in production and under ongoing development), collaborative portals (Swiki pilot project underway), and a Content Management System.

WORD Project

See Cyberinfrastructure Strategic Initiative

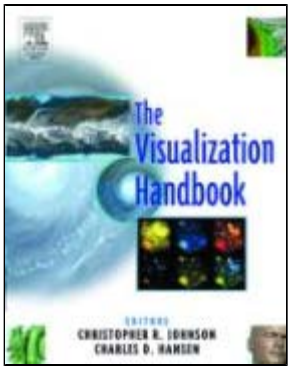
WEB Metrics

The WEG web cluster served over 158 million web pages in FY2004, a 50% increase over last year, and a total of 5.8 terabytes of content. UCAR websites hosted by the WEG received over 10 million visits. Peak load has reached over 3 million pages per day, nearly 4 times last year's peak.

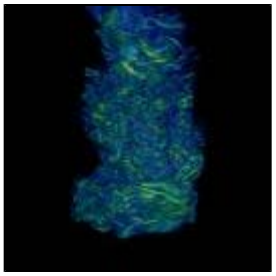
Special Projects in Science, Technology, and Collaboration

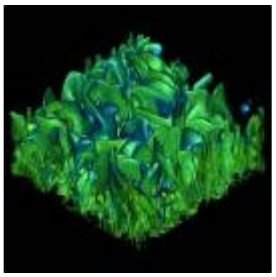
VETS continued to collaborate on many different modeling efforts and research projects across the organization and the broader community. Staff members work directly with NCAR researchers and scientists inside and outside the organization to jointly develop new technologies and visualization solutions to their problems. The examples below summarize VETS FY2004 collaborative visualization efforts.

Middleton, Scheitlin, and Wilhelmson (NCSA) collaborated with editors Johnson and Hansen (University of Utah) to develop a new book for the visualization and science community: *The Visualization Handbook*. This team authored a chapter entitled Weather and Climate Visualization, and drew on examples from R&D projects in universities, centers, and commercial firms from around the world. Academic Press will publish the new text in November 2004.



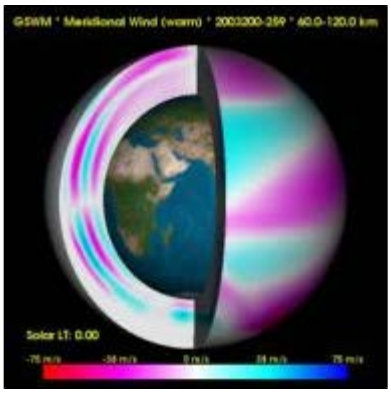
Mendoza continued collaborations with HAO's Rast on the production of numerous visualizations of Compressible 3D Starting Plumes and Compressible Convection, utilizing over 5 TB of turbulence data.



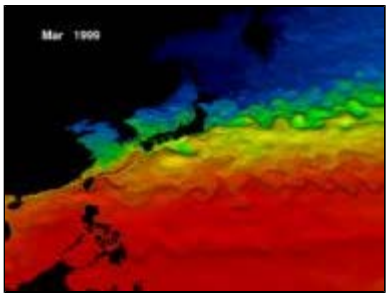


Clyne worked with Jack Herring (NCAR, Emeritus) and Yoshi Kimura (Nagoya University, Japan) on exploration of "pancake" structures found in high-resolution, stratified, decaying turbulence simulations.

Clyne continued collaborations with HAO's Qian Wu and Tim Killeen on the production of numerous visualizations of TIMED Doppler Interferometer (TIDI), Global Scale Wave Model (GSWM), and Thermosphere-Ionosphere Electrodynamic General Circulation Model.



Scheitlin worked with Frank Bryan (CGD) to generate several visualizations from the high-resolution 0.1-degree POP model. Visualizations show sea surface temperature and sea surface height animated with daily timesteps.

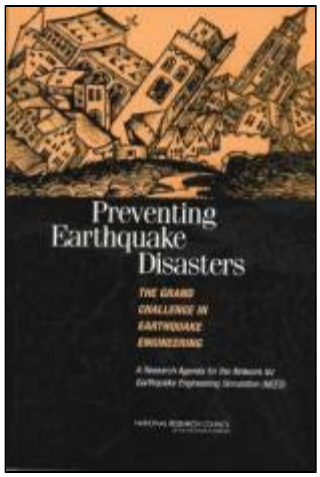


VETS provided several climate visualizations that were used in an American Museum of Natural History September video feature. CGD scientist, Jim Hurrell, was interviewed about the North Atlantic Oscillation, and he used VETS animations as a backdrop for his discussion.

Serving on the IEEE Vis 04 Conference Committee, Middleton co-organized the first annual Visualization Challenge. A new WRF simulation of Hurricane Isabel was chosen for the competition, and the NCAR team of Kuo, Scheitlin, Wang, and Bruyere postprocessed the model data, converted it to a simple structure, and published it on the web. Middleton and Kuo served as judges for this new effort, which generated a lot of interest, participation, and exciting results.

Middleton served on the National Research Council "Committee to Develop a Long-term Research Agenda for the Network for Earthquake Engineeering Simulation (NEES). Working with his fellow committee members and experts in the earthquake engineering community, they authored a new report entitled "Preventing Earthquake Disasters: A Research Agenda for the Network for Earthquake Engineering Simulation (NEES)." Middleton focused on the information technology aspects of the

endeavor.



Research Data Support and Services

Stewardship and Curation

SCD's Data Support Section (DSS) manages and curates an important research data archive (RDA) containing observational and analysis reference datasets that support a broad range of meteorological and oceanographic research. Careful curation of the archive extends existing datasets and adds new ones to the collection. Stewardship work improves the RDA by capturing and improving documentation, creating systematic organization, applying data quality assurance and verification checks, and developing access software for multiple computing platforms. All activities are founded in the principles of acquiring the necessary data and making it readily available for scientific research.

Routine Archive Growth

Routine curation builds existing datasets into longer time series. Most often this is simply done by adding files that contain the most current information available, but sometimes it includes extending a time series backward in time, filling data void periods, and replacing segments with reprocessed data. DSS has 79 datasets that receive routine curation at least annually, with most (48 datasets) receiving new data by network transfer. Some data (18 datasets) are still delivered by CDROM and tape. Slightly fewer than half are updated monthly or more frequently (26 monthly and 3 daily). These frequently updated sets are typically global observations and model outputs from NCEP, various SST analyses, and near-real-time observations and model data from the Internet Data Distribution system.

New datasets are added to the RDA for many reasons, but two major purposes are to preserve historical observational or analyzed collections against loss and to make new products available that are necessary for leading-edge research at NCAR and the university community. The 25 new datasets for the past year are shown in Table 1.

Table 1: New datasets added to the SCD Research Data Archive in FY2004

Dataset ID Number[1]	Dataset Title
ds117.0 ds117.1 ds117.2 ds117.3 ds118.0 ds118.1 ds119.0 ds119.1 ds119.2 ds119.3 ds120.0 ds120.1 ds123.0	ERA-40 Output Analyses 13 different product datasets

ds277.5	Extended Reconstructed Sea Level Pressure, 1854-1997
ds335.0	Historical Internet Data Distribution Gridded Model Data, beginning May 2003
ds336.0	Historical Internet Data Distribution Global Observational Data, beginning May 2003
ds351.0	NCEP ADP Global Upper Air Observations, BUFR format, start April 2000
ds435.0	Monthly Mean Rawinsondes, from NCEP/NCAR Global Reanalysis, beginning 1948
ds461.0	NCEP ADP Global Surface Observations, BUFR format, beginning April 2000
ds506.0	U.S. Surface Hourly Data (1928-1948) from NCDC
ds530.0	Supplementary (Add-on) Datasets
ds533.1	Marine surface meteorological and actinometric observations from Russian RV
ds540.6	GTS, SEAS, and keyed Marine Surface Data from NCDC
ds556.0	Global Monthly Stream Flow Time Series
ds744.8	QSCAT & ADEOS-II / NCEP Blended Ocean Winds

[1] The web address for each dataset is constructed by substituting the Dataset ID Number into the following template: http://dss.ucar.edu/datasets/ds*xxx.x*/

Important New Research Data and Initiatives

ECMWF Re-Analysis

Curation and stewardship are often combined, and the recent acquisition of the ECMWF Re-Analysis (ERA-40) serves as a major example. The ERA-40 project has produced a comprehensive global analysis for the 45-year period covering September 1957 to August 2002. The project utilized an atmospheric model with 60 vertical levels, T159 spherical harmonics representation for the basic dynamic fields, and a reduced gaussian grid with an approximate uniform spacing of 125 km for surface and other fields. The reanalysis model ingested multiple archives of *in situ* and satellite observations.

As a partner in the project, DSS is the sole distributor of the ERA-40 data products in the US and to UCAR members in North America. The products include atmospheric model resolution analyses and forecasts, ocean wave analyses and forecasts, many parameters at lower resolution (2.5 degree latitude by longitude grids), monthly mean analyses, vertical integrals of atmospheric energy, mass, and fluxes, analyses on isentropic and potential vorticity surfaces, and special products for research in chemical transport and radiative transfer.

The total archive is over 30 TB in size. The primary analyzed data and locally computed supplementary products (about 10 TB) will be maintained online and organized into smaller product subsets to promote easier access for the public research community. Currently, there is about 2.1 TB online. A web interface for each product provides direct access for both large and small data downloads initiated in real-time. Users may also design their own subsets for some products by selecting variables, time, and levels through a web interface. These custom requests are typically processed in a delayed mode with user notification by email when the data are ready. Users with SCD computing accounts have unlimited access to the data on the data server. For those users, all ERA-40 data are available from the MSS, and the product web pages need only be used to ascertain the MSS file names and acquire software to read the data. A comprehensive

description of the ERA-40 archive and access to the data are available at http://dss.ucar.edu/pub/era40.

The stewardship work to prepare ERA-40 is not complete. Some software has been developed to decode, regrid, and reformat the data. More software and subset products are planned, and additional products will be computed to aid scientific research, e.g. process the spectral harmonic data (T159) on both model and pressure levels and create T85 Gaussian grids (128 x 256).

User access to ERA-40 is just beginning, and early indications are it is useful for many research projects, with usage from both the MSS and the online data server being comparable. The users and data amount statistics for the first nine months and a linear prediction for the 2004 annual values are given in Table 2. It is likely that in the first year, ERA-40 will have 125 unique users accessing nearly 20 TB of data. It must be noted that these statistics reflect the minimum usage, because a single copy provided by SCD can be used by many in multiple-member research groups.

Table 2
ERA-40 Data distribution metrics for January-September 2004, and a 2004 annual estimate

	Unique Users	**Data Amount (TB)** [2004 est.]
Data Server (Web and FTP)	49 [61]	8.8 [11.0]
MSS	51 [64]	6.8 [8.5]
Total	100 [125]	15.6 [19.5]

North American Regional Reanalysis

NCEP completed the North American Regional Reanalysis (NARR) model run in April 2004. Temporally, it is three-hourly and spans 1979 through 2003. Spatially, it is 32km and 45 levels with a coverage that is quite large; from extreme northern South America to the Canadian Arctic and includes vast regions of the eastern Pacific and western Atlantic Oceans. It is planned that the time series will be extended into 2004 and beyond as an ongoing near-operational product.

The scientific focus for NARR is high resolution with significant improvements in moisture fluxes (e.g. precipitation) and budgets in both the atmosphere and soil. It is largely believed to have achieved this goal and is therefore an important data product for the research community.

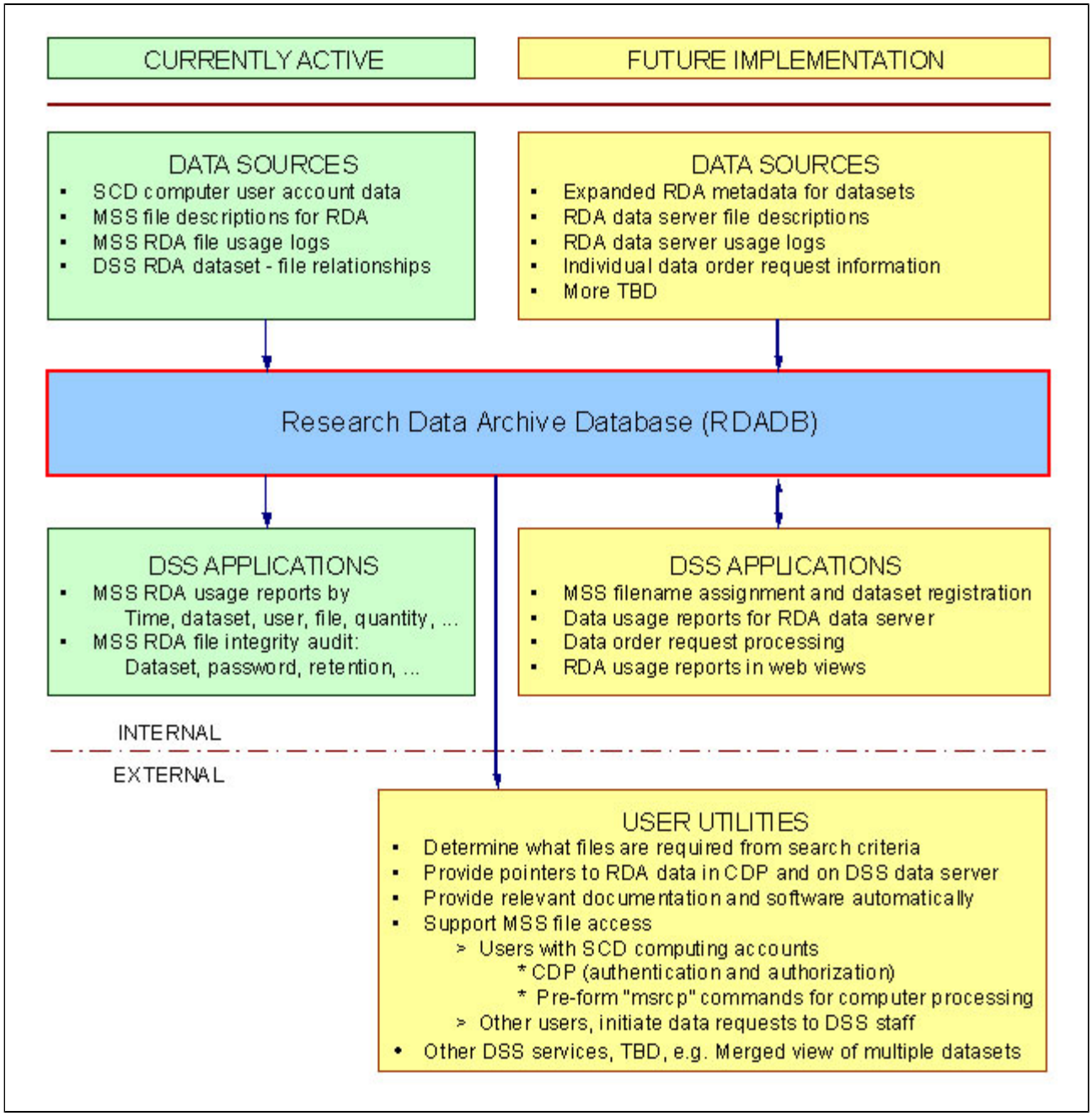
Our plan was first to use magnetic tape to transfer the data from NCEP to NCAR, but circumstances and an unwillingness for further delay made us adopt FTP network transfer for NARR. The transfer was begun in June 2004, and as of October, 2.8 TB including data for 1987-2003 have been moved to the NCAR MSS. That transfer rate is in lock step with the rates at which NCEP has been making the data available, and the transfer will go on to include the period back to 1979 in the coming months. All totaled, the NARR primary analyses will be about 5 TB. Currently, we are considering what selected parts of the forecast data, which are not included in the analyses total, might be important for our users and as a backup archive for NCEP.

We are developing plans to prepare the NARR archive, maintain it, and make it readily accessible. It is expected that NARR will be a very useful research dataset because of the high temporal and spatial resolutions and from the fact that the code was expressly developed to capture the precipitation and atmospheric water budget. As an example, NARR will be a primary research dataset for the Global Energy and Water Cycle Experiment (GEWEX) Americas Prediction Project (GAPP).

Research Data Archive Database

Database technology has been implemented with objectives to improve DSS internal operations and external RDA user support. In the broadest terms, the RDA Database (RDADB) combines metadata information from DSS and SCD sources, has applications that quantify how the RDA is used, is used to monitor the RDA integrity, and will provide users with information that improves access and service. The system is schematically shown in Figure 1. Active and future implementations are distinguished by color and labels, data sources and applications are labeled, and arrows show the data flow. User utilities, which have not been implemented yet and are an external provision from the RDADB, will be developed once all the internal features have been completed. The system is currently about 30% completed.

Figure1
Data Support RDADB Schematic



Research Data Archive Metadata Development

The DSS has been capturing and storing dataset and data file metadata in systematically organized ASCII files for over 20 years. The content of the RDA has been made more visible by extracting basic metadata from the ASCII files and writing a Dublin Core compliant form that has been compiled into THREDDS catalogues and hosted on the UCAR Community Data Portal (CDP). This is a first step toward improved data discovery of the RDA within the context of all UCAR data holdings.

Improvements on the first step will be through a DSS project to standardize the capture and storage of metadata across all datasets and data files. Standardized metadata will make it possible to create better dataset and data file descriptions, enhance data search capabilities, and ensure that the RDA metadata is easily mapped to standards being used in the CDP and other data portals, e.g. the NASA Global Change Master Directory.

Work is underway to develop XML formats for storing dataset and data file metadata and create applications that automatically extract and store metadata. To begin the effort and prioritize the work on the large (more than 500-member) RDA, the datasets have been ranked by usage frequency over the past year. The datasets in the top 15% are

being modified first, and all new datasets will be included. The expertise of all DSS staff is necessary to accomplish this goal, which has involved improvements to the dataset summary texts, and will require verification and editing of discovery and use metadata in a system that has a constrained standard vocabulary. The strategy is such that improvements will be factored into our operational system as soon as they are ready, providing the users with the earliest possible benefit. Moreover, as improvements are made they will be mutually represented on the CDP the RDA data server.

Continuing Research Data Development and Services

International Comprehensive Ocean-Atmosphere Data Set

The International Comprehensive Ocean Atmosphere Data Set (ICOADS) was updated to include new data for 1998-2002. This is Release 2.1 and now covers 1784-2002. ICOADS is the largest available set of in situ marine observations. Observations from ships include instrument measurements and visual estimates while data from moored and drifting buoys are exclusively instrumental. The ICOADS collection is constructed from many diverse data sources, and made inhomogeneous by the changes in observing systems and recording practices used throughout the period of record, which is over two centuries. Nevertheless, it is a key reference dataset that documents the long-term environmental state, provides input to a variety of critical climate and other research applications, and serves as a basis for many associated products and analyses.

The observational database is augmented with higher-level ICOADS data products. The observed data are synthesized to products by computing statistical summaries, on a monthly basis, for samples within 2 degrees latitude x 2 degrees longitude and 1 degree x 1 degree boxes beginning in 1800 and 1960, respectively. For each resolution the summaries are computed using two different data mixtures and quality control criteria. This partially controls and contrasts the effects of changing observing systems and accounts for periods with greater climate variability. The ICOADS observations and products are freely distributed worldwide. The ICOADS project is a three-way cooperation between the National Oceanic and Atmospheric Administration (NOAA) -- its Climate Diagnostics Center (CDC) and National Climatic Data Center (NCDC) -- and the National Science Foundation (NSF) National Center for Atmospheric Research (NCAR).

NCEP/NCAR Global Atmospheric Reanalysis - Reanalysis 1

NCEP/NCAR Global Atmospheric Reanalysis (R1) is a very important component of the RDA. R1 covers the period 1948 to 2004 and is updated on a monthly basis, adding about four GB of data each month. The four-times-daily analyses provide products on various atmospheric reference frames (pressure and isentropic levels) and at the surface. Simple monthly means are computed, and related derived products (e.g. monthly mean rawinsondes from R1) are available to augment the research. CDROMs for each year -- 2003 is the most recent -- are created to aid in the data distribution of the most-used data. All monthly mean data products and the most recent past 12 months analyses on pressure levels and fluxes at a 6-hourly interval are available on the RDA data server. Table 3 shows the users and data amounts distributed for 2004. It is remarkable that this archive first became available, with a limited number of years of data, in 1995 and is still very popular with several hundred unique users and over 8 TB of data distributed in 2004.

Table 3
NCEP NCAR Global Reanalysis data distribution metrics for January-September 2004 and a 2004 annual estimate

	Unique Users	**Data Amount (GB) [2004 est.]**
Data Server (Web and FTP)	n/a	616 [770]
CDROM	22 [28]	148 [185]
MSS	146 [183]	5483 [6853]
Individual Request	26 [33]	458 [573]
Total	194[1] [243]	6705 [8381]

[1] Low estimate because number of unique users were not available for the Data Server

NCEP Final Global Analyses and Global Observational Files

The operational weather model and observational archives from NCEP are now more readily available to users. The past 12 months of data from the NCEP operational Global Final (FNL) Analyses at 1 degree x 1 degree resolution and the companion upper air and surface observations are now available online (dataset ID numbers ds083.2, ds353.4, and ds464.0). These online data have greatly assisted MMM and WRF model users. The FNL ranks number one, and the surface observations rank number three for largest data amounts downloaded from the RDA data server.

Real-time Data from the Internet Data Distribution System

The UCAR Unidata staff operates and maintains a software system as a primary node on the Internet Data Distribution (IDD) system. SCD provides the site and administrative support for the system. As part of the collaboration, some of the real-time model and observational data are preserved in RDA datasets. The full period of record, model data beginning December 2002 and observations May 2003, are available from the MSS. Researchers that need near-real-time data further benefit because the most current 90 days of both data streams are kept online. The model data are used by some (approximately 320 unique users and 31 GB of data downloaded for January - September 2004) while the observational data, both upper air and surface, are more popular. It ranks number eight among all datasets downloaded from the RDA data server and has about 1,700 unique users that have received 100 GB over the first three quarters of 2004.

Service

The RDA is an important collection of reference datasets. With simple metrics we quantify the number of users and amount of data delivered. These measures are an assurance that we are providing a valuable service in the most general sense. They also provide one indication of where we should focus our stewardship resources.

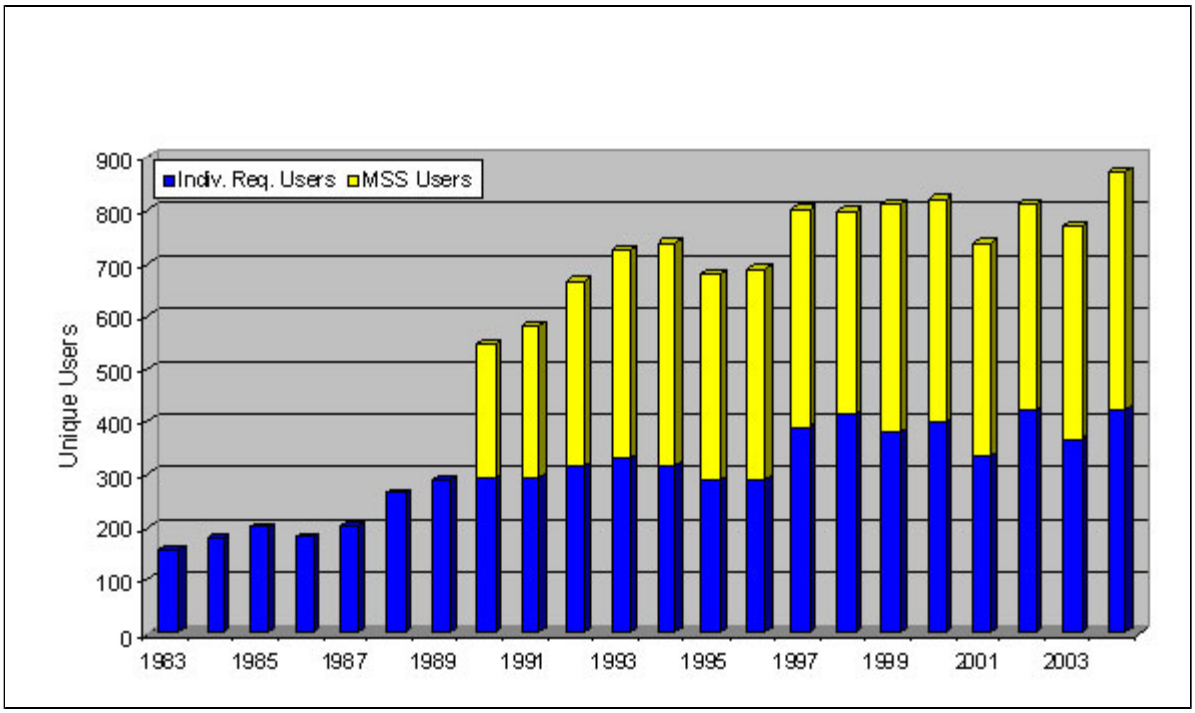
Metrics for Users

The RDA users can be separated into two categories; those who are known (by name, email, etc.) and those who are anonymous. Known users contact the DSS to submit individual data requests or use an SCD computing account to access data from the MSS. Anonymous users access the RDA from the data server and use web browsers, anonymous FTP, and script codes to gather the data they need. These two user categories are individually significant, but cannot be jointly summarized on an equivalent scale.

Known users with SCD computing accounts have access to all files in the RDA from the MSS and can find them by using online documentation. Users without computing accounts who need parts of the RDA that are not available from the data server or who have access limitations must contact DSS to arrange for their requests to be filled. We have been tracking the number of unique users who make individual requests since 1983 and those accessing the RDA from the MSS since 1990 (Figure 3). Since 1997, about 800 unique users are served annually by these methods.

Figure 3

Unique Users of the Research Data Archive

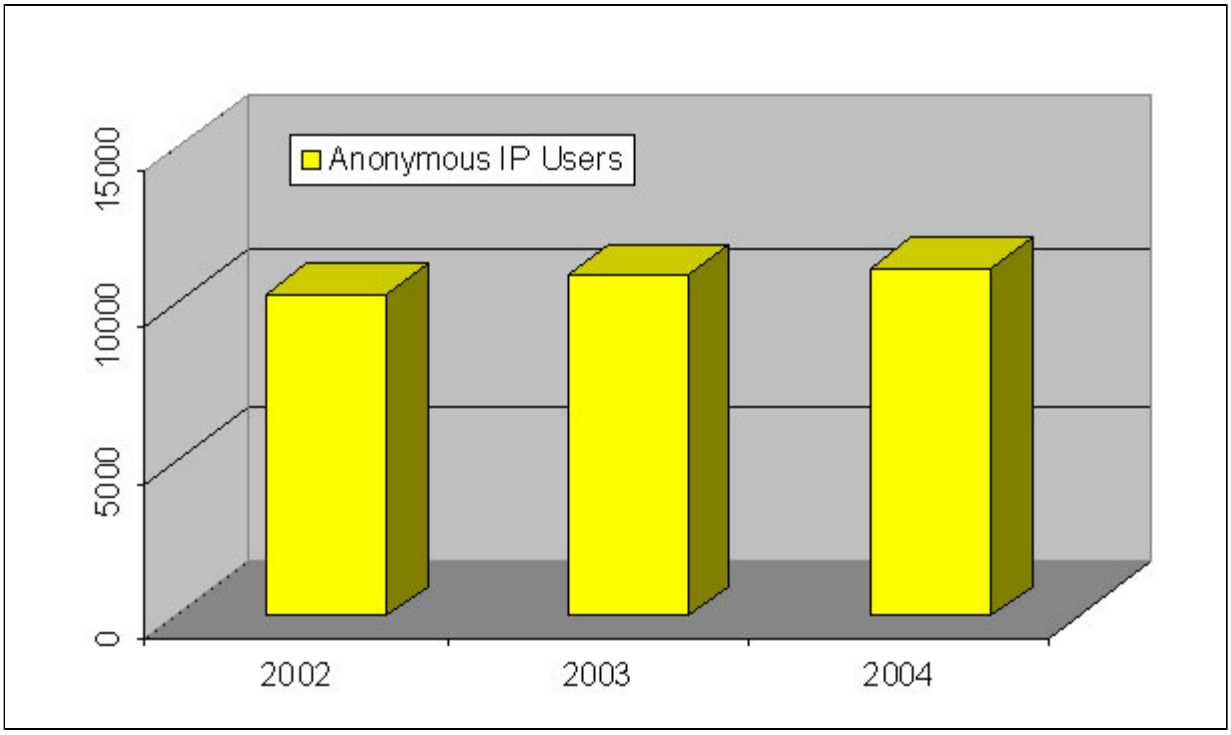


Known users identified through individual requests to the DSS or by SCD computing account information. The 2004 values are estimated by adding 25% to January - September measured amounts.

Anonymous users are only identified by unique IP addresses captured in web and FTP log files for the RDA data server. The log file information is filtered to reasonably approximate data access only. The filtering mechanisms are; all data are in a controlled directory structure, only full data file downloads are tabulated, and automatic web engines and robots are excluded. Annually since 2002 about 10,000 unique IP addresses connect to the RDA server and download data files (Figure 4). Downloads of web pages, images, documentation, and other general information are not summarized here. These values are typically two orders of magnitude greater than the data downloads and represent the ancillary service that accompanies the data itself.

Figure 4

Anonymous Users of the Research Data Archive



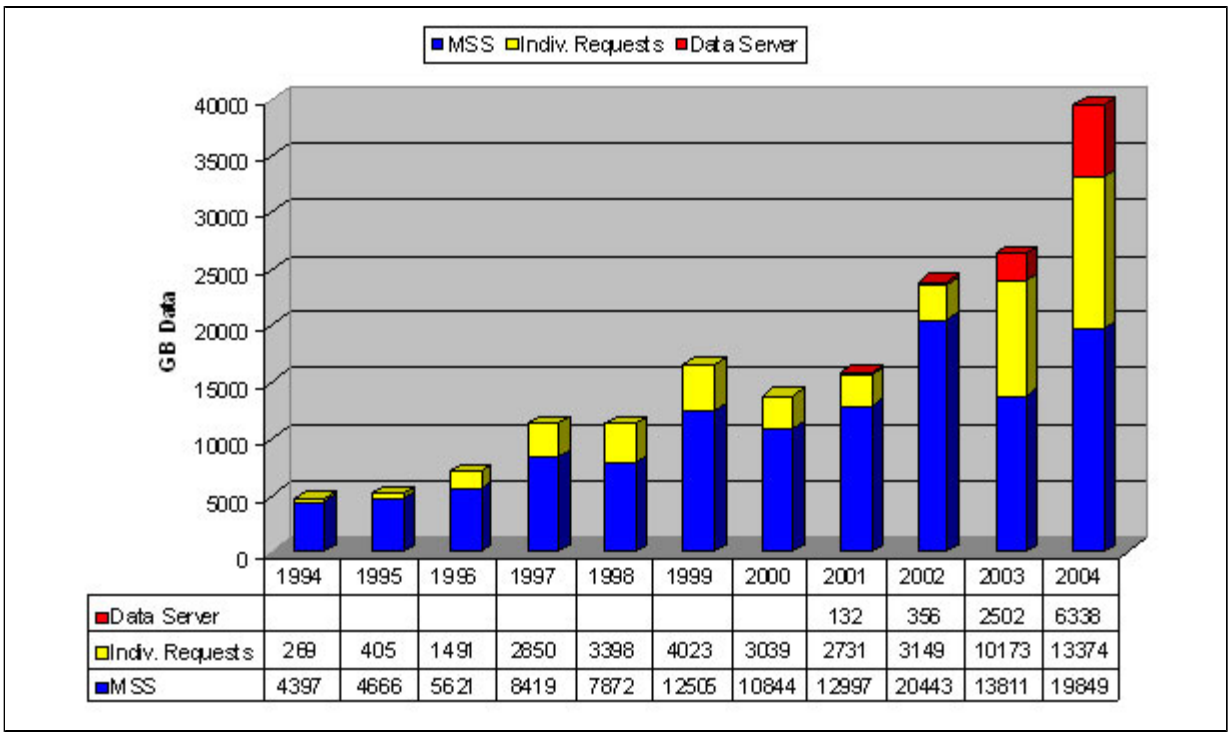
Anonymous users, identified by IP address, that have accessed data files from the RDA data server. The 2004 values are estimated by adding 25% to January - September measured amounts.

Metrics for Data Usage

RDA usage will be quantified by the total amount of data read by users and by identifying the top datasets leading to those amounts. Users gain access to the RDA in three ways; from the MSS, by individual requests to the DSS, and by online files from the RDA data server. Since 1997 the total amount of data delivered to all users grew from 10 TB to 39 TB (Figure 5). The usage from the MSS for 2002 (20 TB) was anomalously high relative to 2001 and 2003. This was largely due to data processing increases of NCEP/NCAR Global Reanalysis by CGD staff. In 2003, data usage through individual requests grew from about 3 TB to 10 TB. This significant step increase was the result of several large data deliveries on DLT magnetic tape. The 10 TB amplitude grew to 13 TB for 2004 in this category. This was not due to futher magnetic tape delivery but rather a shift to ERA-40 data delivery (11 TB) over the network. The RDA data access from the data server also showed large growth from about 2 TB to 6 TB between 2003 and 2004. The main component (over 3 TB) of this change was due to making more NCEP observational and operational model data available online for MMM and WRF model users. (See NCEP Final Global Analyses and Global Observational Files for details.)

Figure 5

RDA Data Accesses



	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Data Server								132	356	2502	6338
Indiv. Requests	269	405	1491	2850	3398	4023	3039	2731	3149	10173	13374
MSS	4397	4666	5621	8419	7872	12505	10844	12997	20443	13811	19849

Amount of RDA data accessed by three ways; from the MSS, by individual request to the DSS, and by online files from the RDA data server. The 2004 values are estimated by adding 25% to January - September measured amounts.

Finally, we look at what datasets from the RDA are the most significant contributors to the usage statistics for 2004. This is summarized for the data taken from the RDA data server and the MSS. The top ten datasets acquired from the RDA data server, ranked by the amount of data downloaded during January-September 2004, are shown in Table 4. By far the leading dataset is the NCEP Global Tropospheric Analyses, as discussed above, with over 3 TB downloaded. The top three are rounded out with related NCEP ADP observations as third and the ever-popular NCEP/NCAR Global Reanalysis. Note that datasets that have restricted access (e.g. ERA-40) are treated as individual requests and are not tabulated here with the unrestricted data.

Table 4

Top 10 datasets downloaded, ranked by data amount, from the Research Data Archive data server for January-September 2004

Dataset ID[1]	Download (GB)	Title

ds083.2	3114	NCEP Global Tropospheric Analyses (FNL), 1°x1°
ds090.0	560	NCEP/NCAR Global Reanalysis
ds464.0	302	NCEP ADP Global Surface Observations
ds744.4	318	QSCAT/NCEP Blended Ocean Winds from Colorado Research Associates
ds540.0	125	International Comprehensive Ocean Atmosphere Data Set (ICOADS), Global Marine Surface Observations
ds090.2	123	NCEP/NCAR Reanalysis Monthly Mean Subsets
ds759.3	102	NGDC, ETOPO2 Global 2' Elevations
ds336.0	100	Unidata Internet Data Distribution (IDD) Global Observational Data
ds010.0	58	Daily Northern Hemisphere Sea Level Pressure Grids
ds083.0	50	NCEP Global Tropospheric Analyses, 2.5°x2.5°

[1] The web address for each dataset is constructed by substituting the Dataset ID Number into this template, http://dss.ucar.edu/datasets/ds*nnn.n*

The top ten datasets, acquired from the MSS and ranked by the amount of data downloaded during January-September 2004, are shown in Table 5. As expected, because model output files are larger than observational data files, the top four datasets are from reanalysis projects (at NCEP and ECMWF) and operational model output. The fourth-ranked dataset here is the same as the first-ranked from the data server. The ERA-40 is showing growing strength, with four products in the top 10, and quite possibly will overtake the top level in this tabulation in coming years. The number of unique users per dataset varies greatly, but the high numbers (greater than 80) for four different ones indicate that many users access multiple datasets in their research (total number of unique users over all RDA datasets from the MSS is 360 for this period).

Table 5

Top 10 datasets, ranked by data amount, from the Research Data Archive data accessed from the MSS for January-September 2004.

Dataset ID[1]	Users	Access (GB)	Title
ds090.0	145	5458	NCEP/NCAR Global Reanalysis
ds118.1	21	3904	ERA40 2.5-Degree Upper Air Analysis on Pressure Surfaces
ds117.2	5	1391	ERA40 Model Resolution Upper Air Analysis on Model Levels
ds083.2	81	1065	NCEP Global Tropospheric Analyses

ds609.2	92	758	GCIP NCEP Eta operational model analyses
ds464.0	91	706	NCEP ADP Global Surface Observations
ds118.0	91	703	ERA40 2.5-Degree Surface and Single Level Analysis
ds117.0	9	539	ERA40 Model Resolution Surface, Vertical Integrals, and Other Single Level Fields
ds091.0	11	178	NCEP/DOE Global Reanalysis
ds111.2	43	177	ECMWF Operational 2.5-Degree Global Surface and Upper Air Analyses

[1] The web address for each dataset is constructed by substituting the Dataset ID Number into this template: http://dss.ucar.edu/datasets/ds*nnn.n*.

The breakdown of RDA users of MSS files by UCAR, NCAR divisions, and university shows our largest service is going to the universities as a whole (317 users) followed by the NCAR Divisions, CGD, MMM, and ACD (Table 6). This is good support for the university researchers, and we will continue to promote this type of service. As datasets become larger, the SCD facilities, storage, and computing will become more important as the practical place to manipulate data.

Table 6.
Research Data Archive Usage from the MSS by user group; University, NCAR Divisions, and UCAR Programs. Values for January-September 2004 and a 2004 annual estimate.

	Users	**Access (GB)[2004 estimate]**
University	254 [317]	8,822 [11,027]
CGD	32 [40]	5,855 [7,319]
MMM	30 [38]	307 [384]
ACD	11 [14]	350 [438]
Others (10 entries)	33 [41]	544 [680]

Noteworthy Support

The skill and knowledge in DSS reaches beyond simple RDA curation and stewardship to support some projects in UCAR and at related data centers nationally and internationally. The activities can involve the mechanics of moving data, data archive backup, or assistance with user support. Table 7 shows some noteworthy support during 2004.

Table 7.
Noteworthy Support

Collaborating Organization	**Support Activity**

Max-Planck-Institut für Meteorologie	Courtesy updates of NCEP/NCAR Reanalysis
NCAR CGD	Provide tape import device and server for 33 TB of IPCC data, 315 SDLT tapes
NOAA Climate Diagnostic Center	Full 2.5-degree ERA-40 archive set
Cosmic Suominet	Data backup and 80 GB data recovery
CSU, Garrett Campbell	Transfer the ISCCP DX time series to the RDA
RAP, Greg Thompson	Provide user download for three years of RUC and Eta model data
NOAA Climate Diagnostic Center	NCEP/NCAR Reanalysis data (23 GB) for data recovery

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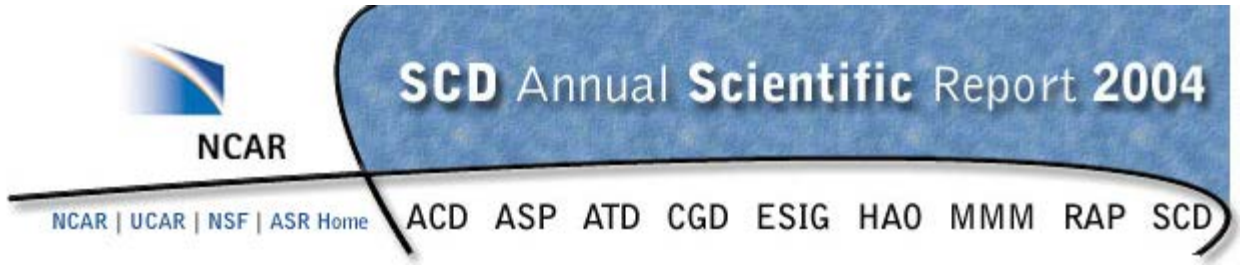


Education and Outreach

SCD organized a two-day NSF-funded workshop, the Cybersecurity Summit 2004, in Washington DC, September 27-28, 2004 for the purpose of forming community-wide recommendations on cybersecurity. There were 125 attendees from the nation's high-performance computing centers, their university partners, and mid-size university computing centers. Through breakout sessions the workshop explored the competing needs of an open, collaborative research environment and protecting the security and integrity of the nation's research computing and data assets. By sharing information about recent cybersecurity incidents, it is hoped that future security incidents can be avoided, mitigated, and/or better managed, thereby reducing their disruptive impact on the nation's research agenda. This workshop was a significant step toward increasing the communication and cooperation between the nation's research HPC centers in the area of cybersecurity.

Luca Cinquini gave presentations about the ESG and CDP projects for NSF officials Sang Kim, head of NSF Cyberinfrastructure and Cliff Jacobs, and to Dr. Geerd Hoffman, a visitor from Germany. Cinquini was invited to give a talk about the CDP at the Unidata Seminar Series. Cinquini demonstrated the ESG Website for Bob Harris, Director of NCAR/ESIG and university representatives as well as for Dick Valent (SCD) and visitors John Michalakes (NCAR/MMM) and Akshara Kaginalkar from C-DAC Punje, India.

John Clyne gave a presentation on the SCD Visualization Lab to a group from the U.S. National Weather Service. Clyne gave an NCAR Geophysical Turbulence Program (GTP) presentation titled "Exploiting progressive access for interactive analysis of highresolution CFD simulation data." Clyne gave a presentation at the Arizona State University, Department of Computer Science titled "Scientific visualization in the earth sciences: myth and reality." Clyne gave a talk at the DOECGF entitled "GPUs: They're Not Just for Graphics Anymore." Clyne participated in a DOECGF panel on visualization software interoperability. Clyne gave a VisLab talk to DARPA visitors hosted by Scott Swerdlin.

Nancy Collins hosted CCA (Common Component Architecture) Quarterly Meeting at NCAR, April 2004. Collins presented "Components in the Earth System Modeling Framework" at the SIAM Conference on Parallel Processing for Scientific Computing held in San Francisco, California, February 24-28, 2004. Collins presented "Components in the Earth System Modeling Framework" at the 6th International Workshop on Next Generation Climate Models for Advanced High Performance Computing Facilities" in Honoloulu, Hawaii, February 25-27, 2004. Collins presented "Development of the Earth System Modeling Framework" at the Fall Science Seminar Series, Arctic Research Supercomputing Center, Fairbanks, Alaska, September 8-10, 2004.

Cecelia DeLuca presented "What is ESMF and What Does It Mean to Adopt It?" at the 3rd ESMF Community Meeting held at NCAR, July 15, 2004 and at the 1st Joint ESMF-PRISM Meeting, GFDL, Princeton, New Jersey, September 8-9, 2004. DeLuca presented "Update on the Earth System Modeling Framework" at the CCSM SciDAC Meeting, May 19, 2004 and at the CCSM Software Engineering Working Group Meeting, July 8, 2004. DeLuca was the plenary speaker on "Architecture of the Earth System Modeling Framework" at the Geospace Environment Modeling (GEM) Workshop, June 25, 2004. DeLuca presented "Emergence of the Earth System Modeling Framework" at the Symposium of the 50th Anniversary of Operational Numerical Weather Prediction, June 17, 2004. DeLuca presented "Modeling in the Geosciences" at the ESMF-sponsored workshop series for middle and high school teachers, Boulder, CO, June 29, 2004.

J.M. Dennis, S.J. Thomas, and E.R. Jessup presented "Development of a Block Conjugate Gradient Algorithm for Shifted Systems," April 2004, at the Conference on Iterative Methods, Copper Mountain, Colorado. J.M. Dennis, A.H. Baker, and E.R. Jessup presented "Reducing Data Movement in a Block Variant of GMRES," February 25, 2004, at the

Parallel Processing for Scientific Computing PP04 in San Francisco, California. J.M. Dennis, H.M. Tufo, and R.D. Loft presented "Partitioning the Cubed-Sphere for BG/L," February 25, 2004, at the Parallel Processing for Scientific Computing PP04, San Francisco, California. J.M. Dennis presented "Quantifying the Impact of Memory Characteristics on the Design of Krylov Subspace Algorithms" on January 8, 2004, as his Ph.D. thesis proposal in Boulder, Colorado.

Natasha Flyer presented "Radial Basis Functions: Interpolation and Derivative Approximations" in February 2004 at the 12th Applied Mathematics Forum of South Korean, Suanbo, South Korea. Flyer presented "Time-Space Corner Singularities for Initial-Boundary Value Problems" in February 2004 at the Kyungpook National University (KAIST), Taegon, South Korea. Flyer presented "The Elusive Time-Space Corner Singularity: The Hidden Nature of Initial-Boundary Value Problems" at the Colorado School of Mines, April 16, 2004. Flyer presented "Applications of Asymptotics to Geophysical Fluid Dynamics" at Uppsala University, Sweden, June 2004. Flyer gave two separate lectures, on August 2 and August 3, 2004, to high school students participating in the High School Honors Institute on "The Role of Applied Mathematics in Space and Geophysical Modeling at NCAR." Flyer visited Fairview High School, Boulder, Colorado, to present "What is it like to be a mathematician/scientist?" October 2003. Flyer presented "Applied Math at NCAR" to the Math Club from the University of Colorado-Colorado Springs, September 2004. Flyer presented "Radial Basis Functions: The Basics and Why They Are So Hot," to the scientists, postdocs, and graduate students in the NCAR Geophysical Statistics Program, March 2004. Flyer presented "Time-Space Corner Singularities for Initial-Boundary Value Problems" to the Korean Advanced Institute of Science and Technology (KAIST), Taegon, South Korea, February 2004.

Mary Haley gave a presentation on PyNGL during a scientific Python conference (SciPy 2004) at Caltech.

Christiane Jablonowski presented "Adaptive Mesh Refinements for Weather and Climate Models" on March 29, 2004, at the 8th Copper Mountain Conference on Iterative Methods (Minisymposium), Copper Mountain, Colorado. Jablonowski presented "An Adaptive Mesh Refinement Strategy for Future GCMs" on July 23, 2004, at the 2004 Workshop on Partial Differential Equations on the Sphere, Yokohama, Japan. Jablonowski presented "Adaptive Grids for Weather and Climate Models," September 9, 2004, at the ECMWF 2004 Seminar on Recent Developments in Numerical Methods for Atmospheric and Ocean Modeling, Reading, UK. Jablonowski was a guest lecturer at the University of Michigan, Department of Atmospheric and Space Sciences, March 15 and 17, 2004 (Graduate Course: Sun-Earth Relations). Jablonowski gave a poster presentation on "Adaptive Grids for Weather and Climate Models," July 7-9, 2004, at the Ninth Annual CCSM Workshop, Santa Fe, New Mexico.

Rodney James presented an invited talk on "High Performance Numerical Methods for Super-Scalar and Epic Microprocessors" at the Gelato Strategy Council Meeting in Stockholm, Sweden in October 2003.

Richard Loft gave a technical presentation on the Software Design of the IOM System at the Inverse Ocean Modeling Workshop, held July 6, 2004, in Corvallis, Oregon. Loft gave an invited presentation, "Advancing Atmospheric Science with Blue Gene/L," March 17, 2004, at IBM's T.J. Watson Research facility in Yorktown Heights, New York.

Don Middleton gave a technical presentation to NASA visitor Ron Birk entitled, "Data Management, The Grid and Other Emerging Technologies." Middleton gave an invited presentation at the National Academy of Sciences in Washington, D.C. for the GeoForum2004 entitled, "The Sky is Not the Limit!" in March 2004. Middleton organized and contributed to a DataMonster presentation session for the SCD Executive Committee, with contributions from Luca Cinquini, John Clyne, Mark Uris, and others. This generated a lot of much-needed and fairly deep discussion about futures and strategies in the storage and services area. Middleton was invited by the Rockefeller-Brothers foundation to participate in a small retreat/think-tank of people drawn globally from science, technology, environment, and religion to discuss and plan for sustainable future society; Middleton gave a presentation on "Visualizing our Planet." Middleton delivered an invited presentation for CU's Computer Science seminar series "The Earth System Grid: Building a DataGrid for Climate Research." Middleton participated in the DMWG-sponsored meeting on strategic next steps for data and CDP, and also contributed to the presentations and goal development, November 2003. Middleton gave an invited presentation on ESG at SC in the DOE SciDAC Theater. Middleton served as a co-chair for a Cyberinfrastructure Breakout Group for the UCAR Board of Trustees meeting and co-delivered a presentation on Cyberinfrastructure with Dr. Jim Hansen of MIT. Middleton gave an invited presentation, "Cyberinfrastructure in Earth System Modeling," for the APAN eScience Workshop in Honolulu, Hawaii in January 2004. He also co-presented a session with V. Balaji of GFDL. Middleton gave an invited presentation on the Earth System Grid and also served as session chair for Grid Workshop for the APAN Meeting, Honolulu, Hawaii in January 2004. Middleton gave a presentation and live demonstration on ESG to the SciDAC Climate Modeling Group meeting at NCAR in May 2004. Middleton chaired a panel at the DOE National Collaboratories meeting at ANL entitled "Next Generation Research for Creating and Interacting with Advanced Software Environments" and also served as a contributing author for this workshop's report, August 2004. Middleton delivered a presentation on visualization and data management research activities to the new acting director of the NSF, Arden Bemmet, August 2004. Middleton attended the Workshop on Advanced Collaboration Environments in Nice, France, and was backup for Fran Berman, who had a potential travel schedule difficulty (didn't have to serve as backup), September

2004, and was nominated and accepted to serve on the Program Committee for 2005. 2005 will be hosted and financially sponsored by Microsoft!

R.D. Nair presented "A high-order conservative shallow water model on the cubed-sphere" at the 2004 workshop on the solutions of PDEs on the sphere, July 20-23, Yokohama, Japan. Nair presented "Development of a discontinuance Galerkin atmospheric model on the cubed-sphere" at the ADAPT'03 conference, Oct. 10-11, 2003, at RPI, Troy, NY.

Darin Oman gave a nontechnical VisLab presentation to Steve Howe and five others.

Tim Scheitlin provided Vislab demos to the following groups and individuals: Mr. Grubisic from the Desert Research Institute; Japanese Storage Tek visitors (60); Supercomputing 2003 (Phoenix) attendees; Ridge Scientists (20) who study ocean floor and currents; Northrop Grumman Visitors (2); Alan Norton and School of Mines visitors (17); Comet Class (20); Local AMS Chapter (Josh Hacker hosting). Non-Technical Presentations: Scheitlin provided Vislab demos to the following groups and individuals: Board of Trustees Insurance visitors. Scheitlin gave a THIC demo for 40 people. Scheitlin gave nontechnical presentations to environmental journalists (35 people; Beth Holland also presented), geoscience teachers (17 people), and school superintendents and their spouses (100 people). Scheitlin provided a Vislab demo for Larry McDaniels (ESIG) and two University of Colorado Art and Math visitors. Scheitlin provided Vislab demos for: Rear Admiral Richard West, President of the Consortium for Oceanographic Research and Education (CORE); Appropriations Staffers (3); and, NASA Technology Team (26). Scheitlin presented several scientific and technical presentations to Forty ASP Colloquium participants, RAP/Sharman group including OMB Examiner and their funding sponsor, NWS Director, General D.L. Johnson. Scheitlin gave nontechnical presentations to 10 Congressional staff and CU visitors, NSF visitors George Strawn (CIO of NSF) and Andrea Norris (Director of the Division of Information Systems of NSF, Geerd Hoffman and family, ML receptionist Susan Stevens and guests, and seven SCD staffers.

Amik St-Cyr and Martin Gander (McGill University and the University of Geneva) presented the SCD seminar, "Parallelism in Time: Can Parts of the Solution Later in Time be Computed Before the Solution Earlier in Time is Known?" at NCAR/Boulder on July 29, 2004. St-Cyr presented an SCD seminar, "Improved Time-Stepping Schemes for Locally Refined Atmospheric Models" at NCAR/Boulder on March 2, 2004. St. Cyr participated in the McGill Computational Science and Engineering Seminar Series by presenting an invited talk on "Nonlinear Operator Integrating Factor Splitting for a Non-Conforming Spectral Element Atmospheric Model" at McGill University-Canada on January 30, 2004. St-Cyr presented "Optimized Schwarz Preconditioning for High-Order Spectral Element Methods," at the 8th Copper Mountain Conference on Iterative Methods, Copper Mountain, Colorado, April 2004. St-Cyr gave a contributed talk on "An Efficient Non-Conforming Spectral Element Atmospheric Model Using Nonlinear Operator Integration Factor Splitting," at the International Conference on Spectral and High Order Methods, Providence, Rhode Island, June 2004. St-Cyr presented "Non-Conforming Adaptive Spectral Element Atmospheric Model," at the 2004 Workshop on the Solution of Partial Differential Equations on the Sphere, Yokohama, Japan, July 2004. St-Cyr presented an invited talk on "Operator Integrating Factor Splitting for a Non-Conforming Spectral Element Atmospheric Model," at an Applied Mathematics Seminar, the University of Colorado (CU) at Boulder, Boulder, Colorado, January 20, 2004.

S.J. Thomas, A. St-Cyr, R. Nair, R. Loft, and H. Tufo presented "The NCAR Spectral Element Dynamical Core: Moist Semi-Implicit Formulation," at ICOSAHOM 2004, Brown University, Providence, RI. Thomas gave an invited presentation on "The Equivalence of Semi-Lagrangian and OIFS Time-Stepping," Department of Applied Mathematics, CU Boulder, Boulder, CO, in February 2004.

Henry Tufo and Steve Thomas organized a mini-symposium, "Iterative Solvers for Geoscience Applications," for the 8th Copper Mountain Conference on Iterative Methods, April 2004.

Dick Valent gave a seminar on "Recent Changes in Computing at NCAR" at the Center for Ocean-Land-Atmosphere Studies (COLA) on June 18, 2004. COLA is located in Calverton, Md. The seminar's focus was on the changes required by the security problems in March and April of this year; it discussed the need for greater security on our supercomputers, justification of CryptoCARDS, and an explnation of the new supercomputer security perimeter in SCD. This seminar was attended by more than 25 COLA staff.

The Visualization and Enabling Technologies Section (VETS) continues its outreach to the scientific community and general public through its many visualization demonstrations, digital media support, and conference participation. VETS attended the SC2003 conference in Phoenix and provided a platform for SCD presentations as well as the regular visualization demos in the NCAR booth on the exhibition floor.

VETS continued its support and collaboration with ASP post-doc Kirsten Butcher. Butcher is researching cognitive processes of learning and, in particular, how visualization tools and animations affect learning with digital media. Butcher has conducted assessments of visualization tools in classroom studies, researched methodologies used in expertise studies, and conducted emperical studies and quantitative statistical tests on student learning with visualization.

Butcher's research has resulted in several manuscripts, journal articles, and research posters.

VETS also contributed to the organization and presentation agenda for the GeoForum 2004 event, held this spring at the National Academies of the Sciences in Washington, DC. GeoForum was targeted at generating enthusiasm and contacts in under-represented student populations in the DC area.

Besides its regular schedule of visualization demos to Vislab visitors, scientists, researchers, and government representatives, VETS also continues its successful partnership with PVP to provide presentations to public visitors including many student and teacher groups hosted by the NCAR tour program.

VETS also collaborated with MMM to produce a 62-GB hurricane dataset that was published on the web and used as the raw data for a visualization contest at IEEE Viz this year. VETS also produced several climate visualizations that were used by CGD scientist Jim Hurrel in an "Earth Bulletin" video production by the American Museum of Natural History.

Also, VETS has extended its outreach program through the continued deployment and use of the Access Grid technology. Along with direct participation in the SOARS mentoring program, VETS was also instrumental in supporting AG meetings for SOARS proteges located at remote sites including Puerto Rico and Norman, Oklahoma. VETS continued to provide demos, consulting, and support to staff interested in using the AG for meetings and tutorials. In particular, CGD has shown interest in developing a program for using the Access Grid to facilitate a remote teaching lab for NCL.

Figure 8: Darin Oman (VETS) facilitates AccessGrid use for SOARS proteges.

Steven Worley and Chi-Fan Shih presented "Model Output for GAPP" for the GAPP PIs Meeting in August 2004 in Boulder, Colorado. Worley presented "ERA-40 Data Availability" to the SCD Advisory Panel, April 1, 2004, in Boulder, Colorado. Worley presented "Data Archiving, Maintenance, and Migration" to the National Science Board Meeting on Long-Lived Data Collections, March 23, 2004, in Arlington, Virginia. Worley presented "ICOADS Status and Plans" at the Second Workshop on Advances in Marine Climatology (CLIMAR-II), November 17-23, 2003, in Brussels, Belgium. Worley presented "German Maury Digitization Plan" at the U.S.-People's Republic of China 8th Meeting on Data Exchange, at the China National Oceanography Data Center, October 17-20, 2003, in Tianjin, China. Worley gave a Data Tutorial to UCAR SOARS student classroom teaching, 9 June 2004.

Community Service Activities

Bill Anderson was a presenter on "Simulating the NCAR Mass Storage System to Improve Performance," to the June 29-30, 2004, THIC (Tape Head Interface Committee) meeting held at NCAR.

Tom Bettge served as the Principal Investigator for the Cybersecurity Summit 2004, sponsored by NSF, held in Arlington, VA. Over 70 facilities were represented at this Summit. In October, Tom participated in the IBM/Forbes Executive Forum in San Diego. He attended the International Conference for High Performance Computing and Communications, SC2003, in Phoenix in November. He is an active member of the National Partnership for Advanced Computational Infrastructure, and attended meetings in Urbana, Illinois, Las Vegas, Nevada, and Washington DC. Bettge visited the new computing center at Oak Ridge National Laboratory in Oak Ridge, Tennessee in March. He also visited the Texas Advanced Computing Center (TACC) in May to gain a better appreciation of potential areas of overlap in their general approach to the integration of supercomputing services. He attended the 4th Linux Cluster Institute in Austin, Texas in May. He participated in the Ninth Annual CCSM Workshop in Sante Fe, New Mexico in July. Also in July, he attended the Council on Competitiveness HPC Conference in Washington DC. Tom is a member of the CSL Advisory Panel which also gathered in Washington DC in July. Tom is very active in all security activities, attending the 13th Usenix Security Symposium held in San Diego, California in August 2004. He also represents NCAR/SCD on the Coalition for Academic Scientific Computation (CASC), which meets three times each year.

Brian Bevirt served as a science writing mentor in the 2004 SOARS program.

Kirsten Butcher served as research advisor for University of Colorado (CU) students enrolled in "Technology and Cognition Series: HCI Models, Theories, and Frameworks" (a class sponsored by CU's Institute of Cognitive Science, cross listed in the Computer Science, Education, Linguistics, Philosophy, and Psychology departments). Butcher reviewed an initial draft of SCD's Strategic Plan (SP) as part of the SCD SP Review Committee.

Fred Clare reviewed book selections for the NCAR Library.

John Clyne served as a panel reviewer for the DOE's Early Career Principal Investigator (ECPI) awards, reviewing nine funding proposals. Clyne reviewed three research papers for IEEE Vis04. Clyne reviewed "medium sized" ITR funding proposal for NSF.

Susan Cross served as a community mentor in the 2004 SOARS program. Cross participated in the seminar, Coaching Skills for Mentors in January 2004, in preparation for the upcoming SOARS Program.

Cecelia DeLuca (CSS) is serving a third term as Co-Chair of the CCSM Software Engineering Group. She also participated in the NCAR/UCAR workshop on Strengths, Weaknesses, Opportunities and Threats (SWOT), November 18, 2003, and, along with Natasha Flyer (CSS), she co-moderated the NCAR SCD Town Meeting on the SWOT activity on August 18, 2004. Cecelia presented the "Report on the NCAR SCD Response to the SWOT Initiative to UMC," September 16, 2004. She is a member of the NCAR Committee on Software Engineering (SECOMM).

Tom Engel served as a science research mentor in the 2004 SOARS program.

Natasha Flyer served on the Committee for the Formation of the Institute of Mathematics Applied to Geosciences (IMAGe), headed by A. Pouquet and L. Winter. She is a representative member for SCD on the Steering Committee of the Early Career Scientist Assembly and a referee for the journal *Computers and Mathematics with Applications.* Natasha Flyer is a referee for the *Journal of Computational Physics.* Flyer was advisor to Paule Ecimovic at the

Department of Earth and Space Sciences, York University, Toronto, Canada, for his Ph.D dissertation on Pseudospectral Modeling. Flyer is a member of the Thesis Committee for Julia Zuev, Department of Applied Mathematics, University of Colorado-Boulder. Flyer participated in the following: a half-day meeting with the NCAR Advisory Board and 19 other Scientist Is to discuss the Present and Future Environment for the Development of Young Scientific Careers at NCAR; a group discussion luncheon with Dr. Len Fisk, Head of the National Space Science Board, and three other Scientist Is and IIs in HAO, during Dr. Fisk's visit to HAO; a panel discussion luncheon with Dr. Argen Bement, Director of NSF, and eight other Scientist Is, on the "Future of Science at NCAR;" and a full-day NCAR/UCAR retreat on the Strengths, Weaknesses, Opportunities, and Threats (SWOT) facing the organization, on November 18, 2003.

George Fuentes is the NCAR voting member of IBM's SP-XXL Group. The SP-XXL group is comprised of IBM SP installations that are 128 nodes and greater. The SP-XXL group meets three times a year and provides technical input to IBM on new functionality that should be added to the AIX and PSSP operating system product toolset.

Pam Gillman is the System Administration working group chair for the IBM SP-XXL Group.

Gene Harano was on the Program Committee for the 12th NASA Goddard / 21st IEEE Conference on Mass Storage Systems and Technologies. The conference was held in College Park, Maryland, on April 12-16, 2004. Harano was the Session Chairman of the June 29-30, 2004, THIC (Tape Head Interface Committee) meeting held at NCAR. Tim Scheitlin, Darin Oman, and Susan Cross (all VETS) provided a VisLab demo, Bill Anderson presented the NCAR Mass Storage System, Stan McLaughlin arranged power drops, and BJ Heller managed logistics. Gene Harano is a member of the Program Committee for the 13th NASA Goddard / 22nd IEEE Conference on Mass Storage Systems and Technologies, which is scheduled for April 2005, in College Park, Maryland. Harano is a member of the StorageTek Strategic Advisory Council, which provides feedback on corporate planning, and is also a member of the StorageTek Large Tape Users Group (LTUG). Harano, along with BJ Heller, the Mass Storage Systems Group, and Tim Scheitlin of VETS, hosted the StorageTek Japan and Korean User Groups in October 2003.

Al Kellie participated in several IBM/Forbes Executive Forums through the year. Mr. Kellie was an invited expert in information technology and attended the World Meteorological Organization/Commission for Basic Systems/Information Systems and Services/Interprogramme Task Team on the Future WMO Information System in Kuala Lumpur in October. Mr. Kellie made presentations on U.S. technology projects (ESG/CDP) that are relevant for potential application to the WMO. Mr. Kellie attended the International Conference for High Performance Computing and Communications (SC03) in November, which was held in Phoenix, Arizona. He joined the 2003 AGU Fall meeting in December in San Francisco. Mr. Kellie joined Lawrence Berkeley National Laboratory for the SPXXL Winter Workshop at the Maui High Performance Computing Center in January. He traveled to Seattle to attend the 2nd Users Conference/NOAA Stakeholders Forum during the 84th AMS Annual Meeting in January. Mr. Kellie was in Berlin for the Global Grid Forum10 Workshop in March. He is a member of UNICORE, and while in Germany attended the 11th General Meeting. Mr. Kellie joined Dr. Tim Killeen on a trip to San Diego to visit the San Diego Supercomputing Center in March. Mr. Kellie accepted an invitation to speak in April at The National Academies Board on Atmospheric Sciences and Climate (BASC) in Washington DC. He is a member of the AGU Joint Assembly in Montreal, Canada and attended the annual meeting in May. He attended the MSC Symposium in Toronto, Canada in June. In June he traveled to Heidelberg, Germany for the International Supercomputer Conference ISC2004. Mr. Kellie was invited to participate in the 35th COSPAR (Committee on Space Research) Scientific Assembly and Associated Events in July, held in Paris, France. Mr. Kellie attended the CSL Advisory Panel meeting in Washington, DC in July. Mr. Kellie is on the External Advisory Board for IBM and attended the Deep Computing Executive Symposium 2004 in Zurich, Switzerland in September.

Jeff Kuehn served as a Co-chair for Technical Papers Committee at SC2004.

Linda LaBrie is a four-year board member and advisor for Boulder County's Vo-Tec high school education program. Some students enrolled in the program are considered high risk, and part of a board member's role is to inspire and encourage. In 2004 LaBrie mentored one young woman and assisted her with many options, ideas and opportunities in the field of science, with emphasis on opportunities for young women. The board resumes again in October 2004. LaBrie is a member of Boulder county's community support program which assists and mentors needy families currently in the TANIF (temporary aid needed in families). Mentors present various options and opportunities for client(s), helping to place them in various training programs to attain job skills, maybe find appropriate affordable housing, but most importantly to help them attain complete independence from welfare assistance programs. Guidance, encouragement, and letting the clients know that 'somebody does care' can make a huge difference in their lives.

Richard Loft served as a technical contributor and reviewer of the NRC report, "Getting Up to Speed: the Future of Supercomputing." He is also serving on the Technical Working Group of NSF's Petascale Computing Initiative.

The MSS Group provides administrative support for three Linux nodes providing DataSpace service in support of the

National Center for Data Mining (NCDM) of the University of Illinois at Champaign. The MSS Group participated in a series of presentations and machine room tours in October 2003 for two groups of visitors from Japan and Korea that were sponsored by StorageTek. This has become an annual event, and has been well received by all of the attendees.

Don Middleton completed his service on the National Research Council, Committee to Develop a Long-Term Research Agenda for the Network for Earthquake Engineering Simulation (NEES). Middleton served on the Organizing Committee for the IEEE Vis 2004 conference and co-chaired the The Visualization Challenge. Middleton served on the Steering Committee for the Development of the Next-Generation DOE National Collaboratories Program. Middleton authored a letter of support for Dr. David Ebert's (Purdue University) proposal on Multifield Visualization for Atmospheric Research. Middleton authored a letter of support for Bill Kramer's DOE Science Grid SciDAC renewal proposal. Middleton authored an overall NCAR letter of support for the LEAD proposal (Kelvin Drogenmeir, PI), including persectives from WRF, the director's office, and ESG/VETS; Killeen signed. Middleton authored a letter of support for Arie Shoshanie's (LBNL) Storage Resource Management SciDAC Renewal Proposal. Middleton authored a letter of support for Rick Stevens' (Director, ANL/MCS) AccessGrid Renewal Proposal.

R.D. Nair reviewed manuscripts for the *Quarterly Journal of the Royal Meteorological Society* and *Monthly Weather Review.* Nair served as a reviewer for the NCAR Opportunity Fund FY2004 proposals and the ASP post-doctoral program.

Alan Norton reviewed a paper for the *Springer Journal* entitled "Engineering with Computers."

Darin Oman provided consulting services regarding Access Grid technology for Mike Celaya from Colorado State University.

Mike Page served as a science writing mentor in the 2004 SOARS program.

Stan McLaughlin is a member of the MERT (Medical Emergency Response Team) at NCAR.

Leonard Sitongia gives Geology programs based from the Mesa Lab site to school kids.

Lana Stillwell is a member of the MERT (Medical Emergency Response Team) at NCAR. Stillwell also reviews book selections for the NCAR library.

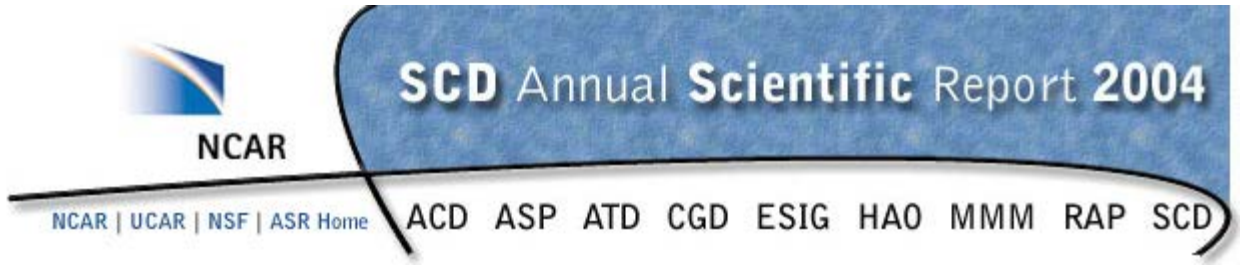
Amik St-Cyr refereed papers for *Applied Numerical Mathematics* and *ACM Transaction on Mathematical Software.*

Markus Stobbs gave a presentation to NOAA Web developers on Web Usability Design and Testing.

Stephen Thomas is a member of the NCAR Geophysical Turbulence Program (2000-Present); the NCAR Re-Organization Committee for IMAGe (math institute); the NCAR Scientist I Appointments Review Committee (2003-2004); the NCAR ASP Post-Doc Appointments Review Committee (1999-Present); the NCAR Scientist Assembly (NSA) Executive Committee; and the Scientific Advisory Committee, Canadian HPC Association (c3.ca). Thomas is a reviewer for the National Science Foundation, Mathematics Directorate (2003-present) and for the Canadian Foundation for Climate Change Research (2001-Present). Thomas organized and hosted the SCD seminar series. He is an Associate Editor for *Monthly Weather Review* (2003-present); Co-Editor for the *Journal of Computational Physics'* special issue on multi-scale modeling; and a Reviewer for *Monthly Weather Review* (15 papers) and the*Journal of Computational Physics* (5 papers). Thomas is a member of John Dennis' Ph.D committee, Department of Computer Science, CU Boulder.

Henry Tufo is serving as Advisor to Matthew Woitaszek and Theron Voran. Both are Ph.D. candidates in Computer Science (CU). Henry is also serving as Advisor to Michael Oberg, a B.S. candidate in Computer Science (CU). Tufo is a member of these committees:
Ernesto Prudencio's Thesis Committee, Ph.D. candidate in Computer Science (CU);
John Dennis' Thesis Committee, Ph.D. candidate in Computer Science (CU);
Hassa Alsukhni's Thesis Committee, Ph.D. candidate in Electrical and Computer Engineering (CU); and
Micah Hamady's Thesis Committee, M.S. candidate in Computer Science (CU). Tufo taught CSCI 4576/5576, "High-Performance Scientific Computing," 2004 Spring Semester at CU. Tufo served on the Program committee for the 6th LCI International Conference on Linux Clusters: The HPC Revolution. Tufo is a member of NCAR's Geophysical Turbulence Program, the SCD Linux Cluster Procurement Committee, the Colorado Center for Information Storage (CCIS), and the Affiliated Faculty, Department of Applied Mathematics, University of Colorado at Boulder. He also serves as a reviewer for the NCAR ASP program, the *SIAM Review, AIAA Journal,* the *Journal of Computational Physics,* and the Sixth IEEE Symposium on Parallel and Distributed Systems and *SIAM Journal on Scientific Computing.*

Nathan Wilhelmi participates in the Boulder Design Patterns User Group.



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Awards

Christiane Jablonowski, CSS, was given a Distinguished Achievement Award by the University of Michigan College of Engineering in March 2004 in recognition of her academic and personal excellence.

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Publications

Books

Refereed

Butcher, K., 2004: *Lecture Notes in Artificial Intelligence: Diagrammatic Representation and Inference*. Springer, 445 pp.

Marcuson III, W.F.*, **G.C. Beroza**, **J. Bielak**, **R. Desroches**, **E.M. Gath**, **R.D. Hanson**, **A.S. Kiremidjian**, and D. Middleton, 2004: *Preventing Earthquake Disasters*. The National Academies Press, 172 pp.

Middleton, D., **K. McGuffie**, and **A. Henderson-Sellers**, 2004: *A Climate Modelling Primer*. John Wiley & Sons, Inc., 200 pp.

Thomas, S.J., J. Tribbia-editor*, and R. Teman-editor*, 2004: *Time-Stepping Schemes for Atmospheric General Circulation Models: NCAR/NSF Summer School on Apps. of Advanced Mathematical and Computational Methods to Atmos. and Oceanic Problems (MCAO 2003)*. Lecture Notes, 20 pp.

Articles in a Periodical

Refereed

Chervenak, A., **B. Drach**, **D. Williams**, D. Middleton, E. Deelman*, B. Allcock*, I. Foster*, and **C. Kesselman**, 2003: High-Performance Remote Access to Climate Simulation Data: A Challenge Problem for Data Grid Technologies. *Parallel Computing*, **29**, 1335-1356.

Dimonte, G., **A. Dimits**, **S. Weber**, **D.L. Youngs**, **A.C. Calder**, **B. Fryxell**, **J. Biello**, and H.M. Tufo, 2004: A Comparison of High-Resolution 3D Numerical Simulations of Turbulent Rayleigh-Taylor (RT) Instability: Alpha-Group Collaboration. *Phys Fluids*, **16**, 1668-1693.

Flyer, N., and **B. Fornberg**, 2004: On the Nature of Initial-Boundary Value Solutions for Dispersive Equations. *SIAM J. Applied Math.*, **64**, 546-564.

Flyer, N., **B. Fornberg**, S.J. Thomas, and B.C. Low, 2004: Magnetic Field Confinement in the Solar Corona. I. Force-Free Fields. *ApJ.*, **606**, 1210.

Fornberg, B., and N. Flyer, 2004: Accuracy of Radial Basis Function Interpolation and Derivative Approximations in 1-D (Electronically Published). *Adv. Comp. Math.*, **00**, 00-000.

Hill, C.*, C. DeLuca, V. Balaji*, M. Suarez*, and A. DaSilva*, 2004: The Architecture of the Earth System Modeling Framework. *Computing in Science and Engineering*, **6**, 18-28.

Lepage, C.Y., A. St-Cyr, and **W.G. Habashi**, 2004: Parallel Unstructured Mesh Adaptation on Distributed-Memory Systems. *American Institute of Aeronautics and Astronautics (AIAA)*, **2532**, 1-11.

Nair, R.D., 2004: Extension of a conservative cascade scheme on the sphere to large Courant numbers. *Mon Wea Rev*, **132**, 390-395.

St-Cyr, A., and S.J. Thomas, 2004: Nonlinear Operator Integration Factor Splitting for the Shallow Water Equations.

Applied Numerical Mathematics, **0**, Published Electronically.

Thomas, S.J., **J. Hacker**, **P.K. Smolarkiewicz**, and **R. Stull**, 2004: Spectral Preconditioners for Nonhydrostatic Atmospheric Models. *Monthly Weather Review*, **131**, 2464-2478.

Non-Refereed

Woodruff, S.*, and S.J. Worley, 2004: Rescuing Marine Data. *WMO World Climate News*, **25**, 10.

Articles at a Conference

Non-Refereed

Odstricil, Dusan and Cinquini, Luca, "Remote Access to Heliospheric Computations," *Space Weather Week*, Boulder, CO, poster, Apr. 2004.

Parker, David and Worley, Steven, et al, "Second JCOMM Workshop on Advances in Marine Climatology," *CLIMAR II Workshop on Advances in Marine Climatology*, Brussels, Belgium, pp. 157-159, Apr. 2004.

Theses and Dissertations

Non-Refereed

Jablonowski, Christiane, "Adaptive Grids in Weather and Climate Modeling." Ph.D, University of Michigan, 2004.

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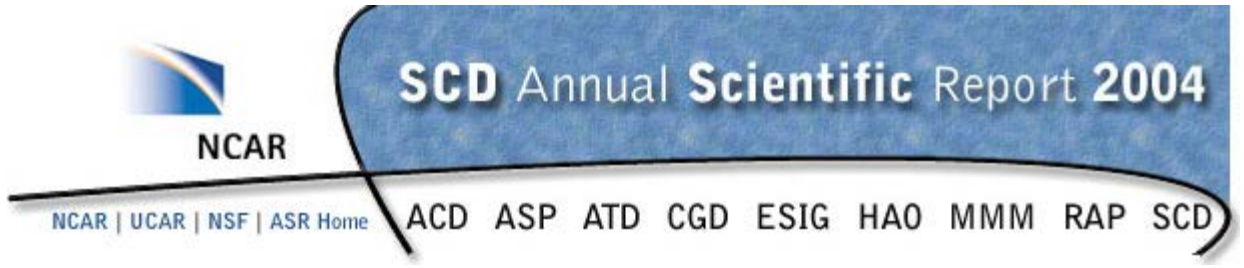

SCD Staff, Visitors, and Collaborators

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Darin Oman
Andrei Rodionov
Manish Salian
Tim Scheitlin

Leonard Sitongia
Markus Stobbs
Nathan Wilhelmi
Josh Yambert

Visitors: 2004

10/27/2003 - 10/28/2003:
Michael Boettinger, DKRZ (German Climate Research Ctr). Visualization R&D. Hosted by Don Middleton, VETS.

11/03/2003 - 11/04/2003:
Bryan Lawrence, British Atmospheric Data Center (BADC) and UK National Environmental Research Council Data Grid (NERC). Federation of Data Portals. Hosted by Don Middleton, VETS.

11/07/2003 - 11/07/2003:
Denny Morse, Northrop Grumman Space Technology. Primary interest is how we manage large volumes of data and how large we allow our file systems to get. Will visit VisLab, SSC/MSSG, and TCG. Hosted by Mary Haley, VETS.

11/07/2003 - 11/07/2003:
Al Danial, Northrop Grumman Space Technology. Primary interest is in how we manage large volumes of data. More specifically, how large we allow our file systems to get. Will visit the Vis Lab, meet with SSC/MSSG, and TCG staff. Hosted by Mary Haley, VETS.

11/12/2003 - 11/12/2003:
John Martellaro, Apple Computer, Inc. Apple G5/Panther Seminar Hosted by Don Middleton, VETS.

11/12/2003 - 11/12/2003:
Ron Ustach, Apple Computer, Inc. Seminar on Apple G5, Mac OS X 10.3 "Panther", and High Performance Computing/Clustering. Hosted by Don Middleton, VETS.

10/27/2003 - 10/27/2003:
STK Japan Visitors (60), StorageTek Japan Users Group. Sixty StorageTek Japan visitors came for an overview of the Mass Storage System, a VisLab demonstration, and a Computer Room tour. Hosted by Gene Harano, HPS.

10/27/2003 - 10/27/2003:
STK Korean Visitors (30), StorageTek Korean Users Group. Thirty StorageTek Korean visitors came for an overview of the Mass Storage System, a VisLab demonstration, and a Computer Room tour. Hosted by Gene Harano, HPS.

11/11/2003 - 11/11/2003:
Al Daniel, Denny Morse, NGST. Supercomputing and Mass Storage technology exchange. Hosted by Gene Harano, HPS.

02/04/2004 - 02/04/2004:
Jose Castanos, IBM T.J. Watson Research Center. Present "Early experience on BlueGene / L Prototype" Seminar. Hosted by Henry Tufo, CSS.

02/23/2004 - 02/24/2004:
Robert Ferraro, NASA GSFC. ESMF collaboration. Hosted by Cecelia DeLuca, CSS.

03/10/2004 - 03/12/2004:
Gerhard Theurich, SGI. ESMF collaboration. Hosted by Cecelia DeLuca, CSS.

03/19/2004 - 03/19/2004:
Robert Ferraro, NASA GSFC. ESMF collaboration. Hosted by Cecelia DeLuca, CSS.

03/19/2004 - 03/19/2004:
Jim Fischer, NASA GSFC. ESMF collaboration. Hosted by Cecelia DeLuca, CSS.

04/14/2004 - 04/17/2004:
Jennifer Ryan, Oak Ridge National Laboratory. Presented SCD seminar. Hosted by R. Nair, CSS.

05/01/2004 - 10/31/2004:
Lorenzo Polvani, Columbia University. Collaboration with CSS (S. Thomas) on the development of new test cases for atmospheric general circulation models. Professor Polvani visited NCAR in May, August, and October 2004. Hosted by S. Thomas, CSS.

06/15/2004 - 08/15/2004:
Michael Levy, CU. NCAR Summer Student Visitor. Hosted by H. Tufo, CSS.

06/15/2004 - 08/15/2004:
Jason Cope, CU. NCAR Summer Student Visitor. Hosted by H. Tufo, CSS.

07/14/2004 - 07/14/2004:
Nils Wedi, ECMWF UK. ESMF collaboration. Hosted by Cecelia DeLuca, CSS.

07/14/2004 - 07/14/2004:
Steve Hankin, NOAA GFDL. ESMF collaboration. Hosted by Cecelia DeLuca, CSS.

07/24/2004 - 08/04/2004:
Martin Gander, Geneva University. Presented an SCD seminar, along with Amik St-Cyr on "Parallelism in Time: Can Parts of the Solution Later in Time be Computed Before the Solution Earlier in Time is Known?". Hosted by Amik St-Cyr, CSS.

08/30/2004 - 09/11/2004:
Andrzej Wyszogrodzki, IBM Research. Collaboration with CSS (R. Loft, S. Thomas, H. Tufo) to develop and test a model with Cloud Resolving Convection Parameterization (CRCP). Hosted by R. Loft, CSS.

08/30/04 - 09/17/04:
Geerd-Rudiger Hoffmann, DWD. North American Technology Projects and Their Relationship to the Future WMO Information System (FWIS). Hosted by Al Kellie in the Director's Office.

08/31/2004 - 09/04/2004:
Mark Taylor, Sandia National Laboratories (SNL). Collaboration with CSS (R. Loft, H. Tufo, S. Thomas) on the DOE/SNL-funded project, "LDRD: Massively Parallel Scalable Atmosphere Model." Hosted by S. Thomas, CSS.

09/04/2004 - 09/30/2004:
Vani Cheruvu, CU. Visiting postdoc. Hosted by H. Tufo, CSS.

09/13/2004 - 09/13/2004:
Dr. Geerd Hoffman, DWD. Mass Storage technology exchange. Hosted by Gene Harano, HPS.

Collaborators: 2004

Markus Stobbs - Worked with Space Science Institute to be a mirror site provider for their MarsQuest Online Website.

Michael Burek and Luca Cinquini - Met with DLESE to discuss collaboration of CDP and DLESE; they met with UNIDATA personnel to discuss the use of THREDDS in CDP and an extension to the THREDDS specification; they met with CAS and ACD, and ATD personnel to discuss adding more data to the CDP; and they have been corresponding with JOSS personnel, discussing the addition of JOSS data to the CDP.

Richard Grubin - Set up classroom/lab software configuration for an NCL workshop at Purdue University for D. Shea and S. Murphy (NCAR) and Prof. M. Huber (Purdue).

Kirsten Butcher - As part of Butcher's joint postdoctoral appointment, she works closely with the Digital Library for Earth System Education (DLESE) as well as the National Science Digital Library (NSDL).

Tim Scheitlin began working with Frank Bryan (CGD) and Scott Weiss (CGD) to produce visualizations of 1/10th-degree ocean model data that was generated on the Earth Simulator in Japan. Scheitlin began learning VTK, and he developed code to map, manipulate, and render the data. Scheitlin participated in helping to remotely test a new AG node at NOAA/GFDL (Remik Ziemlinski).

John Clyne collaborated with U.C. Davis' Kwan-Liu Ma on developing methods for visualizing volumetric

data on "stretched" Cartesian grids as part of their NSF ITR award on time-varying data. Clyne collaborated with U.C. Davis' Ken Joy on the second draft of a System Requirements Specification for a next-generation visualization framework. Clyne continued work with Tim Killeen and Qian Wu on TIDI, TGCM, and GSWM animations. Clyne met with Alan Norton from the Colorado School of Mines to discuss potential collaboration with their respective wavelet and volume rendering work. Clyne continued collaborative work with HAO's Mark Rast on 3D numerical turbulence.

L. Cinquini, R. Loft, D. Middleton, P. Thornton (PI), H. Tufo, N. Wilhelmi, M. Woitascek are the collaborators of the NASA-funded Grid-BGC (Grid BioGeoChemistry) project.

Luca Cinquini - ANL, LBNL, LLNL, NCAR, ORNL, and USC/ISI are collaborating institutions in the DOE-funded project "The Earth System Grid" (ESG).

Luca Cinquini collaborated with the following scientists and data providers to publish datasets to CDP: Louisa Emmons (ACD), Lesley Smith (CGD), Susan Stringer (ATD), Mike Daniels (ATD), John Allison (JOSS), Dusan Odstrcil (CU).

Luca Cinquini collaborated with Scott Ritz (NASA/GCMD) to publish VETS' visualization records to the GCMD archive.

Luca Cinquini collaborated with the following NCAR staff to promote the CDP initiative: L. Buja (CGD), G. Strand (CGD), S. Aulenbach (CGD).

METIS: Research on Workflow in Distributed Collaborative Organizations. Aaron Andersen (NCAR), Ken Andersen (CU Boulder).

Luca Cinquini, Rich Loft, Don Middleton, Peter Thornton (PI), Henry Tufo, Nathan Wilhelmi, Matthew Woitascek are the collaborators of the NASA-funded Grid BioGeoChemistry (BGC) project.

Kirsten Butcher is working with Naomi Friedman, postdoc at the Institute of Behavioral Genetics at the University of Colorado and an expert on visual working memory, to address testing for visual learning and memory.

Kirsten Butcher has been asked to serve on the advisory team for collection development by Mark McCaffrey, Science Communications Specialist at the NOAA Climatic Data Center. McCaffrey is developing a specialized DLESE collection on Climate Change.

Kirsten Butcher is collaborating with Walter Kintsch, Cognitive Psychology Professor at the University of Colorado, on cognitive aspects of learning with multimedia.

Kirsten Butcher is working with Richard Mayer, Cognitive Psychology Professor at the University of Colorado. Mayer is contracted as a co-PI for the NSF proposal (to the NSDL Targeted Research track) submitted Third Quarter FY2004.

Kirsten Butcher is working with Tamara Sumner, Computer Science Professor at the University of Colorado, to examine digital library design and comprehension.

John Clyne co-authored a research paper with U.C. Davis' Kwan-Liu Ma and Hiroshi Akiba for IEEE, VolVis04. This effort was part of their ongoing NSF ITR collaboration.

Nathan Wilhelmi worked with the University of Colorado development group to establish a job management protocol for Grid BGC.

Burek and Cinquini continued the collaboration with Unidata which resulted in Version 1.0 of the THREDDS specification.

NCAR, NOAA/CDC, and NOAA/NCDC are collaborators on the International Comprehensive Ocean-Atmosphere Data Set (I-COADS) project. Steven Worley, DSS, is the co-PI from NCAR.

DSS and VETS are collaborators on the UCAR Community Data Portal. Steven Worley and Bob Dattore are DSS collaborators, D. Middleton, L. Cinquini, and M. Burek are VETS collaborators.

Rick Grubin is a member of the Software Infrastructure Group (SwIG), comprised of members from SSG, TCG, and CSS to collaborate on software development/environment issues for the Linux supercomputers. Headed by M. Page (TCG), with R. Kelly (CSS) and M. Oberg (SSG).

The VETS ESG team collaborated with ESG participants from ANL, ISI, LBNL, LLNL, LANL, and ORNL.

CSS (Rodney James) continues an ongoing collaboration with Yoshi Kimura of Nagoya University, Japan, on Direct numerical simulation of decaying and forced stratified turbulence.

Ramachandran Nair (CSS/NCAR), Phil Rasch (CGD/NCAR), and Henry Tufo (CSS/NCAR and CU) are collaborators on the SciDac (DoE) Project "Improved Transport Processes for CCSM," 9/15/04 - 9/14/07. Dr. Tufo is the PI and Dr. Rasch and Dr. Nair are the co-investigators.

Ramachandran Nair (CSS) and Prof. Bernardo Cockburn (Minnesota University) are co-PIs on the NSF/CMG proposal 2004.

B. Pulleyblank (IBM), G. Bhanot (IBM), H. Tufo (CU and CSS/NCAR), (R. Loft (CSS/NCAR), S. Thomas (CSS/NCAR), W. Grabowski (MMM/NCAR), Janice Coen (MMM/NCAR), T. Manteuffel (CU), S. McCormick (CU), X.-C. Cai (CU), C. Farhat (Stanford), J. Mandel (CU Denver), A. Knyazev (CU Denver) are collaborators on the NSF MRI funded project, "Acquisition of an IBM BG/L Supercomputer," 7/1/04 - 6/30/07. Collaboratiion between IBM, NCAR, and CU Denver. R. Loft is the PI for NCAR and H. Tufo is the PI for CU.

H. Tufo (CSS/NCAR and CU), P. Thornton (CGD/NCAR), D. Middleton (VETS/NCAR), L. Cinquini (SCD/NCAR), R. Loft (CSS/NCAR) are collaborating on the NASA AIST funded project, "Implementing an Efficient Supercomputer-Based Grid Compute Engine for a High-Resolution, High-Volume Terrestrial Carbon Cycle Model," 8/1/03 - 7/31/06. H. Tufo is the co-investigator.

H. Tufo (CU and NCAR/CSS), T. Warburton (Rice), A. Gelb (U. Arizona), and J. Hesthaven (Brown) are collaborators on the NSF ITR funded project, "An Integrated Simulation Environment for High-Resolution Computational Methods in Electromagnetics with Biomedical Applications," 1/15/04 - 1/14/08. This is a collaborative proposal with UNM, Brown, and U. Arizona. H. Tufo is the PI.

H. Tufo (NCAR/CSS and CU), P. Fischer (ANL), S. Thomas (CSS/NCAR), T. Manteuffel (CU), S. McCormick (CU), and X.-C. Cai (CU) are collaborators on the IBM Shared University Research project "Equipment for Bio-Fluid Flow Investigation," 3/15/04 - 3/14/05. H. Tufo is the PI.

H. Tufo (CSS/NCAR and CU), S. Thomas (CSS/NCAR), A. St-Cyr (CSS/NCAR), J. Dennis (CSS/NCAR) are collaborators on the NSF-CMG-funded project "An Adaptive Mesh, Spectral Element Formulation of the Well-Posed Primitive Equations for Climate and Weather Simulations," 10/1/02 - 9/30/05. S. Thomas is the PI and H. Tufo is the co-investigator.

H. Tufo (NCAR/CSS and CU), P. Fischer (ANL), H. Bassiouney (U. Chicago), and F. Loth (U. of Illinois) are collaborators on the NSF-NRAC-supported project, "Simulation of Transition in Vascular Flows," 750,000 SUs cumulative on the TCS1 at the Pittsburgh Supercomputing Center, 4/1/02 - 3/31/05. H. Tufo is the PI.

H. Tufo (NCAR/CSS and CU), S. Thomas (NCAR/CSS), M. Taylor (SNL), B. Spotz (SNL), and M. Boslough (SNL) are collaborators on the DOE/SNL-funded project, "LDRD: Massively Parallel Scalable Atmosphere Model," 10/1/03 - 9/30/06. S. Thomas and H. Tufo are co-Investigators.

H. Tufo (CU and NCAR/CSS), D. Grunwald (CU), M. Woitaszek (CU/NCAR), M. Oberg (CU/NCAR), and J. Cope (CU) are collaborating on the SCD Director-funded parallel file system project. H. Tufo is the PI.

CSS (Cecelia DeLuca) and the following list of people are collaborators on the ESMF project:
Arlindo da Silva, NASA GFSC
Max Suarez, NASA GSFC
Will Sawyer, NASA GSFC
Atanas Trayanov, NASA GSFC
Weiyu Yang, NOAA NCEP
Mark Iredell, NOAA NCEP
Henry Huang, NOAA NCEP
Michael Young, NOAA NCEP
Phil Jones, DOE Los Alamos
Chris Hill, MIT
V. Balaji, NOAA GFDL
Shep Smithline, NOAA GFDL

Sophie Valcke, Cerfacs, FR
Rene Redler, MPI, DE/NEC Europe
Rick Allard, DoD/NRL
Steve Payne, DoD/NRL
Jerry Wegiel, DoD/AFWA
John Michalakes, NSF NCAR/MMM
Mariana Vertenstein, NSF NCAR/CGD
Erik Kluzek, NSF NCAR/CGD
Tom Henderson, NSF NCAR/CGD
Byron Boville, NSF NCAR/CGD
Spencer Rugaber, GA Tech
Dean Williams, DOE LLNL
Carlos Mechoso, UCLA
Rob Armstrong, DOE Sandia

CSS is formally collaborating with IBM Research to develop and test a model with Cloud Resolving Convection Parameterization (CRCP), 10/1/04 - 9/30/05. Dr. Andrzej Wyszogrodzki has been hired as an IBM post-doc to collaborate with CSS on this task. Richard Loft, Steve Thomas, and Henry Tufo are co-PIs on the project.

Piotr Smolarkiewicz (NCAR/MMM), Clive Temperton (ECMWF), Andrzej Wyszogrodzki (IBM), and Stephen Thomas (NCAR/CSS) are collaborators on the Spectral Preconditioners for the Anelastic EULAG Model, October 2003 - October 2004.

Jim Purser (NCEP) and NCAR/CSS (Stephen Thomas) are collaborators on an Iterative Solver and Spectral Preconditioner for the Semi-Implicit Semi-Lagrangian Version of the WRF Model being developed at NCEP, October 2003 - October 2004.

Juergen Steppler (DWD), Bill Skamarock (NCAR/MMM), and Stephen Thomas (NCAR/CSS) are collaborators on Spectral Preconditioners, Solvers and Test Cases for Non-Hydrostatic Models. Research using the DWD LM mesoscale model and WRF; October 2003-October 2004.

Martin Gander (University of Geneva) and Stephen Thomas (NCAR/CSS) are collaborating on Optimized Schwarz Preconditioners, October 2003 - October 2004.

Lorenzo Polvani (Columbia University) is working with Stephen Thomas (SCD/CSS) on the development of new test cases for atmospheric general circulation models. Professor Polvani is an Associate Scientist who collaborates jointly with CGD and SCD on the ongoing project (October 2004-October 2005).

NCAR/CSS (Natasha Flyer) is conducting the Radial Basis Function Research Group with Professor Bengt Fornberg at CU-Boulder. The team consists of postdocs Dr. Suzanne Nezzar and Dr. Grady Wright (at the University of Utah), together with graduate students Susan Hovde, Cecile Piret, and Julia Zuev. Meetings are held on a weekly basis.

Natasha Flyer (NCAR/CSS) is collaborating with B.C. Low (NCAR/HAO), Bengt Fornberg (CU-Boulder), and Stephen Thomas (NCAR/CSS) on Modeling of Solar Magnetic Topology.

Natasha Flyer (NCAR/CSS) is in collaboration with Mei Zhang (Chinese Astronomical Observatory) to prove an upper bound on the magnetic helicity and azimuthal flux of the solar magnetic field in an axisymmetric force free configuration.

Natasha Flyer (NCAR/CSS) is collaborating with Dr. Elisabeth Larsson of Uppsala University to study the interpolation properties for oscillatory radial basis functions on unstructured grids.

Don Middleton continued development work toward a joint NCAR/DOE analysis & visualization effort, working with ESG collaborators Williams and Drach at LLNL/PCMDI, January 2004.

Don Middleton and Tim Scheitlin collaborated with Bob Wilhelmson of NCSA as co-authors of a chapter on Weather and Climate Visualization for the new publiction, *The Visualization Handbook,* February 2004.

Don Middleton collaborated with Berman and Moore of SDSC and co-developed Chronopolis proposal with SDSC. This is a proposal to develop a petascale, distributed digital library/archive and was submitted to NSF in May 2004.

Don Middleton collaborated with Cecelia Deluca and V. Balaji (GFDL) to develop the Earth System Curator Proposal for NSF/SEIII, March 2004.

Don Middleton worked with Dr. Jim Hansen of MIT and Dr. Bill Collins of NCAR/CGD to develop a proposal to NSF's ITR program entitled Climate@Home, March 2004.

Don Middleton collaborated with Worley and Cinquini to develop a proposal for provisioning Reanalysis data for NSF's NMI/SEIII program, March 2004.

Don Middleton collaborated with Foster and Nefedova (ANL), Chervenak and Kesselman (USC/ISI), Shoshani and Sim (LBNL), Williams and Drach (LLNL/PCMDI), Bernholdt and Pouchard (ORNL), and Strand, Fox, Garcia, Cinquini, Markel (NCAR), and played lead author role in the development of a renewal proposal for the Earth System Grid. Middleton also led the effort to add LANL to ESG and worked with Malone, Ahrens, and Sievers at LANL to accomplish this. This resulted in an additional $1M award to NCAR, April 2004.

Don Middleton contributed to a proposal development workshop and was on the proposal development team for Dave Randall's proposed Multiscale Modeling of Atmospheric Processes (MMAP) Science and Technology Center (Dec. 2003), a proposal to develop an NSF Science and Technology Center, May 2004.

Don Middleton collaborated with Dr. Chaitan Baru of SDSC to develop an NSF proposal for a Geosciences Cyberinfrastructure Summer Institute. The proposal was successful, and the workshop was held at SDSC in August 2004.

Don Middleton collaborated with UCAR E&O and agreed to serve as Science Advisor for UCAR E&O contribution to NSF Proposal for developing a new IMAX movie and program entitled Wild America. Middleton's role would be to advise on computer graphics and visualization work in the area of climate and global change, July 2004.

Don Middleton worked with Steve Worley and contributed a modest amount of material on the Community Data Portal and possible collaborative work in the context of a proposal by JOSS to NSF to host a 50-70 GB collection of polar data, July 2004.

Don Middleton collaborated with Peter Fox and Stan Solomon of HAO and Deborah McGuiness of Stanford University's Knowledge Systems Lab to develop the Virtual Solar Terrestrial Observatory (VSTO) proposal to NSF's Middleware Intitiative Program (NMI). The NSF SE3 Virtual Solar and Terrestrial Observatory proposal was awarded the requested funding in full, approximately $1.5M for three years, August 2004.

Don Middleton worked with Stevens and Papka of ANL as a newly appointed member of the Program Committee for the Workshop on Advanced Collaboration Environments, this year held in Nice, France, September 2004.