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NCAR Annual Report 2012

A Message from the Director

With 2013 upon us, the NCAR Annual Report allows me to take a look back at some of the community science and support highlights of the previous year. Among these highlights was the much-anticipated opening in October of the **NCAR-Wyoming Supercomputing Center** (NWSC) in Cheyenne, Wyoming. The NWSC provides advanced computing capabilities to scientists via one of the world's most powerful supercomputers dedicated to

Roger Wakimoto

the geosciences, and also provides a premier data archival facility that will preserve valuable research data. The NWSC results from a broad public-private partnership among NCAR, the National Science Foundation, University of Wyoming, the state of Wyoming, Cheyenne LEADS, the Wyoming Business Council, and Cheyenne Light, Fuel and Power.

Among the field campaigns this year, the **DC3 (Deep Convective Clouds and Chemistry) project** investigated the impact of deep, mid-latitude continental convective clouds on upper tropospheric composition and chemistry. With university scientists, NASA, and the German Aerospace Center participating, the experiment investigated the influence of thunderstorms on air just beneath the stratosphere, allowing a comprehensive look at both thunderstorm chemistry and physics, including air movement, cloud physics, and electrical activity. A vital tool for this effort was the Mission Coordinator Display system, which provided rapid-refresh visuals of evolving weather situations, and linked ground-based researchers with airborne crews through interactive chat. This system has become mission critical, facilitating real-time decision-making, and allowing those on the ground to direct airborne crew to areas of research interest, thereby optimizing atmospheric sampling.

Continuing NCAR's focus on helping educate the next generation of scientists, the Integrated Science Program (ISP), Advanced Study Program, and Centers for Disease Control and Prevention (CDC) graduated its first two post-doctoral students from the **two-year fellowship focused on the health-climate nexus**. Now assistant professors – Chris Uejio at University of Florida, and Sean Moore at University of New Mexico – continue their work in this area, and the leaders of the ISP-ASP-CDC partnership look forward to continuing the joint post-doctoral program in this relatively new study area. This year's **ASP colloquium** focused on the **Weather-Climate Intersection**. The colloquium again featured a three-week program for student participants, with top researchers invited to a Researcher Colloquium during the second week. Structured this way, professional colleagues that otherwise see each other infrequently had an opportunity to meet and identify areas for future collaboration, while students not only have an opportunity to talk to experts in their field, but they add to their cohort of future research colleagues.

NCAR and our community participated in many other notable scientific efforts. Please take time to read the suite of stories that comprise the 2012 NCAR Annual Report for details on these projects and many other exciting research efforts that occurred in 2012. I encourage you to see the annual reports created by each of our Laboratories, Programs and our Observatory. These provide a further variety and breadth of details on 2012 work.

With best wishes for 2013 and sincere thanks for your ongoing support, and the hard work of the past year,

Roger

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    - GLOBE
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    - Unidata
    - VSP
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    - UCP Budget & Administration
  - President's Office
    - Communications & Media Relations
    - Development & Partnerships
    - Government Relations
    - Membership
    - Office of General Counsel
    - University Relations
  - Human Resources
  - Finance & Administration
- NCAR
  - National Center for Atmospheric Research
  - Atmospheric Chemistry Observations & Modeling Lab
  - Climate and Global Dynamics Lab
  - Computational & Information Systems Lab
  - Earth Observing Lab
  - High Altitude Observatory
  - Mesoscale & Microscale Meteorology Lab
  - Research Applications Lab
  - Director's Office
  - Advanced Study Program
  - Integrated Science Program
  - Budget & Planning Office
  - NCAR Library
- Find People
  - Staff Directory
  - Scientific Visitors
- Locations/Directions
  - Maps, Directions, Help
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NCAR Annual Report 2012

Science Serving Society

Both the National Science Foundation and NCAR focus on the service of science in benefit of society as part of their overall mission. Most of the stories highlighted in this annual report have societal benefit integrated into the research effort, but an ongoing focus for NCAR and our community is to bring in a greater diversity of voices to the geosciences field. Another emphasis is on effectively communicating our science, scientific results, and how these lessons learned might affect the public. The following set of stories provides a snap shot of some of the efforts by NCAR and

community scientists to achieve this end.

Portable, automated weather stations--lightweight and powered by solar panels--have been used to monitor and study microbursts, sudden changes of wind speed or direction that are extremely hazardous to aircraft). These record meteorological information such as wind speed and direction, temperature, humidity, pressure, and rainfall. By concentrating high technology observing systems in a small area, current conditions can be constantly monitored, allowing vastly improved forecasts and severe weather warnings.

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    - Communications & Media Relations
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    - Government Relations
    - Membership
    - Office of General Counsel
    - University Relations
  - Human Resources
  - Finance & Administration
- NCAR
  - National Center for Atmospheric Research
  - Atmospheric Chemistry Observations & Modeling Lab
  - Climate and Global Dynamics Lab
  - Computational & Information Systems Lab
  - Earth Observing Lab
  - High Altitude Observatory
  - Mesoscale & Microscale Meteorology Lab
  - Research Applications Lab
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Supporting the Future of Science

A focus for NCAR is ensuring development and support for the next-generation of scientists. NCAR achieves this through a variety of efforts, which includes summer colloquia and internship programs, partnerships with community universities, as well as provision of state-of-the-art computing to both the existing and upcoming generations of scientists.

Scientists at the National Center for Atmospheric Research (NCAR) and universities across the country are launching a series of initial scientific projects on the center's flagship, a 1.5-petaflop IBM supercomputer known as Yellowstone. These first projects focus on a wide range of Earth science topics, from atmospheric disturbances to subterranean faults, that will eventually help to improve predictions of tornadoes, hurricanes, earthquakes, droughts, and other natural hazards.

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Tools of the Trade

Many in our research community rely on NCAR to provide research tools that are critical to helping find answers to scientific and societally relevant questions. The tools developed and supported at NCAR and within the community range from global- to regional-scale models, research instruments, computing power and support, and data output, among other capabilities. Some of these tools of the trade are described in the stories found within this section.

NCAR scientist Ethan Gutmann examines a laser instrument for measuring snow. Gutmann, Kristine Larson at the University of Colorado, and others are working to solve a critical wintertime weather mystery: how to accurately measure the amount of snow on the ground. Transportation crews, water managers, and others who make vital safety decisions need precise measurements of how snow depth varies across wide areas. Specialized laser instruments under development at NCAR may offer promising solutions.

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  - Advanced Study Program
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NCAR-wide efforts

A number of events occurred in 2012 that affected NCAR and our community. Among the exciting news is the opening of the NCAR-Wyoming Supercomputing Center in Cheyenne, Wyoming in October 2012. The effects of Colorado's summer wildfires touched both NCAR and Colorado State University; some of these experiences are shared in one of the stories in this section. And, with input from experts within our community, NCAR and its Laboratories and Observatory had their every-five-year review, the outcomes of which are reported on.

The Mesa Laboratory of the National Center for Atmospheric Research, located atop Table Mesa at the west end of Boulder, Colorado.

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Metrics

The metrics featured below offer qualitative and quantitative measurements and assessments of the productivity, quality, and impacts that NCAR programs and activities have on our research community, our sponsors, and society in general.

Field Programs

Collecting field data is a scientist's stock in trade. Direct observations shed insights on weather, climate, and related Earth-system phenomena. Ranging from a few weeks to several months, field programs (field-based observing campaigns or experiments) ensure successful data collection.

NCAR led or participated in 11 field campaigns in 4 countries and the United States. Locales ranged from the Sierra Madre mountain range in Southern Wyoming to the Eastern Tropical Pacific including Chile, and included more than 261 participants.

Editorships

NCAR staff also serve as publication editors. These positions recognize the appointee's leadership in the field and serve a critical role in developing a given field's future focus.

Forty-nine NCAR staff served in 65 different editorial roles on 51 different publications or journals. Publications included top-tier journals such as *Water Resources Research* and *Astrophysical Journal.*

External Committee Service

NCAR staff are called upon to participate in and often lead external scientific, technical, policy, and educational committees. These committees are instrumental to advancing and promoting the work of the scientific and technical community.

This year, 114 NCAR staff served in a multitude of roles on 306 external committees for national and international scientific, education, and governmental organizations, including entities such as the Board of Governors, the U.S. National Committee for the International Institute for Applied Systems Analysis, and the International Land Surface Databank Development Committee. Positions ranged from Co-organizer to Panel Member. More than 63% served on more than one committee.

Presentations

NCAR Staff give presentations about data, models, theories, hypotheses, reviews, and results around the world to audiences ranging from scientists and engineers to the general public.

More than 93,000 people were in the audience when 257 NCAR staff made more than 1,200 presentations across the country and around world, from New Orleans, Louisiana to Abiko, Japan. Examples range from Susan Bates' (NESL/CGD) presentation on "Learning about Oceanography" in Rocky Mount, North Carolina to Gokhan Danabasoglu's "Decadal climate prediction: Where are we?" in La Paz, Mexico.

Posters

NCAR Staff present posters about their research at conferences and workshops.

More than 62,225 people were in the audience when 109 NCAR staff presented more than 193 posters across the country and around world, from Beijing, China to Salt Lake City, Utah. Examples range from Helen Worden's (NESL/ACD) poster "Satellite-based estimates of reduced CO and CO2 emissions due to traffic restrictions during the 2008 Beijing Olympics" at the IGAC-GEIA Workshop in Toulouse, France to Donald Schmit's (HAO) poster on "Diagnosing the prominence-cavity connection" at theSDO-4/IRIS/Hinode Workshop: Dynamics and energetics of the coupled solar atmosphere," in Monterey, California.

Colloquia, Symposia, and Tutorials

Smaller, often unilateral events, colloquia, symposia and tutorials focus primarily on education or training. This metric measures entire events that NCAR hosted alone, or co-hosted with other institutions or agencies.

NCAR sponsored 65 colloquia, symposia, and tutorials in Boulder and abroad. Participants per session averaged out to more than 36, for a total audience of more than 2,350 peers and students. Some of the co-hosts include the USGS Woods Hole Coastal and Marine Science Center, the Asian Disaster Preparedness Center, and the Air Force Weather Agency.

Workshops and Conferences

NCAR-hosted or co-hosted workshops and conferences are generally larger, bilateral events convened for the purpose of discussion, consultation and exchange of views and information.

NCAR sponsored 65 workshops and conferences in seven countries and nine U.S. states. We partnered with sponsors from the university community, such as Jackson State University, University of Warsaw, and the University of Michigan, and with government agencies including the National Centre for Atmospheric Science, the National Renewable Energy Laboratory, and the National Aeronautics and Space Administration, as well as with non-profit partners like the Front Range Consortium for Research Computing. In total, these workshops and conferences reached just over 4,243 participants around the world.

Teaching Appointments

NCAR staff make important contributions through teaching appointments at institutions of higher education in positions ranging from Faculty Affiliate to Professor.

Teaching appointments at institutions of higher education currently number 32. Twenty-five percent of these appointments occur in seven countries around the world; 75% took place in eight U.S. states, including the University of Utah. The longest term is 19 years.

Graduate Advisors

NCAR staff serve as research advisors for graduate students around the world.

Of the 85 graduate students that have NCAR staff serving as graduate advisors, 31% hail from Colorado institutions; 40% attend schools in 14 other states. The remaining 29% study at schools in 16 countries around the world, including five students from the University of Vienna who are advised by Vanda Grubisic.

Thesis committees

NCAR staff serve as dissertation or thesis committee members for internal and external graduate students.

Eleven Masters students and 73 PhD candidates work with 53 NCAR staff as they pursue their degrees from universities in 21 U.S. states; this includes 34 students from Colorado institutions. Sixteen students come from 11countries, with Swiss students leading the international count at three.

NCAR Student Appointments

Students also enjoy NCAR-based appointments.

In FY12, there were 39 Graduate Student, 15 Graduate Research Assistant and 14 undergraduate Student Assistant appointments. There were also 17 student internships coordinated through the **Summer Internships in Parallel Computational Science (SIParCS) program**, the **EOL Technical Internship Program**, and the **EOL Undergraduate Program for Engineering Research**. These students hail from home institutions ranging from George Mason University in Fairfax, Virginia to National Central University in Taiwan. NCAR also awards postdoctoral fellowships to talented staff through the **Advanced Study Program** and **other laboratory visitor programs**.

Special Appointments

NCAR Affiliate Scientists: Select university and research-community scientists are invited to carry out long-term, highly interactive, collaborative work with UCAR scientists and are appointed as Affiliate Scientists with three-year terms. This appointment is particularly suitable for parties who desire an extended, close-working relationship on scientific problems of mutual interest. Currently, 33 hold appointments including Dr. John Finnigan of the Commonwealth Scientific and Industrial Research Organization (CSIRO) in Australia. He is collaborating with NCAR scientists on measuring surface atmosphere exchange from towers and in surface parameterisations in climate, weather and boundary layer models; Dr. Finnigan collaborates with MMM in NCAR Earth Systems Laboratory.

Emeritus/Emerita: Scientific and Research Engineering staff who have made significant contributions to NCAR through long and distinguished service in senior positions in research may be granted emeritus or emerita status. This designation confers a life-long honorary distinction. Approval of the President and the Board of Trustees is required. Currently the ranks of Emeritus/Emerita number 15 with the recent appointment of eminent HAO scientist Ray Roble who is continuing his research on developing a new model of the global atmospheric electrical circuit.

K-12 Outreach

Staff across NCAR work directly with classes and groups of K-12 students by developing or delivering lectures, conducting tours, and leading or participating in field trips and other educational activities.

Thirty-seven NCAR Staff worked with K-12 students from 33 schools. Activities included mentoring, lectures, tours and field trips reaching 17 different communities. Examples range from participating in the Earth Explorers program by educating and mentoring underrepresented youth, to providing a weather demonstration at Red Hawk Elementary School, to serving as a judge in a science fair.

Among the highlights: Alexandra Jahn (CGD) served as a facilitator for an online climate change course for K-12 science teachers through the Research Experience for Teachers Institute (RETI) program; Carl Drews (ACD) served as an adult chaperone for lab experiments during a three-day science field trip to Pingree Park for Flagstaff Academy 7th grade students; and Michelle Harrold (RAL) mentored a SPARK pre-college student, in a program designed to introduce a diverse community of high school students to the world of atmospheric and related sciences.

Awards

Each year a number of NCAR Staff are honored for their work and contributions to the Atmospheric and related

sciences.

Twenty-five staff received special recognition for their work. Clayton Arendt (EOL) received the CO-LABS Governor's Award for High-Impact Research. This award provides an opportunity for the federal labs in Colorado to demonstrate how they are making a difference in the state, at the national level and globally. Alex Guenther (NESL/ACD) received the Yoram J. Kaufman Award from the American Geophysical Union. The award is given for broad influence in atmospheric science through exceptional creativity, inspiration of younger scientists, mentoring, international collaborations, and unselfish cooperation in research. Peggy LeMone received the American Meteorological Society's Joanne Simpson Mentorship Award. The award recognizes individuals in academia, government, or the private sector, who, over a substantial period of time, have provided outstanding and inspiring mentorship of professional colleagues or students.

Fellowships

A fellowship is typically a special appointment granting support for a term in order to support advanced research or study.

Nine NCAR staff received fellowships in 2012. Among the highlights: Alexandra Jahn was awarded the National Academies Christine Mirzayan Science & Technology Policy Graduate Fellowship, which is an early career educational and training opportunity. The goal of the fellowship is to engage its Fellows in the analytical process that informs U.S. science and technology policy. Fellows develop basic skills essential to working or participating in science policy at the federal, state, or local levels. Her project involved contributing to several national academy reports on sea ice predictability, the future of climate modeling, and urban meteorology.

Scientific and Technical Visitor Appointments

Each year students, scientists, engineers, weather forecasters, and other professionals from around the country and world receive special visitor appointments from labs and programs across NCAR to collaborate with scientific, educational, or technical staff; conduct independent research; or participate in and/or oversee a professional project. Many receive financial support for their visits and some visitors temporarily join the NCAR staff.

This year, colleagues visited NCAR 932 times and hailed from 393 institutions, located in 46 different U.S. states and 40 different countries.

Visit Length - Number of Scientific and Technical Visitors in FY12

1 day to 1 week: 235

8 days to 2 weeks:108

>2 weeks to 2 months: 244

>2 months to 6 months: 217

> 6 months to 1 year or more: 128

Total: 932

Scientific and Technical Visitor Types - Headcount in FY12

Visitors on Payroll: 41

NCAR funded Visitors: 342

Externally funded Visitors: 549

Total: 932

Publications in the UCAR Open Sky Institutional Repository

NCAR's publication records are curated in the **UCAR Open Sky Institutional Repository**. OpenSky is the open access institutional repository supporting UCAR, NCAR, and UCP, extending free and open access to our scholarship for the benefit of research and education.

OpenSky is operated by the NCAR Library, with the goal of providing free and open access to the scholarship of UCAR, NCAR, and UCP. Founded on the principle that public access to the scholarly record is essential to the advancement of science and society, the vision of OpenSky is to support the broad mission of UCAR to foster science, support its community, and facilitate the transfer of knowledge.

In support of this vision, OpenSky will provide long-term storage, preservation, access to scholarly works and the products of scientific research created by UCAR, NCAR, and UCP authors.

A publication is an academic or technical work of writing containing original research results, reviews of existing

results, or scholarship. "Refereed" publications undergo an editorial "blind" or anonymous process of peer review by one or more referees (who are experts in the same field) in order to check that the content of the paper is suitable for publication in the journal. A paper may undergo a series of reviews, edits and re-submissions before finally being accepted or rejected for publication. "Non-refereed" articles have been reviewed by editors or boards before being accepted for publication but have not gone through a formal blind review. **Attached are NCAR's refereed lists for the period October 1, 2011 to September 30, 2012**. Search for recent NCAR publications by author, date, keyword or status please go to the **NCAR Publications database**.

For excellent library resources please go the **NCAR Library Web site**.

663 Total Publications (**download bibliography**)

Refereed: 663
UCAR and Other: 106
UCAR and University: 184
UCAR only: 86
UCAR, University and Other: 287

UCAR Outstanding Publication award for FY12:

Thomas Karl (NESL/ACD), Peter Harley (NESL/ACD), Louisa Emmons (NESL/ACD), Alex Guenther (NESL/ACD), Andrew Turnipseed (NESL/ACD, received the FY12 Outstanding Publication Award for"Efficient atmospheric cleansing of oxidized organic trace gases by vegetation" published in the journal *Science,* volume *330,* pages 816-819, 2010.

This paper shows that deciduous plants absorb far more pollution than previously thought. The research uses observations, gene expression studies, and computer modeling to show that vegetation can play an unexpectedly large role in cleansing the atmosphere.The findings presented came as a surprise and connected separate scientific communities across atmospheric, biological, and chemical science fields. A unique, diverse group consisting of atmospheric scientists, plant physiologists, and molecular biologists was able to tackle a complex biogeochemical problem and study the impact on the atmosphere.The paper's scientific significance is already demonstrated by its high **ISI citation** rate (27 citations in two years).

For a full list of each metrics topic, contact Helen Moshak, **moshak@ucar.edu**.

Attachment	Size
FY12 OpenSky Publications Report.docx	117.7 KB

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Advanced Study Program | ASP
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ASP Annual Report 2012

ASP Director's Message

The Advanced Study Program (ASP) helps NCAR and the scientific communities that it serves to prepare for the future by engaging in human, institutional and broad intellectual capacity building. ASP entrains a broad

community of scholars, encourages the exchange of information and the development of new perspectives, and provides unique hands-on educational experiences and many opportunities for students, advisors, and early career scientists to collaborate with a wide variety of NCAR scientists and engineers engaged in research, modeling, and observational activities.

The two-year ASP Postdoctoral Fellowships encourage the development of early career scientists in the field of atmospheric and related sciences and direct attention to timely cutting-edge scientific areas. Approximately 10 new appointments are made annually for positions across NCAR. Fellows' research advances are reported separately in the NCAR Laboratory Annual Reports.

Through its remaining components, the Graduate Visitor Program (GVP) and Faculty Fellowship Program (FFP), ASP promotes research activities, fosters graduate education, and develops partnerships between NCAR scientists and their colleagues in universities and other institutions.

Accomplishments

The ASP awarded 12 new postdoctoral fellowships in spring 2012. These new fellows have already begun to arrive and to participate in ASP activities, providing a boost to the ongoing program. Between the FFP and the GVP, the ASP supported 188 months of long-term visits to NCAR in FY12. Five faculty members came to NCAR as part of the 2012 Faculty Fellowship Program while 31 GVP awards were given as a result of the 2012 GVP search. Most of the GVP awards also include an advisor visit.

The ASP continued its ongoing efforts to better serve diverse communities in FY2012 through the continuation of postdoc exchanges with Minority Serving Institutions (MSI).

Finally, the ASP supported the first-ever Software Engineering Assembly (SEA) conference on scientific computing and software development that included participants from NCAR and from other scientific agencies in the area.

More on all of these programs can be found in this report.

FY2013 Plans

ASP will continue to engage and develop the scientific workforce of the future through its core visitor and fellowship program elements that engage all graduate students and postdoctoral fellows in residence at NCAR, including monthly seminars, monthly informational socials, the annual ASP retreat and ongoing mentoring opportunities. Through the highly successful Thompson Lecture Series, ASP will bring two prominent scientists to NCAR for extended interactions with this cohort. Andrew Dessler, a professor at Texas A&M, will be visiting October.

The annual ASP Colloquium series will focus on the topic of Carbon-climate connections in the Earth System. As in the past two years, the colloquium will expand to three weeks from two to accommodate a revival of an NCAR tradition: the ASP Research Colloquium. The current format includes a one-week colloquium geared toward researchers engaged in the colloquium topic. Students will stay for three weeks to participate in lectures and hands-on activities.

ASP will support the NCAR Software Engineering Assembly's second conference and also provide organizational support for the activities of the Early Career Scientists Assembly (ECSA).

ASP will continue to promote diversity in the atmospheric sciences by supporting travel of NCAR scientists to give seminars at MSIs, supporting teaching opportunities of NCAR postdocs at MSI's and encouraging participation in ASP programs of individuals from underrepresented groups. ASP's Sean Moore will teach for a semester at the University of New Mexico, Albuquerque.

Additional details along with other ASP plans are included in this report.

Group picture of the NCAR fellows association retreat attendees

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CISL ANNUAL REPORT 2012

COMPUTATIONAL & INFORMATION SYSTEMS LABORATORY

NCAR

2012 CISL Annual Report

CISL Director's Message

Message from CISL Director Al Kellie

CISL's top FY2012 accomplishment is the inauguration of the supercomputer dedicated to Earth System sciences at the NCAR-Wyoming Supercomputing Center (NWSC). This is the eighth year that laboratory staff have devoted to realizing this achievement. CISL fully deployed Yellowstone, a 1.5-petaflops supercomputing environment integrated with a centralized file system, massive data storage resources, and two data analysis and visualization systems by the end of FY2102. As a discipline-specific computing laboratory, CISL provides the capabilities and targeted user services required to support important computational and field campaigns with on-demand resources that include those driven by unfolding natural

CISL Director Al Kellie

events. CISL's commitment to a data-intensive computing strategy also includes a full suite of community data services and science gateways.

CISL's top imperative is to provide world-class computing facilities for its user communities. In FY2012, the NWSC facility received its first full complement of Information Technology (IT) equipment, staff, and visitor exhibits. For decades to come, NWSC will be home to many generations of supercomputing systems.

CISL has transitioned supercomputing operations to the NWSC in Cheyenne, Wyoming from the Mesa Lab Computing Facility (MLCF) in Boulder, Colorado. The MLCF is completing its 47-year run as NCAR's community supercomputing center, and it is now being repurposed to house NCAR's and UCAR's divisional-class and enterprise-class IT equipment. MLCF will continue providing significant value to Earth System researchers for decades into the future.

CISL also continues to focus on science and education, its other two strategic missions. A long-running science program in IMAGe, the Data Assimilation Research Testbed (DART), received the 2012 UCAR/NCAR Outstanding Performance Award for Scientific and/or Technical Advancement, and a CISL education program in its Technology Development Division (TDD) received the 2012 UCAR/NCAR 2012 Outstanding Performance Award for Education and Outreach. That education program is the long-running series of national and international NCAR Command Language (NCL) training workshops. These two awards recognize CISL's commitment to elevate not only the technology, but also the science and the people of our research community.

Data assimilation, the process of combining observations with models, is providing rapid advances in geophysical studies, and CISL scientists in IMAGe perform fundamental research on ensemble data assimilation methods for a wide range of geophysical problems. During FY2012, the DART program advanced a broad range of collaborative simulation and observation projects with university and NCAR scientists. In addition, the DART software fully incorporated more than a dozen major geophysical models, including nearly all NCAR community models. The UCAR/NCAR award recognized the team of Jeff Anderson, Nancy Collins, Tim Hoar, Hui Liu, Kevin Raeder (all from CISL/IMAGe), and Glen Romine (NESL/MMM) for their years of transformative impact on the Earth System sciences. DART is being used at 48 UCAR member universities and 360 other organizations, and it contributes to dozens of research papers being published every year.

CISL's NCL training workshops are a premier example of outreach to a wide range of universities and other centers. Analyzing large, complex data is a rapidly growing challenge in our community. CISL's unique NCL training program helps researchers become proficient using CISL's NCL toolkit designed specifically for scientific data processing and visualization. The free NCL workshops directly target each student's needs because they analyze and visualize their own datasets. The instructors work with students individually during the labs, and by the end of each 3-1/2-day workshop, most students develop nearly complete NCL programs that produce meaningful results from their own data. Further, the NCL workshops also train students in the fundamentals of scientific data analysis and visualization for the Earth System sciences, along with instruction in general programming. For their 12 years of education services, the team of Mary Haley, Dave Brown (both from CISL/TDD), and Dennis Shea (NESL/CGD) received the 2012 UCAR/NCAR education and outreach award. This dedicated team of engineer- and scientist-educators has trained 915 students at a total of 61 local, national, and international NCL workshops.

This annual report offers many more highlights of the breadth and excellence of CISL's programs. CISL provides far more than balanced, easy-to-use computational and data environments designed for the requirements of the Earth System sciences. CISL also develops and delivers high-quality science and education programs to strengthen NCAR's leadership position at the intersection of large computational resources, large data sets, and community needs. As we envision the future of our science, we now begin looking beyond the horizon of the NWSC achievement to ready ourselves, NCAR, and the communities we serve for the challenges ahead.

As you read this report, I hope you share our excitement about the past year's significant progress. It is my pleasure to present our FY2012 CISL Annual Report.

CISL Annual Report Table of Contents ›

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  - University Corporation for Atmospheric Research
  - UCAR Community Programs
    - COMET
    - COSMIC
    - DLS
    - GLOBE
    - JOSS
    - MetEd
    - UCAR Center for Science Education
    - UCARConnect
    - Unidata
    - VSP
    - UCP Director's Office
    - UCP Budget & Administration
  - President's Office
    - Communications & Media Relations
    - Development & Partnerships
    - Government Relations
    - Membership
    - Office of General Counsel
    - University Relations
  - Human Resources
  - Finance & Administration
- NCAR
  - National Center for Atmospheric Research
  - Atmospheric Chemistry Observations & Modeling Lab
  - Climate and Global Dynamics Lab
  - Computational & Information Systems Lab
  - Earth Observing Lab
  - High Altitude Observatory
  - Mesoscale & Microscale Meteorology Lab
  - Research Applications Lab
  - Director's Office
  - Advanced Study Program
  - Integrated Science Program
  - Budget & Planning Office
  - NCAR Library
- Find People
  - Staff Directory
  - Scientific Visitors
- Locations/Directions
  - Maps, Directions, Help
  - Public & School Tours
- Closures/Emergencies

NCAR | ASP | CISL | ISP | HAO | EOL | NESL | RAL

Integrated Science Program | ISP
2012 Annual Report

sponsored by NSF

ISP Director's Message

The **Integrated Science Program** (ISP) was formed in 2009 as an NCAR Directorate entity that supports scientists working on crosscutting research across NCAR Laboratories and other research institutions. The overarching goal of the Integrated Science Program

(ISP) is to develop the understanding needed to manage and adapt to climate change, weather, and chemical weather through research that integrates the atmospheric sciences with other scientific disciplines. ISP is:

- Developing new connections among the atmospheric sciences, social sciences, ecology, hydrology, and health science
- Fostering collaborations across NCAR laboratories, divisions, institutes, and programs
- Building new relationships with university programs and other research institutions whose expertise complements NCAR expertise
- Promoting innovation in NCAR research and development

ISP is unique within NCAR as a “virtual” organization that does not maintain its own staff (except for a very small central administrative group) and carry out its own projects. All ISP activities are defined and undertaken in cooperation with other NCAR organizations and collaborators in the university community and other research institutions. ISP helps define, set up, and fund projects that are carried out by staff from NCAR labs and outside collaborators.

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High Altitude Observatory | HAO
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2012 HAO Annual Report

Welcome to the High Altitude Observatory at the National Center for Atmospheric Research

HAO's Mesa Lab Dome and Undergraduate Engineering Interns at work.

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Earth Observing Laboratory | EOL
2012 Annual Report

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Director's Message

Welcome to the FY2012 Earth Observing Laboratory (EOL) Annual Report, which summarizes many of our accomplishments over the past year. The report is organized around the Imperatives and Frontiers of the **EOL Strategic**

EOL Director Vanda Grubišić

Plan. As you will read, our FY2012 activities reflect our mission to "develop and deploy observing facilities and provide data services needed to advance scientific understanding of the earth system." Through our provision of world-class observational facilities, field support, data management, and research services to the NSF-funded user community, EOL enables and actively contributes to significant progress in the atmospheric sciences.

As in every year, EOL scientists and staff supported and participated in several exciting field campaigns. In FY2012, two campaigns stand out in terms of their complexity and the Laboratory-wide support effort. One of these, the Dynamics of the Madden-Julian Oscillation (**DYNAMO**) campaign, saw us deploy and directly support ground- and ship-based instrumentation across a swath of the Indian Ocean that stretched from Diego Garcia to The Republic of Maldives. EOL also ran the main DYNAMO Project Office, organizing and coordinating 11 nations, 3 ships, 2 aircraft, and multiple radars, surface stations and moorings. This campaign, in which we unfortunately had to deal with a military coup in the Maldives, was both challenging and rewarding for both the investigators and for EOL. Support of DYNAMO showcased EOL's well known "can-do" spirit as well as the benefits of our unique end-to-end observational science enterprise.

The Deep Convective Clouds and Chemistry (**DC3**) field experiment also put our team to the test, as it involved three research aircraft supported by three different agencies and over 350 participants studying the role of deep convection over the U.S. Great Plains in vertical transport and mixing of some important chemical species in the atmosphere. EOL's coordination of the 4 U.S. government Agencies, the German Aerospace Center (DLR), and the 25 U.S. universities that participated was beyond compare. The ground-based instrumentation and the NSF/NCAR HIAPER aircraft that EOL deployed contributed tremendously to the science goals of the project.

Beyond field campaigns, EOL has continued to develop the next generation of instrumentation for use by the scientific community. You can read about many of these innovations under **Imperative III**. I highlight here the new surface network facility of up to 100 self-contained flux systems. This facility, called **CentNet**, is designed to scalable up to 100 stations and deployable at a broad range of spatial scales to support a variety of biogeophysical studies. In FY 2012, we designed new tower infrastructure for this facility and made progress towards minimizing field maintenance of sensors. Expansion of CentNet and its capabilities will continue in the coming years so that it could be used for both weather and climate process studies at the critical atmosphere terrestrial interface.

Our data activities in FY 2012 involved reaching out to partners in the community to enhance our data stewardship activities and begin the examination of open-source software development collaborations. As always, we continue to develop new data collection and management techniques for use by our investigators in field campaigns. As an example, our **Mission Coordinator display**, described in more detail in Imperative IV, has evolved into a highly extensible and user-friendly tool for situational awareness and mission-planning. In FY 2012, the DC3 project benefited from this display's new and greatly extended menu of customized real-time products delivered to flight crews and ground based scientists.

Finally, EOL continued its work to provide exceptional education and training to new observational atmospheric scientists and engineers, and to inform and excite the public about the impact of observational research. Education and outreach events held during field campaigns, internships for engineering and science support students, and support for educational field campaigns are just some of the examples of how EOL meets this part of its mission. All of this and more is described in greater detail in **Imperative V**.

I am proud to present the Laboratory's remarkable activities and accomplishments in the following pages, and hope you will enjoy reading about them.

-Vanda

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    - UCARConnect
    - Unidata
    - VSP
    - UCP Director's Office
    - UCP Budget & Administration
  - President's Office
    - Communications & Media Relations
    - Development & Partnerships
    - Government Relations
    - Membership
    - Office of General Counsel
    - University Relations
  - Human Resources
  - Finance & Administration
- NCAR
  - National Center for Atmospheric Research
  - Atmospheric Chemistry Observations & Modeling Lab
  - Climate and Global Dynamics Lab
  - Computational & Information Systems Lab
  - Earth Observing Lab
  - High Altitude Observatory
  - Mesoscale & Microscale Meteorology Lab
  - Research Applications Lab
  - Director's Office
  - Advanced Study Program
  - Integrated Science Program
  - Budget & Planning Office
  - NCAR Library
- Find People
  - Staff Directory
  - Scientific Visitors
- Locations/Directions
  - Maps, Directions, Help
  - Public & School Tours
- Closures/Emergencies

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NCAR Earth System Laboratory | NESL
2012 Annual Report

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2012 NESL Lab Annual Report

The past year has been one of considerable scientific achievement across NESL. In particular, the Laboratory continued to build on an exceptionally strong record of scientific leadership and accomplishment, as it fulfilled its mission to advance

Jim Hurrell - Director, NCAR Earth System Laboratory

understanding of weather, climate, atmospheric composition and processes; provide facility support to the wider community, and; apply the results to benefit society.

Many significant accomplishments are described in detail in this annual report. Here, only a few, specifically related to NESL's major community modeling and observational facilities, are highlighted.

The community modeling facilities include CESM (with WACCM), WRF, NRCM and their specialized interdisciplinary modules. These facilities are of paramount importance to numerous NCAR strategic imperatives and frontiers. They are the major, if not the primary, scientific justification for the NWSC, and within NCAR, they are a centerpiece of collaboration between NESL, CISL, RAL, ISP and HAO. Some selected accomplishments in FY 2012 include:

- Successful community user workshops in the summer of 2012, drawing more than 390 participants to discuss progress and plans with CESM and more than 240 participants to do the same for the WRF modeling system. In addition, the release of WRF Version 3.4 in April 2012 offered many new features and improvements to the community.
- The annual CESM tutorial drew 80 student and early career participants from the University and National Laboratory communities, while there was nearly 150 participants in two WRF tutorials held at NCAR. WRF tutorials were also held in the United Kingdom and South Korea in FY 2012. Other training has been provided to early career scientists and graduate students through individual liaison and web-based activities.
- The use of WRF in support of: the NOAA Storm Prediction Center's Spring Forecast Experiment (SFE); the Antarctic Mesoscale Prediction System (AMPS); real-time Atlantic Basin simulations over the 2012 hurricane system; and real-time simulations in support of field operations for the Deep Convective Clouds and Chemistry (DC3) campaign.
- The release of WACCM-X (an extended altitude version of WACCM) to the community, as part of CESM, in February 2012. A tutorial at the 2012 CEDAR meeting introduced this model to the upper atmosphere research community.
- Significant new infrastructure capability and new physical parameterizations were added to CESM, increasing the flexibility and utility of the modeling system to the broad research community.
- Nearly 150 Tb of CESM simulation data were made available for community analysis in FY 2012. The simulations follow the Coupled Model Intercomparison Project Phase 5 (CMIP-5) protocol, and their assessment by the research community will be a major aspect of the upcoming Fifth Assessment Report of IPCC. In addition, they provide the foundation for nearly 70 peer-reviewed papers in a Special Collection of the Journal of Climate comprehensively documenting CESM and its simulation characteristics.
- The NRCM was successfully coupled to an ocean and wave model for the purpose of studying the two-way feedback between the ocean and atmosphere, which is particularly important for regional climate modeling studies of hurricanes. The use of NRCM is growing throughout the academic community, and a successful tutorial on it was given to more than 100 participants as part of the annual WRF user's workshop.
- The initial development phase of the 3-D non-hydrostatic global model within MPAS based on icosahedral grids for discretizing the sphere was completed on schedule, and basic application tests for weather and regional climate applications began.

The second major community facility developed and maintained within NESL, as a long-standing core activity, is an advanced atmospheric chemical measurement capability in support of several NCAR strategic imperatives, including the aforementioned community model development efforts. In serving as an intellectual crossroads for the atmospheric chemistry community, NESL is also a critical player in numerous major field experiments that effectively leverage research resources from universities and federal agencies other than NSF. A few notable accomplishments in FY 2012 include:

- An initial implementation plan for the Atmospheric Chemistry Center for Observational Research and Data (ACCORD) was developed, in consultation with NSF and NCAR/EOL. The ACCORD will serve as a vehicle toward a more coherent and focused chemistry instrumentation program with strengthened capabilities to optimally meet community needs. A February 2012 workshop, with more than 100 participants from across the community, and other community input identified the primary goals for ACCORD.
- The DC3 field campaign was successfully conducted in May and June 2012. Three aircraft (NCAR GV, NASA DC-8, and DLR Falcon) flew a combined 60 flights (~330 hours). Scientists, students (34 undergraduate, 77 graduate level) and post-doctoral scientists (30) participated from 27 different institutes (universities, federal agencies, and international partner DLR). The community analysis of DC3 data is underway.
- The TOGA-HIAPER instrument was extensively evaluated during DC3 test flights. Following the test flights the instrument was extensively tested and optimized in the laboratory.
- The TOGA instrument was successfully deployed during the TORERO campaign. This was the first deployment of the new TOGA instrument (other than test flights) and atmospheric levels 40 VOC compounds were measured with 2-minute time resolution. Preliminary results, using dimethyl sulfide (DMS) as a tracer, show that

convection plays a key role in the redistribution of very short-lived (VSL) halocarbons in the troposphere. TOGA TORERO data will help to quantitatively assess the impact of VSL species on stratospheric ozone.

- NESL processed and delivered new MOPITT 'Level 3' (gridded) Version 5 products to NASA. A comparison of new MOPITT multispectral CO products with in situ measurements from NOAA's 'Tall Tower' network was published and new Version 5 products were validated against NOAA aircraft CO profiles and measurements made during the HIPPO (HIAPER Pole to Pole Observations) field campaign.

As it looks to the future, NESL must enhance efforts to develop strategic and stronger partnerships and to seek broad community input into evolving and implementing its strategic imperatives, frontiers and other new research initiatives. This input will be central to ensuring NESL maintains transformative research, works synergistically with the academic community, and strikes the best balance possible between growth into new scientific areas and sustaining excellence in existing core activities. It is also more important than ever for NESL to embrace a leadership role and more actively engage with community leaders, research agencies, professional organizations, policy makers and others to convey significant research findings and to emphasize the importance of investment in research and major facility development. While the science credentials of NESL are well known within much of the scientific community, there are clear requirements for communicating the science more broadly and, thereby, enhancing its visibility to fellow researchers, stakeholders and the general public.

Finally, given significant financial challenges, and the reality that the increasing sophistication of computing and observing capabilities will continue to stress funding for scientific research, NESL must strive to enhance synergy and collaboration and ensure increased NCAR internal collaboration to achieve and maintain world leadership in its priority areas. Further enhancement of such collaborative efforts and development of new ones that bring NCAR-wide perspectives and experience to new and exciting challenges are critical to NESL maintaining and expanding its core activities and fulfilling its leadership role.

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Research Applications Laboratory | RAL

2012 ANNUAL REPORT

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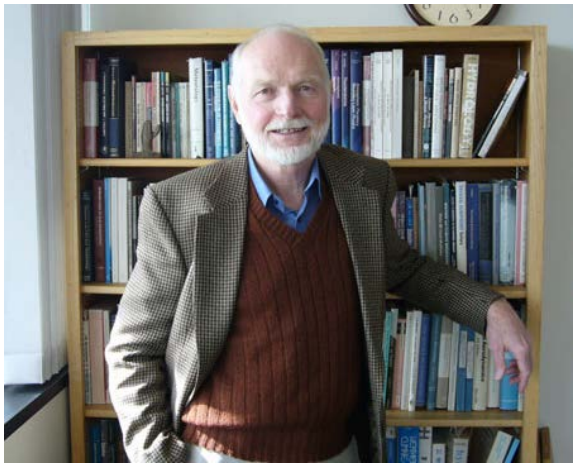
RAL Annual Report

Director's Message

Welcome to the Research Applications Laboratory's Annual Report for FY2012. Our goal is to conduct directed research that contributes to the depth of fundamental understanding of the atmosphere and its interaction with society, and to develop and

Hydrometeorological Applications
Climate, Weather and Society



Brant Foote - RAL Director

transfer knowledge and technology that expands the reach of atmospheric science and contributes to the betterment of life on Earth. We are, at present, an organization with annual expenditures of approximately $32M and a staff comprised of about 200 scientists, software engineers, and management/administration personnel.

I hope you will enjoy reading this year's Annual Report. As in the past, it follows the outline of our strategic plan, providing details on our many accomplishments over the past year and our plans for the future. I would like to highlight here the successful conclusion of an important aviation program in Juneau, Alaska, as well as the significant expansion of two programs in renewable energy and water resources. Both were cast as research "frontiers" in our 2009 Strategic Plan, but are now clear imperatives for the Laboratory as we move forward.

Juneau: In 2012 we successfully concluded a long-term effort on behalf of the FAA to develop an operational wind warning system for the Juneau, Alaska airport. Over the life of this program, our staff made important scientific and technical advances that improved our understanding of turbulent flows over complex terrain; devised new approaches to siting, deploying, and maintaining instruments in extreme weather conditions; and developed new methods for analyzing data from meteorological sensors. This system for Juneau is the first FAA-approved operational, terminal-area turbulence warning system to be deployed in the U.S., and I was pleased to nominate the team that created it for UCAR's Outstanding Performance Award for Scientific and Technical Advancement in 2012.

Renewable Energy: In 2011 we successfully delivered an advanced wind power forecasting system to Xcel Energy, with improved capabilities that are estimated to save many millions of dollars per year for the power utility. In 2013 we will expand the system's capabilities by integrating the Variational Doppler Radar Analysis System (VDRAS) to allow real-time analysis and forecasting for wind power ramps, improve forecasting of extreme events, and add a new probabilistic forecasting capability to the system to provide better uncertainty estimates for predictions. We will also, for the first time, be developing new methods and techniques for incorporating solar energy prediction capabilities into the Xcel forecast system.

In late 2012 we were also notified of the award of a major new solar energy forecasting program from the Department of Energy. RAL will lead a public-private partnership of national laboratories, utilities, and universities focused on creating better forecasts of when, where, and how much solar power will be produced at U.S. solar energy plants. Enhanced solar forecasting technologies will clearly be important in integrating cost-competitive, reliable solar energy into the electricity grid and ultimately providing clean, renewable energy to U.S. consumers.

Water Resources: For more than a decade, RAL scientists have made major contributions to Water System research at NCAR, particularly with regard to the impact of changing climate on the Colorado Headwaters. In 2012, this base-funded work was augmented by complementary programs funded by the Bureau of Reclamation and the Army Corps of Engineers, as well as by private and non-governmental organizations in the U.S. and Europe. I am particularly pleased with advances that have been made in developing the WRF-Hydro model which combines a state-of-the art, community-developed numerical weather prediction model, WRF, and a flexible and extensible distributed hydrological modeling framework into a unified, computational architecture. The code is freely available to the community and is supported, in part, by NCAR. The WRF-Hydro model is now being used in more than ten countries around the world by research groups and operational prediction agencies. With a growing network of model users and increasing record of improved model skill, it is becoming clear that WRF-Hydro is poised to become an essential community resource for hydrometeorological and hydroclimatological prediction.

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National Center for Atmospheric Research | NCAR 2012 Annual Report

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Bringing Diverse Voices to Climate Change Research

African Americans make up 13% of the U.S. population, Hispanic Americans comprise 16%, and Native Americans 1%. However, PhDs awarded from U.S. universities do not mirror these numbers. Moreover, a recent study published in *EOS* indicates that

Award
Supporting the Future of Science
Tools of the Trade
NCAR-wide efforts
Metrics

minorities earned fewer than 4% of the all the PhDs granted in the geosciences.[1] The National Center for Atmospheric Research (NCAR), the National Science Foundation (NSF), and the U.S. university community are well aware of the issue and striving to address it. Already, NCAR, NSF and the university community are involved in robust collaborations with minority-serving institutions such as Howard University, and have regular educational exchanges with Haskell Indian Nations University. In addition, all of NCAR's summer programs for students, including the **Summer Internships in Parallel Computational Science and Significant Opportunities in Atmospheric Research**, have a strong diversity focus.

Participants in NCAR's Research Applications Laboratory's "Enhancing Diversity in Climate Change Science and Applications: From Models to Adaptation workshop," August 2012.

The Research Applications Laboratory (RAL) recently added another program to NCAR's diversity efforts, running a workshop developed for graduate and undergraduate students and their professors. The four-day event, "**Enhancing Diversity in Climate Change Science and Applications: From Models to Adaptation**," was designed to familiarize participants with concepts related to climate change science, modeling, and scientific uncertainty. RAL's Mary Hayden, Olga Wilhelmi and Jennifer Boehnert led the workshop effort, devising it to function as an interdisciplinary training, with the variety of daily sessions focused on topics ranging from fundamental climate science to societal vulnerability and adaptation.

Hayden, Wilhelmi, and Boehnert build from their experiences teaching undergraduates from different U.S. tribal colleges at Haskell University in Lawrence, Kansas. They participate in a NASA Summer Research Experience for Undergraduates grant, led by Kiksapa Consulting, which takes them to Lawrence each summer. Over the course of two days, the trio team-teach an interactive, hands-on class that includes Geographic Information Systems (GIS) training, as well as lectures and discussions. For the workshop at NCAR, a similar approach was taken.

"At the NASA Summer Research Experience, Jenn does all the GIS teaching and trains the students on how to use the tools," explains Hayden. "Olga talks to them about climate science and societal vulnerability related to extreme weather and climate change – for example, talking about the importance of using an approach that integrates physical and social science to understand the effects of heat-wave events on human populations. I teach them about climate from a social science perspective, discussing the differences between qualitative and quantitative research methods related to adaptive capacity. The class goes beyond looking just at demographic data – they learn the importance of actually talking to people."

"The GIS portion of the workshop gives participants a hands-on opportunity to integrate climate model output, socioeconomic data, and survey information in GIS across scales," Boehnert says.

RAL funds targeted specifically for diversity efforts supported bringing 30 students and teachers to NCAR. The finalists included 12 student-teacher teams – 12 professors, and their students – who came to Boulder from minority-serving institutions located around the nation. In addition to the practical GIS training, each day included small-group discussions, as well as topical lectures that tied to the day's scientific focus.

By bringing in faculty members and their students, RAL hopes to strengthen its visitor program, and establish future collaborations that will evolve based on ideas generated during the workshop. Already, some of the faculty participants are interested in replicating the workshop at their home institutions, and one professor has expressed interest in participating in one of RAL's research programs, which is focused on studying the causes of meningitis outbreaks in Ghana; she'd like to use it as a training ground for her university's medical students.

"The level of engagement from the students and professors was great – everyone had myriad questions and all were actively engaged throughout the four days, despite the hectic schedule and are looking forward to future collaboration opportunities," says Hayden.

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[1] Morris, V. R., H. M. Mogil, and T.-W. Yu (2012), A network of weather camps to engage students in science, *EOS Trans. AGU*, 93(15), 153, doi:10.1029/2012EO150001.

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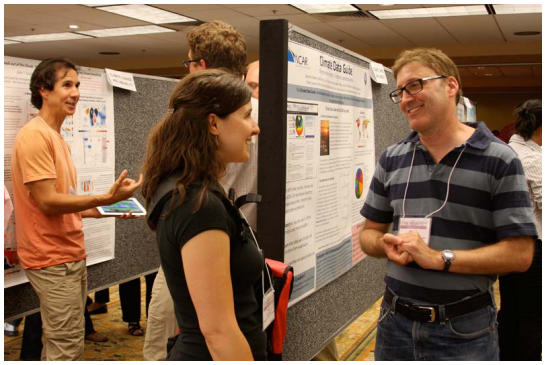
New Working Group Brings a Social Dimension to Climate Modeling

The impacts of changing weather and climate extremes on natural and human systems are anticipated to be profound and will vary greatly in intensity both geographically and temporally. Those taking on responsibility for helping society deal with the wide variety of effects have been quick to adapt new tools, ideas, and information that can help them better manage climate-change effects. Global and regional climate models and the information generated by these models offer an avenue for planning and gaining insight on what might be expected from future climate. Often,

however, current output from global and regional climate models proves difficult for resource managers to use effectively. Scientists and scientific organizations are working to alleviate this problem. Among the solutions supported by the National Center for Atmospheric Research (NCAR) and the National Science Foundation (NSF) is the recent creation of a **Community Earth System Modeling (CESM) working group** focused specifically on society and the needs of those serving society.

To improve the relevance of available climate modeling capabilities to the application sector, as well as to provide a critical feedback path for this experience to improve the model itself, the CESM community recently initiated the **Societal Dimensions Working Group** (SDWG). Because the range of society's needs for managing climate is so broad, the group's founders, which included researchers, resource managers, policy makers, and those in industry, have decided to limit the initial focus to two areas: water resource management and integrated assessment modeling (IAM, which merges socioeconomic and biophysical models to address policy-relevant choices related to climate change).



Among the many researchers at the CESM 2012 Summer Workshop were John Fasullo (NESL/CGD), at far left; Danica Lombardozzi (NESL/CGD), center; and Ben Felzer (Lehigh University), at far right.

Water resource management and decision-making organizations responsible for generating policies that affect the general public have developed sophisticated suites of decision-support software. Climate modelers have long struggled to link their simulations and projections to these decision tools, often due to a mismatch between the data required to address societal needs and what is provided within standard climate model output. The SDWG will provide a venue for aligning climate simulation data with the range of data and resource needs that the resource management community members currently have and anticipate in the future.

A white paper written by some of the water-resource managers that make up the **Water Utility Climate Alliance** (WUCA) describes the benefits that global climate model output offers WUCA members, including the ability to more ably assess potential impacts of climate change on the water resources systems they manage. Of particular interest to the SDWG are improvements to global and regional climate models that might benefit WUCA members. Among these is climate model output that better matches the temporal and geographic scales on which water management operates; WUCA members typically require daily information (at a minimum), and have need of information on spatial scales that range from several meters to several thousand kilometers. Another area of improvement is translation of precipitation and temperature data provided by climate models; water managers need data in a form that is compatible with and digestible by the hydrologic models that are used to generate critical water resource information, such as runoff estimates. One aspect of this "data translation" between global and regional models and smaller scale hydrologic models that would benefit from further enhancement is downscaling, which generates locally relevant information – generally on the watershed scale or smaller – from the global level.

The fixes to some of the issues that exist between global and regional climate model capabilities and water-resource management needs may well occur years in the future due to the difficulty of achieving the desired level of model accuracy. As a result, water managers within and outside of the SDWG working group are collaborating with modelers within the wider CESM community to identify the most urgent needs and figure out the best means to meet these needs. Based on input from the water-resource user community, the SDWG is providing combined observational information and model output focused on the hydrological cycle at a variety of space and time scales. In addition, water resource managers are benefitting from research being done by the CESM Land Use (CLM) working Group, which is exploring the role of land use on climate change and climate-change mitigation. The CLM and SDWG groups are working on developing an understanding of how these changes are influencing water- and land-use decisions, and exploring the variety of feedbacks between the climate system and socioeconomic processes related to these changes.

The water element of the SDWG provides a unique forum where climate modelers directly collaborate with members of the water resource community. After assessing the outcomes of the water resources, and as the capabilities and understanding between climate modelers and resource managers develops, the SDWG plans on taking on a broader spectrum of societally relevant user groups.

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NCAR Annual Report 2012

Jeff Kiehl Wins Climate Communications Award

NCAR's Jeff Kiehl (NESL/CGD) is the recipient of the 2012 American Geophysical Union (AGU) ClimateCommunication Prize. Established in 2011, this Union Prize highlights the importance of promoting scientific literacy, clarity of message, and efforts to foster respect and understanding of science-based values as they relate to the implications of climate change.

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Jeff Kiehl

Jeff has long had a profound interest in the human treatment of the natural world. Returning to school in 2003, Jeff earned a second PhD in psychology from Regis University. Today, he frequently combines this knowledge with his climate expertise to explore why humans treat nature the way we do, and how we value nature from a psychological and philosophical perspective in talks to the public. An important aspect in his effective communication, Jeff's tailors the information he presents specifically for each audience, using images and narratives that have particular relevance to those to whom he is speaking.

Feeling strongly that educating scientists to communicate more effectively with the public about climate science, Jeff has also presented many lectures to young scientists at universities and at various scientific meetings on how to improve science communication. These presentations typically explore both the scientific and psychological dimensions of communicating climate change to the public. The 2012 AGU Climate Communications award recognizes and rewards these public and peer-oriented efforts.

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Student-Scientist Discussion Maps the Intersection of Weather and Climate

Climate and weather are inextricably linked. Weather happens on the scales of minutes to weeks, while climate characteristics are the effects of weather averaged over the longer term – weeks to years or decades or more. Weather forecasting has evolved to be remarkably accurate, however forecasts created for periods beyond seven to 10 days get increasingly less reliable. To a large degree, prediction difficulties come down to deficiencies in the quality or quantity of observational data and computer modeling capabilities. Even more than in other regions of the world,

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predictions and forecasting of tropical climate and weather are made difficult due to the less complete understanding of how tropical convection couples to the large-scale atmospheric dynamics.

In recent years, buoyed by improvements in numerical modeling and more and better observational data, forecasting of longer term weather and climate has improved. These improved forecasts have both improved scientific understanding and expanded current forecasting accuracy. This reality has made possible a more informed study of where and how weather and climate influences and dynamics intersect. In addition to scientific advances, new understanding will inform economic and societal issues related to weather and climate. For example, an improved understanding of what weather extremes might be expected further into the future and how to best prepare for these will benefit the public, as well as those working in industry, such as insurance, finance, energy, and transportation.

“Among the topics that fall within this weather-climate intersection is the Madden-Julian Oscillation (MJO) – a 30- to 60-day pattern of eastward moving precipitation and convection that occurs along the equator,” explains George Kiladis, a research meteorologist in the Earth Systems Research Laboratory at the National Oceanic and Atmospheric Administration (NOAA). “This ‘holy grail’ of tropical weather systems was in fact discovered at the National Center for Atmospheric Research (NCAR) by Rol Madden and Paul Julian back in 1971, and researchers are still working hard to understand it completely.”

When active, the MJO accounts for about a quarter to a third of the resulting precipitation in the tropics, and also strongly affects the weather and the climate of global regions beyond the tropics. If the current models get the MJO right, it might be possible to extend accurate medium-range weather forecasts out another several days, Kiladis says.

Students studying atmospheric science are well aware of atmospheric phenomena such as the MJO and El Niño, and understand that these events have both weather and climate effects, but few move beyond this recognition to consider the interaction between climate and weather in greater detail. Additionally, many students focus on climate and weather phenomena occurring in regions beyond the tropics (i.e., the extratropics) rather than looking at tropical weather and climate in depth. With the recent advances in understanding and technical and observational capabilities, these areas of study offer exciting new research frontiers, not least because atmospheric events happening within the boundaries of the weather-climate intersection have significant impacts on the ocean-atmosphere system over a wide range of space and time scales.

Recognizing these gaps in student experience, Lance Bosart, a distinguished professor from the University at Albany, Kiladis, and Mitch Moncrieff, a senior scientist at NCAR successfully proposed running a three-week program for graduate students that covered these topics for NCAR’s annual Advanced Study Program (ASP).

“We’d been thinking about this topic as an ASP colloquium for at least five years,” says Bosart. “We have all benefited from ASP colloquia when we were students and early career scientists – as have many of the speakers at the 2012 colloquium. Not only is this a topic that we’re all interested in – it’s the way forward for both synoptic meteorology and climate research – but it gives us an opportunity to give back to the ASP program and the science community.”

Boulder geologist and guest speaker Fred Hawkins tells the Advanced Study Program (ASP) Colloquium participants about the local geology on a weekend field trip to Chautauqua Park.

ASP 2012 The Weather-Climate Intersection Colloquium participants.

Titling the program, “**The Weather-Climate Intersection: Advances and Challenges**,” the first week consisted mostly of foundational lectures on climate and weather, with discussions on the final project, a course requirement,

beginning at the end of the week. The second week brought together scientists specializing in the weather-climate intersection who work on related phenomena such as the MJO, El Niño-Southern Oscillation, and midlatitude jet streams and blocking. In addition to lecturing, they had a rare opportunity to talk to their peers for a prolonged span of time, with many of the researchers staying for more than just the middle week. The third week featured lectures from recent PhD graduates on relevant topics, and saw students pushing to finish and present their final projects. Speakers were not limited to those working in government-funded labs or academia; several speakers came from private industry, an area that stands to benefit from the increased understanding of weather and climate.

"We designed the program intentionally to maximize the time that students had with the world-class researchers in this field, while also giving them an opportunity to meet and spend time with the cohort they are likely to work with throughout their careers," Moncrieff says. "In addition, by inviting early-career speakers, we hoped to show students a variety of future possible job options – the challenge of melding weather and climate certainly requires bright new minds."

Erik Swenson, a graduate student working at the Center for Ocean-Land-Atmosphere Studies, and Walter Hannah, a graduate student at Colorado State University, work on their final projects.

"The students enjoyed the colloquium, but the researchers also enjoyed it because they had a chance to catch up on the state of others' research," Bosart says. "The students pushed these discussions further by asking questions of the scientists on topics that often hadn't been considered for decades, or on stuff we generally take for granted, which gave all of us things to think about."

An innovation added to this year's colloquium that Kiladis saw as extremely useful were "map discussions." A tradition in the University at Albany's atmospheric sciences department, the colloquium's morning lectures covered weather characteristics from a theoretical perspective, while afternoon map discussions led by Bosart or other lecturers offered an opportunity to show real-time weather maps illustrating the type of phenomena discussed in the morning. Looking at the maps helped continue the discussion, offering a way of cementing the theoretical ideas with reality, Kiladis explains.

By all accounts, the 2012 ASP colloquium on the weather-climate intersection was a success,enjoyed by organizers, speakers and students alike.

"These ASP colloquia provide a real service to the community by training the next generation of students," Bosart says. "Organizing and running colloquia is a difficult thing for a university to do – NCAR has the resources, and experiences, they know how to do it, and how to do it right, and it is an obvious priority for both them and the National Science Foundation."

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Research Experience for Undergraduates in Solar and Space Physics: Taking Education to Stratospheric Heights (and Beyond)

An undergraduate academic experience is designed to provide the essential educational elements that set the stage for the next step in a student's professional or educational life. Equally important in this process are the mentors and experiences encountered during a student's college career. Recognizing the benefits of future scientists participating directly in scientific projects, the National Science Foundation funds a number of university-led research programs,

called Research Experience for Undergraduates (REU). The REUs pair students with science mentors to work over the summer on finding answers to research questions. The REU programs span the range of scientific topics falling within NSF's purview. Among these programs is an REU in Solar and Space Physics led by the University of Colorado's Laboratory for Atmospheric and Space Physics (LASP) in partnership with the National Center for Atmospheric Research's (NCAR) High Altitude Observatory (HAO).

"LASP has run the REU Program in Solar and Space Physics since 2006, and NSF recently funded us for another five years," says Martin Snow, a Research Scientist III at LASP. "However, members of **Boulder's Solar Alliance** – which includes most of the solar and space physics research institutions in Boulder – also participate, providing additional program funding and/or mentoring for one or more students during their 8-week visit to Boulder."

Mariah Law speaks with University of Colorado's Laboratory for Atmospheric and Space Physics (LASP) research faculty Dr. Stefan Eriksson about her research project at the Research Experience for Undergraduates (REU) poster presentation in August 2012.

Members of Boulder's Solar Alliance (BSA) include LASP, NCAR's HAO, NOAA's Space Weather Prediction Center, the Southwest Research Institute, North West Research Associates, and the Atmospheric & Space Technology Research Associates. In addition to providing scientific expertise that the students benefit from, the additional funding provided by the institutions means that LASP's REU supports more students than might otherwise be brought in to the program.

For example, HAO's annual Visitor Program budget includes support for two undergraduates. In addition to these dedicated spaces, HAO also hosts several more students – six in total for 2012. Funds pay for a portion of a student's airfare to Boulder, a weekly salary of $500, housing, and a meal stipend. With about 170 applicants for 16 spots, competition is stiff, but the payoff is worthwhile from the perspective of both students and mentors.

Martin Snow, a research scientist at the University of Colorado's Laboratory for Atmospheric and Space Physics, and one of the program leaders, with the students participating in the Summer 2012 Solar and Space Physics REU. Students include, back row from left to right, Marty, James Negus, Jordan Stone, Pattilyn McLaughlin, Andrea Egan, Lindsay McTague, Jessica Haskins, Mariah Law, and Lauren Bearden, as well as Erin Wood, LASP's Educational Coordinator. In the front row are Bronwen Cohn-Cort, Hannah LeTourneau, Nancy Holden, Christina Hedges, Eleanor Williamson, Chana Tilevitz, and Ariana Giorgi.

The LASP REU teams the undergraduates with at least two mentors, usually a senior and an early career scientist; this approach provides some scheduling flexibility for the scientists and expands the depth of expertise provided to the students. Projects have ranged from development of research instrumentation to advancing understanding of high-energy physics, or interpreting data from missions such as the Kepler project, which is run by NASA to discover other Earth-sized planets in our galaxy.

"The students have an opportunity to use the math, physics, and analytical skills developed in their first two or three years of college to address real-world research problems," says Hanli Liu, a senior scientist in HAO. "In turn, HAO and institutions in the BSA benefit from the energy and ideas that the students bring, and often new and different ways of approaching research questions."

To be considered for the program, REU applicants must apply online, and provide transcripts and letters of recommendation. The selection committee uses this background information to identify the finalists, with choices often coming down to finding the best match for the projects put forward by the research organizations for the summer.

"Making the final selection is always difficult. Often students that are not accepted would be perfect candidates for the program, but we don't have a good research project match for them and space is always limited," explains Erin Wood, LASP's Educational Coordinator.

Like most of the other NSF-funded REU programs, LASP strives to include students from underrepresented populations, as well as those attending smaller schools that might not be able to provide undergraduates with an equivalent hands-on research opportunity during the summer.

"Our REU is probably unique because Boulder's entire space and solar physics research community gets involved in the program," says Wood. "A result of this effort is that, as a scientific community, we are brought closer together through everyone's work to make the program a successful experience for the students."

Additional Program Details

For more information or to apply to the REU program in Solar and Space Physics, see **http://lasp.colorado.edu/home/education/reu/**. Students may apply to the REU program beginning November 5, 2012; the application window closes on February 1, 2013. For additional information on HAO's Visitor Program, go to **http://www.hao.ucar.edu/people/visitors/summer.php**.

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Instrument Helps Scientists See the Atmosphere in a New Light

In 2005, the National Center for Atmospheric (NCAR) completed the retrofitting of a Gulfstream-V (GV) research aircraft, equipping it to take detailed measurements of the atmosphere. Funded by the National Science Foundation (NSF), funds were held in reserve to support development of additional research tools for the plane. Among the instruments deemed useful but not included in the original GV specifications was a lidar system. Similar to radars, lidars identify certain characteristics of the atmosphere, such as the amount of water vapor or aerosols in the

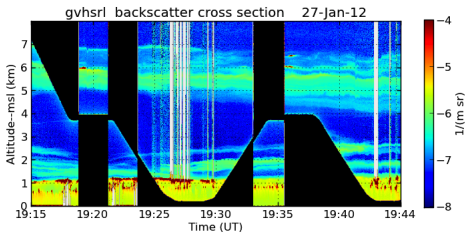
atmosphere, by detecting backscatter of electromagnetic radiation, specifically light scattered back from the outgoing laser pulses.

"Lidars are often used to measure cloud-free and thin-cloud regions of the atmosphere; they emit much shorter wavelengths than radars so they measure different atmospheric characteristics. Lidars "see" reflections of objects such as air molecules, aerosols – for example, pollen and black carbon particulates – as well as ice crystals and water droplets in clouds," Scott Spuler, an EOL research engineer, explains. "If used together, lidar and radar give a more complete picture of the atmosphere."

Loaded on the NSF/NCAR Gulfstream V (GV) in downward-looking mode, the High Spectral Resolution Lidar (HSRL) measures microscale aerosols during a research flight.

In assessing the future trajectory of Earth's climate, one of the largest remaining scientific uncertainties that is critical for improving climate model capabilities is the proper understanding and treatment of cloud processes and, in particular, the interactions between aerosols and clouds. Aerosols affect cloud formation and evolution, and hence have strong indirect effects on the reflective properties of clouds, which may affect the amount of incoming or outgoing radiation, and even on the timing and magnitude of precipitation.

"Models and field observations have shown that an increase in human-made aerosols can ultimately lead to higher concentrations of cloud drops. In turn, this can enhance the cloud's reflective properties (albedo), thereby leading to a cooling effect and affecting precipitation," says Jothiram Vivekanandan (Vivek), a senior scientist in EOL. "Because these processes are highly dependent on the microphysics of the atmosphere, the interaction of aerosols and clouds is currently treated very crudely in the global models used to estimate future climate states. In order to make progress in global modeling, detailed measurements will be necessary to constrain representation of cloud microphysics in global climate models."

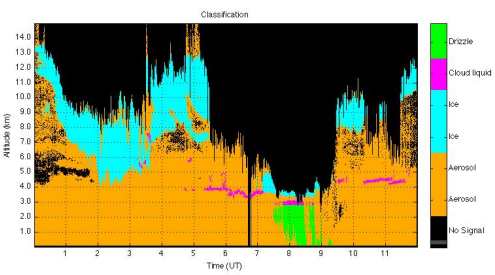


The calibrated backscatter cross-section data in this figure is an example of a typical TORERO flight profile (note, the color bar scale is logarithmic, with the number being the exponent). This atmospheric profile was performed off the coast of Chile on January 27, 2012. The GV starts at an altitude of 7 km, descends to 4 km for a short time, then continues to 100 m. The lidar was switched between upward-looking (zenith) and downward-looking (nadir) modes as the aircraft profiled the atmosphere.

Recognizing the utility of having such a device on the GV, NSF issued a call for proposals to the scientific community to create a lidar system that could be used both on the GV and as a ground-based instrument. The University of Wisconsin (UW) Lidar Group, led by Edwin Eloranta, a pioneer in the lidar field, won the project to build a High Spectral Resolution Lidar (HSRL). The lidar, designed and built by the University of Wisconsin, provides unique measurements of both backscatter and extinction of aerosols and other microscale atmospheric components. HSRL and cloud radar measurements are used for estimating microphysical properties of aerosol and clouds respectively.

NCAR and UW scientists began working together in 2010 to make the hardware and software changes required to create a GV-compatible lidar system. Not only did the HSRL have to be able to withstand in-flight jostling of the instrument and potentially drastic changes in cabin temperature, but it had to be synchronized to the internal navigation such that if the plane was maneuvering at an angle, the system readouts remained accurate. Additionally, ongoing software design enhancements will result in automation that allows the system to be run remotely, while providing data images to an on-the-ground engineering team in real time.

The HSRL was used in its first field campaign in February 2012, one of a suite of instruments operated as part of **TORERO** (Tropical Ocean tRoposphere Exchange of Reactive halogen species and Oxygenated volatile organic carbon). The TORERO mission took place in Costa Rica and Chile, with researchers studying the release and transport of gases and aerosols into the atmosphere during the region's peak period of biologic growth. The HSRL provided a long-distance perspective on the atmosphere, with the laser "looking" either upward or downward from portholes in the NSF/NCAR GV.



Lidar measurements, collected by the NCAR HSRL on July 18, 2010. The image shows vertical profiles of particulates found in the atmosphere between ground and 14 kilometers, including aerosols, ice particles, super-cooled water droplets, and precipitation.

The data output provided researchers with details on cloud cover, as well as specifics on the scattering and extinction of aerosols in the atmosphere. Not only did this information prove useful for answering essential research questions, but it was also used to guide the aircraft into regions of interest such as cirrus clouds and aerosol layers. Flying at varying heights from the boundary layer to 50,000 ft, the GV, equipped with the HSRL and other TORERO instruments, collected data along a broad cross-section to sample the atmosphere at a variety of heights, observing the layers of clouds, aerosols, and gases.

In addition to providing the HSRL for use by researchers, data collected by the instrument, such as that from the TORERO experiment, are available to the science community from EOL's **online data catalog**. Another important component of EOL's service to the community is educating scientists about the potential and capabilities of tools such as HSRL. For the HSRL, EOL staff is helping identify how research might benefit from the lidar's use, as well as showing how the instrument complements radar capabilities. Through this education process, NCAR/EOL hopes to inspire new and interesting research questions, says Spuler.

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Improved Solar Corona Views Advance Predictability of Space Weather Disturbances

Expectations were high that the **Coronal Multi-Channel Polarimeter (CoMP)** would improve views on the solar corona (the extended outer atmosphere of the Sun). Perhaps less expected is how quickly new insights were gained. Configurations in the CoMP images resembling rabbit ears – and heads – seen within coronal cavities provide a new discovery on coronal magnetism. In addition, CoMP velocity observations show a bullseye pattern flowing within these

same coronal cavities. These discoveries are shedding new light on coronal dynamics and seem likely to provide important information that can be used to predict coronal mass ejections (CMEs), which can have dramatic effects on Earth.

The CoMP telescope tracks the magnetic activity occurring around the edge of the Sun. With data collected as often as every 15 seconds, CoMP lets scientists monitor magnetic field direction, of particular interest in regions where magnetism is twisted. These occurrences of twisted magnetic field, called flux ropes, are important to observe because when the flux rope loses its balance a CME can be generated.

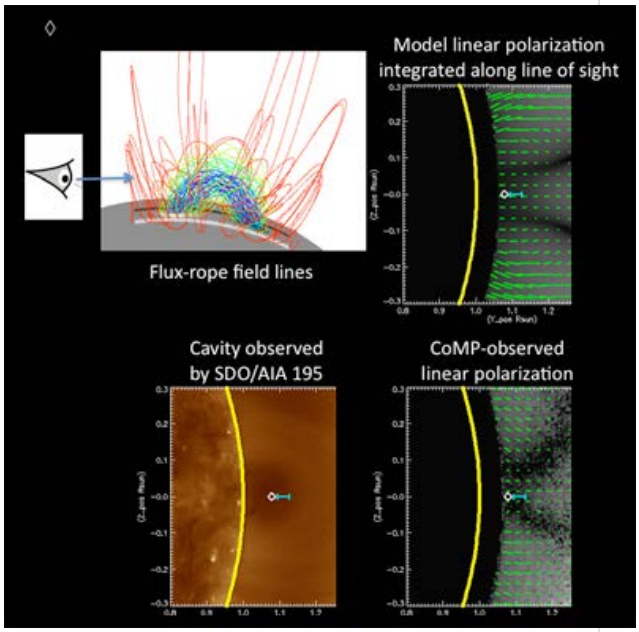
“Energetically, the flux rope wants to expand beyond the magnetic field that overlies it, whereas the overlying magnetic field acts to stop this expansion, keeping the flux rope in check and the system in balance,” explains Sarah Gibson, an astrophysicist in the High Altitude Observatory (HAO) of the National Center for Atmospheric (NCAR).

When flux ropes escape, releasing like coiled jack-in-a-boxes, they produce enough energy to hurl magnetized waves of hot gas into space at incredible speeds – oftentimes toward the Earth. With enough energy, these CMEs noticeably affect electronics, satellites, and power grids on our planet, making the ability to predict such storms desirable.

Among the solar features that CoMP makes easier to pick out are coronal cavities, regions from which CMEs can erupt. Cavities show up as dark disks on the CoMP intensity images, but they are in fact tunnels within the corona in which magnetic flux ropes may be contained.

“Cavities are nice to observe because, although they are not the brightest coronal structure around, their tunnel-like structure means that the coronal plasma within them lines up to form a clear signal.” Gibson says.

CoMP provides information about the plasma lying within the cavity, such as the direction that the magnetic field is oriented. In essence, the direction of the magnetic field traces a path along which coronal plasma flows, explains Gibson.



Bottom left: An observation in the extreme ultraviolet portion of the light spectrum by NASA's Solar Dynamic Observatory on May 25, 2011. The approximate center of a low-density coronal cavity (white diamond) and its approximate radius (turquoise line) are indicated (courtesy NASA).

Bottom right: An observation on the same date by NCAR's CoMP instrument shows the Sun's magnetic signature. Researchers are studying the relationship between this magnetic behavior, the presence of low-density coronal cavities, and the likelihood of a coronal mass ejection. The team has dubbed the observed pattern the "bunny head," with the head indicating the suspected location of the cavity and the ears being an artifact of the way we view these polarized signals from Earth (courtesy NCAR High Altitude Observatory).

Top left: Modeled flux-rope field lines on the solar surface that provide an indication of how cavities within the corona may be aligned. The cartoon "eye" shows the line of sight from Earth (courtesy Yuhong Fan, NCAR).

Top right: The NCAR team's "forward model," predicting where a cavity will appear, matches well with the observation made by the CoMP instrument (courtesy Sarah Gibson, NCAR).

This summer, in looking at images of coronal cavities, Gibson and Urszula Bąk-Stęślicka, a scientist visiting HAO in summer 2012, noticed that an image that resembles a rabbit's head, complete with long ears, could be seen in every coronal cavity. The scientists suspect that the shape and placement of the ears and head may indicate the size of the flux rope, and could be used to investigate the likelihood of eruption. Using simulations created with a flux-rope model developed by HAO's Yuhong Fan's has helped Gibson, Bąk-Stęślicka and their colleagues explain the presence of these rabbit heads and ears, however the scientists are still working on the details of what changes in these formations might mean for CME and related coronal processes.

"Prior to CoMP, the rabbit heads and ears were never seen," Gibson says. "The head is important because it tells you whether shear and/or twist exist within the cavity's magnetic fields, while the ears provide an indication of the characteristics of the overlying magnetic field."

In addition to bunny heads, CoMP is showing the presence of flows within cavities that may take the form of nested, concentric rings, or bulls-eye patterns. Because magnetic field twisting about an axis would trace circular paths along which plasma would flow, the observed bullseye velocity pattern is also understandable if cavities contain magnetic flux ropes.

While CoMP has advanced human viewing capabilities of the corona, and in the process made routine observations of twisted magnetic fields possible for the first time, development of the COronal Solar Magnetism Observatory (COSMO) is important for a deeper analysis of coronal magnetic structures. Currently under development, COSMO will include a telescope (a large coronagraph) much more powerful than that currently used by CoMP. Once ready, COSMO's coronagraph will enable observations providing missing information on the strength of the magnetic field. Such information will further scientists' ability to study and understand the rabbit head, bulls-eye and related formations within cavities. COSMO will offer perspective on the three-dimensional strength and structure of coronal magnetic fields, and so usher in a wealth of new solar discoveries.

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NARCCAP Contributes to the IPCC AR5 and USGCRP National Climate Assessment

Over the past five years, CISL scientists collaborated with statisticians and climate researchers to produce an ensemble of computational experiments

This photo shows some members of the core NARCCAP team who met at the NCAR Mesa Lab prior to the 2012 NARCCAP Users' Meeting in April. Back row from left: Sebastien Biner, Ouranos (Quebec); Bill Gutowski and Gene Takle, Iowa State University; Melissa Bukovsky and Steve Sain, CISL IMAGe. Second row: Larry McDaniel, IMAGe; Ruby Leung, Pacific Northwest National Laboratory; Ray Arritt, Iowa State University; Doug Nychka, IMAGe. Front row, seated: Linda Mearns and Seth McGinnis, IMAGe.

that improves the research community's ability to understand uncertainty when refining global climate model (GCM) output using regional climate models (RCMs). This effort provides valuable data to support researchers' and policy makers' increasing focus on regional climate change impacts and adaptation strategies. The **North American Regional Climate Change Assessment Program** (NARCCAP) simulations were largely completed in the third quarter of FY2012, and 18 TB of data are now available on the Earth System Grid (ESG). To date, NARCCAP results have been used by diverse groups of over 700 researchers to produce around 70 published papers. Results of some of these works will appear in the upcoming report (AR5) of the Intergovernmental Panel on Climate Change (IPCC). Further, NARCCAP results will figure prominently in the U.S. Global Change Research Program's (USGCRP) National Climate Assessment, to be released in 2013. The IPCC is the leading international body for the assessment of climate change. The USGCRP provides impacts and adaptation assessments to help society cope with climate change. The ESG is a federation of international collaborators who provide climate and environmental science data collections to researchers worldwide.

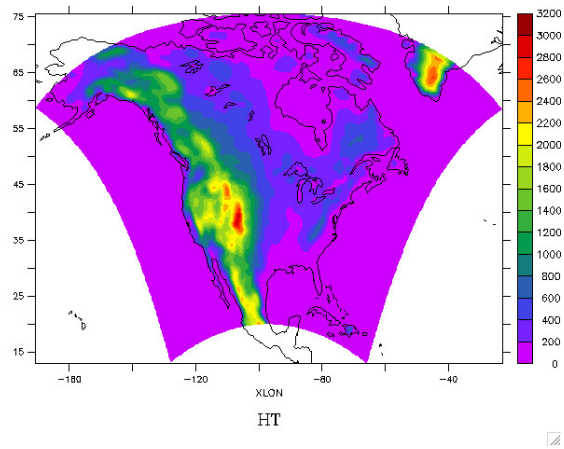
NARCCAP addressed two major questions:

- How does regional climate change projected by the RCMs differ from changes projected by the GCMs, and are the RCM results more credible?
- What are the relative contributions of the RCMs and the driving GCMs to the uncertainty for different seasons (winter, summer) and variables such as temperature and precipitation?

NARCCAP is an international effort to produce high-resolution simulations over North America to investigate uncertainties in regional-scale projections of future climate and to generate climate change scenarios for use in impacts research. The CISL-led NARCCAP effort used a set of four global climate models to provide boundary conditions for six regional climate models. The primary goal of this experimental design is to explore uncertainties of regional projections of climate change as simulated by climate models. Embedding RCMs into GCMs is a way to improve a global simulation's horizontal resolution over an area of interest.

NARCCAP is one of a number of programs throughout the world that use regional models forced by global climate models (GCMs providing boundary conditions for RCMs). However, NARCCAP is unique because it used a statistical design to maximize the value of each model run's results. In this design, each GCM provides boundary conditions to three different RCMs, and each RCM uses boundary conditions from two different GCMs (see Table 1). Thus, the full matrix (four GCMs by six RCMs) is sampled in a balanced way.

This design is intended to quantify the uncertainties in a robust, reproducible way. When fewer constraints are placed on which GCMs are used with which RCMs in other nested modeling programs (such as in PRUDENCE and ENSEMBLES over Europe), the matrix of possible combinations is not thoroughly sampled, and this can



Topography resolved within the domain of the six regional climate models used in NARCCAP experiments. Four global climate models (GFDL, CGCM3, HadCM3, and CCSM3) provided information about the state of the atmosphere and ocean around the boundary of the area in color. The RCMs included MM5 run at Iowa State University, RegCM3 run at the University of California at Santa Cruz, the CRCM used by Ouranos in Quebec, HadRM3 from the Hadley Centre for Climate Prediction and Research, RSM from Scripps Institution of Oceanography, and WRF run at Pacific Northwest National Laboratory.

limit the robustness of the quantification of uncertainty derived from the model outputs. NARCCAP is designed to sample all the possible combinations of a restricted set of regional and global models (see figure caption at right). Sampling these combinations in a statistically robust way improves researchers' ability to quantify the uncertainties.

Table 1. Combinations of GCMs and RCMs used in the NARCCAP experiments.

		GCM			
		GFDL	CGCM3	HadCM3	CCSM3
RCM	MM5			X	X
	RCM3	X	X		
	CRCM		X		X
	HRM3	X		X	
	RSM	X		X	
	WRF		X		X

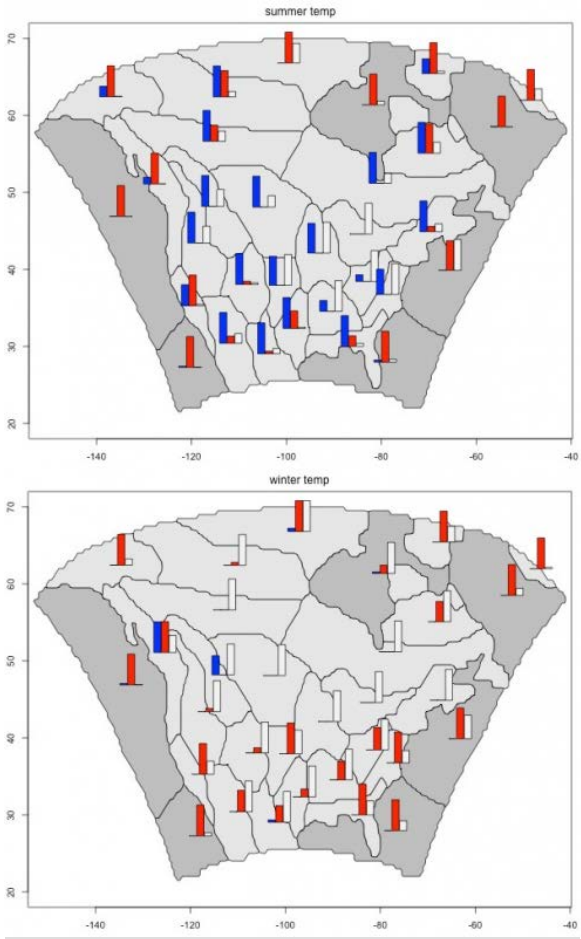
NSF encouraged the NARCCAP team to make these datasets widely available, so the project goals included making the data user friendly and easily accessible to diverse groups of users. The Earth System Grid science gateway provided significant benefits for both of these goals: NARCCAP data is stored in CF-compliant NetCDF format and is distributed through the ESG. ESG's science gateway effort is led by CISL engineers and scientists.

NARCCAP output was used by three primary groups of researchers who: perform climate analyses using NARCCAP model run results, use NARCCAP modeling results in impact and adaptation studies, and use the NARCCAP results to drive the RCMs at even finer regional grid resolution (10 km or less). Analysis of the NARCCAP simulations will continue for the next couple of years.

More than doubling in FY2012, NARCCAP-published data volume grew from 8 TB to 18 TB in managed holdings. In addition to the CISL scientists and statisticians who led the design and completion of the experiments, CISL engineers also contributed by supporting ESG operations, data publication, and user interface bug fixes and enhancements.

An overview paper on the results of the climate change simulations is being prepared for submission in January 2013. Two major results being highlighted include:

- An analysis of the sources of uncertainty (RCM vs. GCM) indicates that the uncertainties in the RCMS predominate in summer for both temperature and precipitation, and that the uncertainty in the GCMs dominate more in winter for both variables (see figure showing summer and winter temperatures at right).
- There is some indication that the climate results from the RCMs -- as opposed to from the GCMs that drove them -- are more intense, for example projecting a more intense decrease in precipitation across the central plains of the U.S.



Summer and winter temperatures for the areas indicated (Bukovsky regions) processed using the Analysis Of Variance Approach (ANOVA). ANOVA is based on a random effects analysis of variance statistical model that focuses on three sources of variation: the RCM, the GCM, and an error or residual term. This statistical model postulates that the total variation in the RCM output can be decomposed into these three terms, but it also exploits the correlations between model runs that share either an RCM or a GCM. The relative magnitude of the first two variance components is a measure of the contributions from RCM and GCM, respectively, with larger values suggesting greater importance. Bar plots represent the variance components for each of the regions.

The NARCCAP project was funded by the National Science Foundation (NSF), U.S. Department of Energy (DOE), the National Oceanic and Atmospheric Administration (NOAA), the US EPA-ORD, the Canadian consortium Ouranos, and the UK Hadley Centre. CISL's contributions to NARCCAP were supported by NSF Core and NSF Special funds. Support for CISL staff using the data continues through NSF Core funding and additional follow-on projects focusing on analysis of the results (NOAA MAPP) and the use of NARCCAP results in research

on adaptation planning (DOE, DOD, and NSF EaSM).

Bars are scaled by region, so the largest variance component for a particular region is shown by the largest bar, and it has value equal to one. RCM variance is shown in blue, GCM variance is shown in red, and white indicates the residual term. These plots show that in the summer, most of the variance in the experiment is represented by the RCMs (more large blue bars over land), and in the winter, GCM variances dominate (more large red bars).

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The Mission Coordinator Display: Guiding Aircraft Field Operations in the 21st Century

When studying the atmosphere, identifying the ideal area for research is a tricky proposition because of the ephemeral nature of the atmosphere. Add to this difficulty are other challenges such as the costs related to keeping an aircraft in the air, sharing air space with other air traffic, not to mention navigating hazardous weather. This makes identifying regions of the atmosphere that will provide the desired scientific information even more important that it might

otherwise be. The Mission Coordinator Display, developed at the National Center for Atmospheric Research's (NCAR) Earth Observing Laboratory (EOL), assists in this regard.

"The Mission Coordinator Display helps to optimize sampling in an operational field environment. Millions of dollars are invested in equipment and personnel during a field campaign, and the system assists in ensuring return on investment by guiding the data collection process in a way that makes efficient use of our sampling strategies and capabilities," says Mike Daniels, manager of EOL's Computing, Data and Software (CDS) Facility.

Mission Coordinator

A snapshot of a Mission Coordinator Display view taken on May 19, 2012 during the DC3 field campaign.

Since 2002, NCAR's Earth Observing Laboratory has provided field program teams with real-time chat and data-transfer capabilities between aircraft and ground crews. However, data transfer costs have always been high, bandwidth has been limited and the chat system used in the early 2000s was run on public Internet Relay Chat (IRC) channels. In 2004, the laboratory built a customized IRC server to support chat needs in a research environment, where network links can be more prone to failure. In 2009, Dan Lagreca, an intern in EOL's Summer Undergraduate Program for Engineering Research (SUPER) program, enhanced existing communications and data transfer functionality with a software system that supported integrated displays of real-time data from other sources, providing a more complete picture and situational awareness during airborne field operations.

EOL Chat

A view of a typical chat that occurred during the DC3 field campaign.

The Mission Coordinator Display creates a comprehensive view of a study area by combining radar and satellite images with modeled weather forecast outputs, flight level winds, sonde data (i.e., atmospheric temperature, pressure, relative humidity), lightning data and video, giving viewers on the ground and in the air a new perspective on the characteristics of the atmosphere during missions. This atmosphere-centric view helps experts on the ground identify and safely guide the airborne crew to areas of research interest.

From a summer internship project, the Mission Coordinator Display has grown into a mission-critical tool. The system is malleable in that it can be updated for each field campaign to portray research-relevant data. For example, in the Deep Convective Clouds and Chemistry (DC3) project, lightning and the high-resolution CSU CHILL radar data were important components of the study. As such, lightning displays and the CHILL radar data were made available as "clickable" overlays for the research team to use as needed. Among the basic views that are useful for all projects are National Weather Service radar and visible satellite data, flight track and flight-level wind speeds, aircraft video and the like.

Given this common display and IRC server to optimize sampling, all parties, whether on the ground or in the air can chime into the conversation related to directing the mission, which has proven to be a significant benefit. Typically, the NSF/NCAR Gulfstream-V (GV) seats a limited number of crew due to the high volume of instruments that are loaded

on the plane during a typical research flight. About six to eight people can be aboard the GV at any one time, but to maximize data gathering and abide by crew duty limits, flights are conducted with crews rotating off and on during a typical project. This often means that those operating the instruments in the aircraft gain benefit from guidance provided by instrument experts on the ground, explains Daniels.

The Mission Coordinator Display continues to evolve, with pressure always on the system and design team to further minimize delays to system inputs such as uploading of radar and satellite observations, and model forecasts. The sheer number of systems involved in providing data affects system efficiency because there can be several points of failure and the inputs are not naturally synched up. For example, satellite images can come in every 15 minutes, radar images every five, and plane location is updated in a matter of seconds. Resources are also being identified to ensure the system is more robust, secure, and scalable and to offer the capability for the display to run on mobile devices such as tablets.

“Several field campaigns occur throughout the year, and they can be happening anywhere in the world. EOL’s engineers, scientists and support staff are online, tracking and providing assistance with the mission process at all hours of the day using the Mission Coordinator Display and other collaboration tools provided by CDS,” Daniels says. “Also, with these systems in place, the level of participation in field campaigns is truly unprecedented. The software is easy to use and greatly improves sampling capabilities, which ultimately builds a better data set for the research team during the critical and relatively short span of a field program.”

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Taking a Systemic Look at Characteristics of the Global Hydrologic Cycle

Changing climate will directly affect the global hydrologic cycle. Many of these effects will be felt regionally, with, for example, potential for flooding or drought increasing. In addition, changes to water quality, quantity, and supply reliability may have effects on human health, aquatic ecosystems, and agricultural and energy production, among other ecosystems and economic sectors. Recognizing a growing need to better understand climate change effects on regional water cycles around the world, the National Center for Atmospheric Research's (NCAR) **Water System**

Program strives to advance hydrologic-cycle research and modeling. Today's climate models agree fairly well on temperature projections, however future projections of precipitation – along with other components of the water cycle, such as evapotranspiration and runoff– are notoriously inconsistent between models and especially so at regional scales.

A cross-NCAR and cross-university effort, Water System Program leaders have chosen a few key areas in which to focus research efforts. Among these:

- Diagnosing the global water cycle behavior in models using observations, data sets, and model output.
- Study key processes controlling regional and global precipitation and use this knowledge to improve convective and orographic precipitation parameterizations.
- Investigate possible futures of the water cycle in the U.S. West under changing climate conditions
- Improve simulation of snowpack conditions in climate models by comparing SNOTEL observations to high-resolution model simulations, and by conducting a snow physics inter-comparison project.
- Examine the impact of land-surface disturbances on the water cycle.
- Analyze the effects of water-resource management (e.g., dams, irrigation) on the Earth's systems.

Predicting Drought

Among the efforts to improve drought prediction is a study by the Water System Program's Aiguo Dai on understanding climate models' capabilities for accurate prediction of future drought patterns in the United States. When comparing real-world observations of historical precipitation, streamflow, and drought patterns to modeled predictions of drying trends generated by climate models, modeled and observed patterns often do not match. One reason for this is that climate models typically have difficulty with accurately replicating air-ocean interactions, which in turn affects projections of continental precipitation patterns. Climate scientists often inferred that this mismatch meant that climate models were over-predicting the probability of future drought-event occurrences and severity.

To address climate models' difficulties in accurately replicating sea surface temperatures, Dai developed a statistical method to account for the natural variation in sea surface temperature. By using data that took this variation into consideration, Dai found that climate models in fact were reproducing past climate conditions better than realized, meaning that climate models' projections about the probability of future drought are likely accurate. One worrying upshot of this study is that in future projections, model output indicates that the world will likely see more severe and widespread droughts in the next 30-90 years in regions of North and South America, Africa, and southern Europe under changing climate conditions.

Periodic drought plays a major role in ecosystems across the western United States. Scientists at the National Center for Atmospheric Research study the short- and long-term aspects of drought, including the processes that help to create and sustain drought-related weather patterns and the societal impacts of drought. This image shows farmland in northern Texas. Copyright University Corporation for Atmospheric Research.

Understanding Effects of Climate Change on Snowmelt-Dependent Water Basins

A long-term focus of members of the Water Systems Program has been modeling the Colorado River Basin's flow under changing climate conditions. Like many other river basins in the world, the Colorado River's hydrologic system gets much of its moisture in the form of seasonal snow melt. To understand the effects of future climate on the Basin, the team worked to refine their understanding of the river's water-cycle dynamics, while at the same time honing the modeling tools to provide finer scale, more precise information. In doing so, the updated models show that future changes in winter precipitation, combined with increasing rates of evapotranspiration (the amount of water that evaporates or is used by plants as they grow) may reduce the amount runoff within the Colorado Basin even under

climate conditions that increase the snowfall in the region. With both farmers and urban regions in the U.S. West reliant upon these resources, this is critical information for regional water-resource users and planners. In addition to the regional benefits, the modeling lessons learned based on the Colorado River Basin will be transferred to study and develop an improved understanding of other hydrologic systems around the world (e.g., the Himalayan hydrologic system).

Pine Beetles, Climate Change, and the Hydrologic Cycle

Bark beetle infestation across western North American forests has caused the death of millions of acres of pine trees over the past decade. The massive die-off has left scientists wondering about the possible effects on the hydrologic cycle. A three-year study, which focused on this question and included scientists from the Water System Program and NCAR's university community, ended in 2012. Early research results are coming in that shed insights on changes in forest ecosystems. Most researchers have assumed that in areas in which large swaths of trees are dead or dying due to beetle infestation, the hydrologic cycle would experience increased runoff, higher soil-moisture content, and, in winter, increased peak snowpack conditions. Instead, the scientists are finding that things may not be so straightforward and that while the affected pine trees may not be using as much water, all the surplus water may not be finding its way into streams and rivers. Other plants underneath the dead and dying trees or in adjacent communities seem to be taking up the excess available water coming into the system. Also, more water seems to be evaporated from the forest soils and sublimated (when water goes from ice to vapor phases) from the snowpack on the ground compared to when the forest canopy is full and shading and sheltering the ground from the sun and wind. Also, year-to-year climate variability – a drought year, followed by a year of heavy snow, followed by low snowpack and cool summer temperatures, for example – seems to be having an overall greater impact on these pine-forest ecosystems than are the effects of beetle kill, making it difficult to quantify the exact impacts of the dying stands of trees.

"An emerging idea from this research is how poorly we understand an ecosystem's compensating effects on the water cycle in regions of beetle kill," says David Gochis, a researcher in NCAR's Research Applications Laboratory and member of the Water Systems Program. "Our ability to see these effects may be a function of scale. At stand scales (several tens to hundreds of meters or less), the compensating effects are more difficult to see than is the case at a larger scale when growth of new vegetation or of non-impacted vegetation uses the available runoff that the pine trees would have used previously."

Trees near Granby, Colorado in the Rocky Mountains show the effects of an attack by the pine bark beetle. A combination of periods of severe drought and a lack of extreme winter cold – weather conditions that are consistent with climate change – have led to an epidemic of damaging beetles in pine forests across much the U.S. West. Copyright University Corporation for Atmospheric Research.

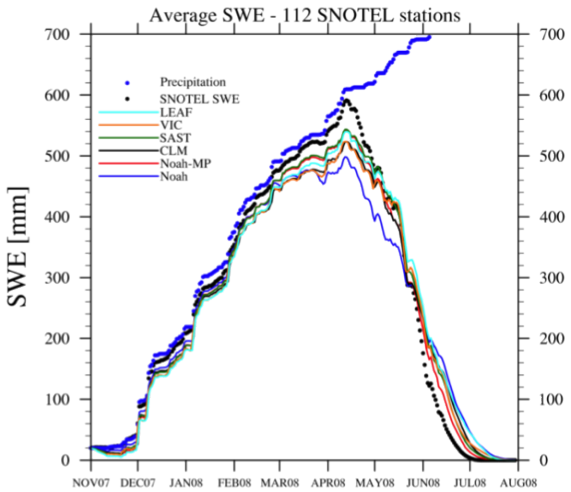
Intercomparison of Snowpack Models Covering the Complex Terrain of the Forested Central Rocky Mountains

Spring snowmelt runoff timing and amount in mountainous regions are critical pieces of information for water resources management. An effort is underway within the university community to utilize data from 112 SNOTEL sites in the Colorado Headwaters region and two Ameriflux sites to evaluate the ability of six widely-used land-surface/snow models (Noah, Noah-MP, VIC, CLM, SAST, and LEAF-2) in simulating the seasonal evolution of snowpack in the central Rockies.

All models captured seasonal evolution of snow water equivalent (SWE; the amount of water equivalent in a snow pack) fairly well (Figure 3). However, they underestimated both early-spring (March-April) snow accumulation and late spring ablation. Underestimating snowmelt from mid-May to mid-June allowed models to compensate for lower SWE

estimates in spring, and consequently resulted in each showing a prolonged snow season. No single model excelled at (or fell overly short of) reproducing the three important features of snow evolution: maximum SWE depth, the timing of maximum SWE, and the timing of spring snow disappearance.

However, models exhibited large disparities in simulating the surface energy partitioning, which is equally important for correctly representing snow-atmospheric interactions in weather and climate models. Some models underestimated the solar energy absorbed at the forest-soil-snow interface from December to March. That resulted in the models showing too little outgoing long-wave radiation and sensible heating being returned to the atmosphere, which could be a crucial deficiency for coupled weather and climate models. Those model disparities and deficiencies can be further traced down by examining the treatment (or lack of treatment) of turbulence and radiation processes within and under the vegetation canopy. Excessive shortwave and long-wave radiation transfer from canopy to the ground/snow often led to larger than actual sensible heating (i.e., the energy required to change the temperature of a substance) from canopy to ground/snow surface, and resulted in larger, undesired weekly SWE change in both accumulation and ablation phases. Accurate radiation transfer between canopy and ground/snow is essential for capturing both snowpack evolution and snow-vegetation-atmosphere interactions.



The figure compares the observed snow water equivalent (SWE) and precipitation (bold blue and black dotted lines) to the model output of SWE. The match between the observed and model data are close until about March, when the models underestimate precipitation and SWE.

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NCAR-Wyoming Supercomputing Center is Ready for Petascale Science

CISL achieved a final milestone in fulfilling the top imperative of its strategic plan at the end of FY2012: the Yellowstone supercomputer demonstrated petascale computing capability at the **NCAR-Wyoming Supercomputing Center** (NWSC). While

Summer Wildfires Offer Risk and Opportunity for Colorado Research Institutions
NCAR Passes its Quinquennial Science Review
Metrics

The NCAR-Wyoming Supercomputing Center (NWSC) in Cheyenne, Wyoming officially opened on 15 October 2012. The grand opening ceremony brought together officials and dignitaries from the institutions that collaborated to make the NWSC a reality. UCAR President Tom Bogdan (at left), Governor Matt Mead of Wyoming, National Science Foundation Director Dr. Subra Suresh, and University of Wyoming Vice President of Research & Economic Development Dr. Bill Gern cut the official ribbon to launch operations at the new facility.

finishing the facility and its support infrastructure, and while selecting, installing, and testing the supercomputer, CISL has been executing its transition to operations plan to shift NCAR's production supercomputing from Boulder, Colorado to Cheyenne, Wyoming.

In partnership with the University of Wyoming (UW), the State of Wyoming, Cheyenne LEADS, the Wyoming Business Council, and NSF, CISL completed construction and infrastructure stress testing of the NWSC in Cheyenne, Wyoming during FY2012. NWSC is designed to meet the rapidly growing high-performance computing (HPC) needs of Earth System scientists and to encourage broader participation in this scientific enterprise. NWSC is fully aligned with NSF's vision for future cyberinfrastructure and will directly contribute to the creation of a national petascale computing capability.

For the 1.5-PFLOPS supercomputer Yellowstone, CISL completed subcontract negotiations with IBM on 8 September 2011, and NSF approved the subcontract on 27 October. In November 2011 NWSC received its first IT equipment to provide authentication, authorization, and domain name services. As part of the AMSTAR contract with Oracle Corporation, two SL8500 tape libraries were then installed to expand CISL's HPSS archive. NWSC staffing proceeded from October 2011 through May 2012 with 18 people; these included new hires and existing staff relocated from Boulder. During winter 2012, Yellowstone's mechanical and electrical components were installed. Yellowstone's computing components, including the test equipment, arrived at NWSC between 9 May and 29 June 2012. Eighteen shipments over a six-week period were required to deliver all of the hardware for the new supercomputer.

The Yellowstone system was then installed, interconnected, powered on, thoroughly tested, and its energy efficiency exceeded expectations. It officially entered its three-week Acceptance Testing Period (ATP) on 4 September 2012. ATP was successfully completed on 30 September 2012 when CISL took ownership of the system. Early users will begin computing in October 2012. (Post-FY2012 note: In November, Yellowstone was designated the 13th most powerful supercomputer in the world by the Top 500 List.) Accelerated Scientific Discovery projects will begin in early December; these highly demanding projects will require large portions of Yellowstone's full capability. The system's production-ready date is expected in mid-December. The almost five-year-old Bluefire system running at NCAR's Mesa Lab Computing Facility (MLCF) in Boulder will be decommissioned at the end of January 2013.

CISL's transition to operations plan was executed throughout FY2012 using a rolling-wave planning methodology in which key milestones and large tasks were developed and driven by the installation of the HPC resources. As the system hardware and software installation and testing proceeded, details of the transition planning were refined in concert with this progress. CISL managers directed support for numerous critical transition elements: facility infrastructure, network services, data and archival services, supercomputing services, enterprise services, cybersecurity, and the relocation of staff and equipment from Boulder. CISL also developed transition plans for the user experience: staff began preparing users for the new resources, allocations, and accounting with documentation, training, and consulting. CISL carefully executed the steps necessary to provide a positive user experience during their transition from the Bluefire environment at the MLCF to the Yellowstone environment at NWSC. A combination of NSF Core funds and NWSC Transition Project funds was used to ensure the successful transition of supercomputing services from MLCF to NWSC.

A key goal of the NWSC facility project was to broaden its impact through an active public visitor program. The primary element of that program was the NWSC Visitor Exhibit to explain the science goals of NCAR and the University of Wyoming, as well as the technology employed at the NWSC to realize these goals. The NCAR-Wyoming partnership's NWSC education and outreach strategic goals are derived from an understanding of the national and regional challenges of STEM education and are designed to leverage the unique strengths of the founding NWSC partners.

The NWSC Visitor Center is intended for self-guided tours for individuals and groups of all ages and backgrounds, and it can also be used for presentations and special events. The visitor center consists of a theater for watching a video overview; two science displays, each with a different science focus area on each side; a young scientist display that includes a tornado simulator and an interactive computer speed demonstration; and a supercomputer display at which visitors can see

inside the supercomputer and interact with an exhibit that connects the concepts of electrical power with computing power. A key educational goal of the visitor center was to include content that would convey elements of computational thinking. These include interactive activities that explain the concept of speedup in parallel computing and identify other kinds of parallel systems in everyday life. To engage diverse audiences, the videos in the exhibits also include Spanish language subtitles. The NWSC visitor center was financed using NSF NWSC construction funds.

CISL finished designing and successfully deployed the NWSC Visitor Exhibit in FY2012, collaborating with UCAR SPARK and the University of Wyoming in this effort. In addition, CISL worked with a Cheyenne-based exhibit integrator and two video production companies to create substantive content customized to the NWSC mission. This content included an original animated video that explains how supercomputers are used to forecast severe weather.

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Summer Wildfires Offer Risk and Opportunity for Colorado Research Institutions

In 2012, a warm, dry winter followed by a warm, dry spring, June found much of Colorado's Front Range enveloped in flames and smoke. Among these, the High Park fire sprang up in the mountains near Fort Collins, Colorado and Colorado State University (CSU), becoming the state's second largest recorded fire. Located at CSU's Foothills campus, the atmospheric sciences department ended up being in the heart of the fire-control action. Not only did the

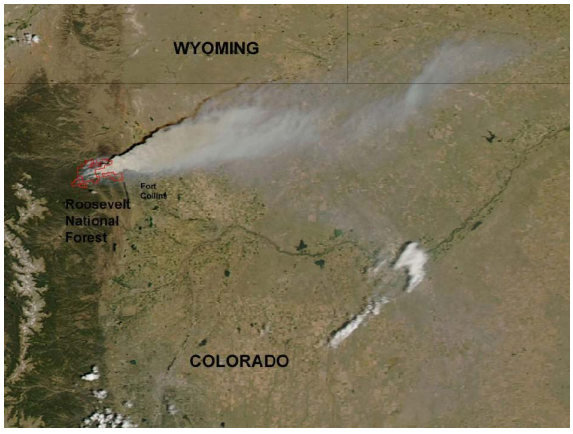
department provide forecasting assistance to the fire-fighting effort, they provided critical assistance and infrastructure used by the Incident Command unit directing this work. In addition to this basic support, CSU researchers also had an opportunity to do some backyard science.

“The department’s atmospheric chemists have a history of looking at air quality related to wildfires,” explains Russ Schumacher, an assistant professor in CSU’s Department of Atmospheric Science. “For the High Park fire, they set up field equipment behind the building for the duration of the fire, and had an opportunity to measure the chemical constituents in the atmosphere, and developed an understanding of the effects of wind direction, smoke, and aerosol loads on the atmosphere during a fire.”

Russ Schumacher, an assistant professor in the atmospheric sciences department at Colorado State University (CSU) made a time-lapse movie. Filmed from approximately 3:20 to 5:00 pm, with shots taken every 25 seconds, the movie was taken on Sunday June 10 2012, of the High Park fire, taken from the roof of the atmospheric science building at CSU.

“Oftentimes, the team will head out to a prescribed burn to deploy instrumentation,” says Gavin McMeeking, a research scientist at CSU. “Because controlled fires are easier for fire crews to manage, these tend to be the ones we get invited to study. From our perspective, controlled burns are great – they are easier to measure, we know when the fire will occur, and over (approximately) what scale the fire will occur, but if we want to model larger fires using data from prescribed burns it’s sometimes hard to be certain that we’re getting a good idea of the fire dynamics.”

Among the things the team hopes to learn more about from the collection of High Park measurements is how aerosols from small-scale fires affect urban areas and visibility, as well as how smoke from fires affects ice formation in clouds. Fires are an important, global source of particles to the atmosphere, so understanding how they affect the formation of clouds and precipitation processes is crucial.



NASA’s Aqua satellite captures an image of the High Park fire on June 10, 2012.

Researchers in the department also ran a real-time forecast model using NCAR’s Weather and Research Forecasting (WRF) model that ran with CSU’s own model configuration to provide forecasts of possible outcomes for precipitation and low-level winds in the area.

“During the fire, the group put together model forecast soundings that provided predictions on temperature, humidity, wind direction and speed for the precise location of the High Park Fire,” says Schumacher.

In addition, CSU's Cooperative Institute for Research in the Atmosphere (CIRA) had an opportunity to evaluate user feedback on FXNet, a portable version of the Advanced Weather Interactive Processing System (AWIPS), software that provides National Weather Service forecasters critical forecasting tools – from surface observations made by ground sensors to satellite observations, and model forecasts – that provides a complete picture of the atmosphere.

"AWIPS, because of its capabilities, is a resource-intensive program," explains Matt Rogers, a research scientist at CSU. "Sher Schranz, a CIRA researcher, led the development of FXNet as a field-expedient tool that has most of AWIPS' capabilities, but runs on a laptop, and can be used in situations where limited internet connectivity exists, such as a fire incident command post."

FXNet is a standard in-the-field tool, so Rogers and Schranz took the opportunity to talk to those in the Incident Command about their experiences using the software. The largest wildfires are typically assigned federal-level resources which deploy to help manage the fire, explains Rogers. Among these resources is the provision of a specially-trained meteorologist who uses weather forecasts to assist in fire suppression planning. FXNet is primarily used by these field-deployed meteorologists, and in talking to the High Park fire meteorologist, Rogers and Schranz gained an understanding of users' perceptions on the benefits of the software, what might be changed, and how FXNet could perhaps be useful to those lacking formal meteorological training (e.g., fire commanders) for smaller fires, which are often not assigned federal resources. Based on this feedback, CIRA researchers are developing new tools based on FXNet for the use in these smaller wildfire incidents.

"We're talking to managers of smaller scale fires with the aim of providing them with meaningful weather data and learning how products derived from FXNet might help them," says Rogers. "We are also trying to understand more about what they might need to know in fire situations – what sort of information is critical, over what time periods, and what kind of training they might need to better utilize weather observations as part of their firefighting efforts."

Fortunately, the Foothills campus and the atmospheric sciences department were never under serious threat from the fire. The department benefitted from its location, which sits near the very large Horsetooth reservoir. That said, at one point, the winds shifted and the flames came over the ridge to the west of the university, but never made it beyond this point, much to the relief of CSU staff and management.

Summer Fire Affects NCAR's Mesa Laboratory

While much smaller in scale than the High Park fire, the National Center for Atmospheric Research's (NCAR) Mesa Laboratory also faced wild fire threats this past summer. The Flagstaff fire, which started as a result of a lightning strike on the ridge behind the Mesa Lab, resulted in a two-day evacuation of staff from the building. While fire fighters had a good handle on the blaze, shifting winds had the potential to push the fire closer to Mesa Lab; the two-day closure resulted to ensure employee safety.

While the transition was underway to the NCAR-Wyoming Supercomputing Center in Cheyenne, Wyoming, much of NCAR's production computing capabilities remained at the Mesa Lab. NCAR's Computational and Information Systems Laboratory, which is responsible for the university community and internal computing capabilities initially opted to "run dark," letting the computers run unattended, so as to ensure staff safety. While the NCAR-Wyoming Supercomputing Center (NSWC) was designed with the intention of running the Mesa Lab computing systems remotely from Cheyenne, the center was still setting up the systems that would allow this functionality, "The fire greatly accelerated these plans," says Aaron Andersen, NCAR's Deputy Director for Operations and Services.

Jasen Boyington, an engineer in CISL's infrastructure support group, decided to stay behind and worked with the University Corporation for Atmospheric Research's (NCAR's managing body) Security, Safety and Site Services team to ensure this occurred safely. At about 10 pm on the first day of evacuation, Boyington smelled smoke coming through fresh-air intake vents where a damper did not close properly. After closing the damper, a CISL skeleton crew that included Boyington, Andersen, and Julie Harris worked from the Mesa Lab with those in Cheyenne to get the remote monitoring systems set up in a robust manner, getting the computing facilities safely through the fire. As of October 2012, CISL's remote monitoring system is fully complete. This effort has paid off doubly, with the system identifying a power outage caused by a failure in the standby generator equipment that allowed CISL staff to begin working on a fix to the problem before the work day began.

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NCAR Passes its Quinquennial Science Review

As part of the cooperative agreement between the National Science Foundation (NSF) and the University Corporation for Atmospheric Research (UCAR), a review of NCAR's laboratories occurs every five years. These reviews look at the work done since the prior appraisal, current achievements, and future plans. Review teams visited NCAR's four laboratories and the High Altitude Observatory (HAO) to talk to staff and program leaders throughout spring 2011, with site-visit results provided to NCAR in fall 2011. Review teams included experts in the various fields that NCAR

science and support covers. NCAR received an overall excellent review, as well as some suggestions on areas to develop further; all are being fed into the center's long-term strategic plan. Some review highlights are provided below.

The managers and designers of the new NCAR-Wyoming Supercomputing Center (NSWC), NCAR's Computational and Information Systems Laboratory (CISL) received praise for their ability to deliver a broad range of data services that benefit a wide variety of users, worldwide. CISL's work in geostatistics, data assimilation, and modeling continue in what the site team terms "…a well-established tradition of success." CISL's scientific and engineering staff was seen as being well matched in terms of achieving the high-performance computing and research capabilities and goals set by NCAR, CISL, and the expert user community, and the lab was extolled for its demonstration of strong scientific leadership within the research community. Combined with the opportunity presented by the NWSC, CISL's review team believes the lab has created a solid foundation for continuing to function as an effective national research center. Recommendations for areas to strengthen include exploring, where possible, the coordination, streamlining, and standardization of data storage and distribution practices with other NSF-supported efforts such as the National Ecological Observatory Network (NEON), and increased testing of code performance on new computing architectures.

NCAR's Earth Observing Laboratory, which develops, supports, and deploys NSF's lower atmospheric observing facilities (LAOF) on behalf of the university community, received review-team recognition for its innovative, dedicated, and responsive staff. The lab's high performance in serving the atmospheric science community also received commendation. Among the areas where the lab was seen to excel was in LAOF deployment, as well as enhancing education and outreach opportunities during such deployments, directed at audiences that might not otherwise be exposed to such scientific endeavors. EOL's data curation and stewardship were also lauded, both for the rescue and preservation of older data sets and for making newly acquired data easily accessible to a broad audience. Among the team's cautions: a concern exists that current staffing levels might not adequately sustain EOL's balance among field deployment, data management, instrumentation development, and research responsibilities; should budget allow, the review team recommends hiring additional staff. Lacking funds, the team recommends that EOL ensure ongoing strong focus on NCAR's core mission of providing research tools and services to the scientific community.

Work within the High Altitude Observatory (HAO) focuses on solar-terrestrial physics to understand the Sun's behavior and its effects on Earth, and to provide support for and extend the capabilities of the broad scientific community and foster knowledge and technology transfer in this area. HAO's reviewers found the observatory's scientific pursuits to be of exemplary intellectual merit, with research implemented by a talented and productive staff. The observatory's research and facilities capabilities were praised, from the research on physics of the Sun, space, and Earth's upper atmosphere using theoretical, modeling, and observational research methods, to the organization's strong visiting scientist program and support of observational facilities that are critical to community-wide research. The review team had concerns that several programs of benefit to the wider solar-terrestrial community were not getting the required level of visibility to ensure success. Among these is the Coronal Solar Magnetism Observatory (COSMO), which HAO has proposed building and operating for synoptic measurements of the coronal magnetic field; seen as a valuable community resource, it has not yet been approved. The review panel felt that the Community Spectro-Polarimetric Analysis Center (CSAC) is another important program lacking in visibility; CSAC provides a repository for spectro-polarimetric data and inversion methods to convert raw polarization measurements into magnetic field components.

Expert reviewers visiting NCAR's Earth System Laboratory (NESL) concluded that the NESL suite of community models is among NCAR's greatest achievements, and that the models are transforming the way in which a substantial fraction of the research in atmospheric and Earth system science is being framed and implemented. The laboratory, which focuses on advancing understanding and prediction of weather and climate phenomena, as well as advancing in-situ chemical measurement capabilities, has developed state-of-the-science global and regional numerical weather prediction and Earth-system models. Built in collaboration with the university community, with all acting as full partners in the model development effort, the review team felt this cooperative endeavor has greatly accelerated the rate of model progress. The flip side of this success, noted the reviewers, is an increased number of users, and more requests for help. Recognizing both the budgetary requirements and constraints, a recommendation of the review team was for NESL to explore ways to cost-effectively increase user support or possibly find ways in which users might better help each other.

The Research Applications Laboratory (RAL) was applauded for the success and utility of its research efforts, which range from forecasting and nowcasting to aviation safety and estimating the effects of climate change on society. RAL's mission to transfer knowledge and technology for societal benefit, the team noted, matches well with NSF's objectives, with societal benefits ranging from improving the efficacy of renewable energy to increasing understanding of some of the world's leading health issues. The review team also noted the highly collaborative, fluid environment in which RAL operates. This setting maximizes flexibility for matching RAL's personnel – whose expertise spans the social and physical sciences – with other scientists and engineers at NCAR, within the university community, and at other laboratories around the world. The most entrepreneurial of NCAR's laboratories, RAL has historically received fewer NSF base funds than the other labs, relying more heavily on funding from other U.S. federal agencies, industry, and non-U.S. governments. The review committee suggested that NCAR increase NSF funding if possible, and that RAL expand funding streams beyond historic sources given current funding realities.

In considering the goals and aspirations of NCAR's laboratories, as well as the provision of service by the labs to the research community, each review panel found that the labs met and generally exceeded the scientific aims outlined in NCAR's 2009-2014 strategic plan. The panel reviews will provide important input to the NCAR strategic plan currently under development, and will also inform each laboratory's strategies for best meeting the requirements of the scientific community NCAR serves.

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Advanced Study Program | ASP
2012 Annual Report

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ASP Annual Report 2012

- Director's Message
- Table of Contents
- ASP Postdoctoral Fellowships
- Building Partnerships with University Faculty
- Providing University Students Access to the Resources of NCAR
- ASP Summer Colloquium

Table of Contents

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ASP Postdoctoral Fellowships

ASP serves as a catalyst for burgeoning research that spans NCAR activities. The most important ASP component is the Postdoctoral Fellowship Program, which has been a part of NCAR for forty-five years and has sponsored over 450 postdoctoral scientists' research. The ASP appoints approximately 10 new postdoctoral scientists each year. During their two-year NCAR appointments, fellows 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

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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.

In FY12, the ASP appointed 12 new fellows (from over 110 applications) in a diversity of disciplines spanning the NCAR activities. In addition to the diversity of disciplines, the new fellows represent a diversity of population including gender and ethnicity. Also in FY2012, the ASP regular “socials” and other activities that often included an education or career development aspect. These activities not only brought members of ASP together, but also included any postdoctoral fellow or graduate student within the organization who wished to attend. For example, the ASP scheduled a video conference with several program managers at the National Science Foundation.

The ASP aims to create a meaningful experience not only for ASP fellows, but for all fellows at NCAR. As part of this plan, NCAR/ASP is a sustaining member of the National Postdoctoral Association and we celebrated National Postdoc Day with a family picnic.

In FY2013, ASP plans to continue the core elements of the program, including monthly seminars, regular research reviews, regular socials, and the Thompson Lecture Series along with the annual research planning sessions and on-going mentoring that ASP postdocs receive.

ASP Phil Thompson Lecture Series, May 16-18, 2012, with Stephanie Pfirman of Barnard College

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2012 Annual Report

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Building Partnerships with University Faculty

The ASP established the Faculty Fellowship (FFP) program in 2005 with the goal of funding medium-to long-term collaborative visits between the NCAR scientific staff and the university community. The program provides opportunities for university faculty to spend three to 12 months at NCAR, and for NCAR scientific staff to spend three to 12 months at a U.S. university. University faculty may also bring graduate students with them to NCAR. The FFP provides support for travel costs, temporary living per diem, and graduate student expenses.

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In FY12, applicants submitted proposals and budgets for 3- to 12-month visits that occurred between 1 June 2012 and 31 May 2014. ASP received six viable applications. All six applicants were extended offers for visits that either occurred in FY12 or will take place in FY13. Included with the faculty visits will be six visits made by students. We supported 50 months of faculty and student visits through this program!

The program gives university faculty an opportunity to take advantage of their National Center in a meaningful and productive way, while providing unique research opportunities for the accompanying graduate students.

In additional to the incoming Faculty Fellowship Program visits, two NCAR Senior Scientists left on one-year outbound FFP visits in FY2012. One went to the University of California, Santa Cruz and the other to Montana State University. Both will be teaching and collaborating with faculty and students during their visits.

FY12 Faculty Fellowship Program participant Jason Ching.

Testimonial:
We'd like to take this opportunity to send our thanks for the wonderful opportunity to visit the Mesa Lab for the month of October. Our supervisor, Alan Robock, invited us to join him for part of his Faculty Fellowship Progam many months ago, and we couldn't be happier with our experience. Aside from the inspiring setting in the flatirons, NCAR provided us with an invaluable opportunity to meet with other scientists and get a feel for what a truly collaborative and engaging atmosphere NCAR fosters. We met many other scientists (such as Peter Gent and Veronika Eyring) during lunches and other casual encounters in the lab, and we also made a few longer lasting relationships with people such as Simone Tilmes and Mike Barlage, both of whom were very generous in spending extensive time with us in discussing project ideas.

We attended the many seminars at both the Mesa and Foothills Labs, all of which were memorable and informative. We were also able to join the Early Career Scientists workshop, October 20-21, which gave us a great idea of the type of work that scientists just a few years older than us are working on.

Finally, we both were able to learn a lot about the computing systems available through NCAR. In particular, we both received an enormous amount of help with the Bluefire and Mirage systems, making accounts for different systems and learning how to properly store model output on the High Performance Storage System. It was extremely handy to be able to run downstairs and ask people like Si Liu and Davide del Vento for help in person. This was definitely one of the major benefits of working at the Mesa Lab.

Overall, we both feel that this visit to NCAR will play a pivotal role for us in our graduate careers. Interacting on a daily basis with such a diverse and helpful crowd of people boosted our spirits every day and made us excited to come into work the next morning.

Thank you very much for giving us this opportunity. It was invaluable to both of us.

- Faculty Fellowship Program Student participants Mira Losic and Lili Xia, Rutgers University.

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Providing University Students Access to the Resources of NCAR

The Advanced Study Program provides university graduate students and their advisors with access to NCAR resources through the Graduate Visitor Program (GVP). The program, now in its seventh year, was created in response to multiple requests from NCAR scientific staff for graduate student support. It was also developed in response to university community requests for access to NCAR resources and facilities that are not available at a university. ASP recognized the need to establish a program that would sponsor a significant number of meaningful visits and

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Supporting Diversity in the Atmospheric Sciences
ECSA Junior Faculty Forum on Future Scientific Directions

collaborations with graduate students and their advisors. The GVP responds to that need.

The Graduate Visitor Program provides NCAR scientific staff with opportunities to bring graduate students to NCAR for three- to 12-month collaborative visits. These visits are undertaken with the endorsement and complementary support of the graduate students' thesis advisors. While residing at NCAR, the students conduct research in pursuit of their thesis requirements. The students receive support to cover their travel and living expenses in Boulder. Funding is also provided to allow the students' advisors to visit NCAR for a period of up to two weeks. The students' home institutions continue to pay the students' salary, benefit, and tuition expenses while they are in residence at NCAR.

As a result of the 2012 GVP search, 31 GVP awards were given to students and most of those included a visit by the student's advisor. ASP supported 138 months of GVP visits in 2012.

The Graduate Visitor Program is becoming more popular every year. The ASP recognizes that students and their advisors are the bridge builders between NCAR and the university community. The ASP contends that the Graduate Visitor Program will seed significant and long-term collaborations. This program helps to extend NCAR capabilities by bringing students on-site to work on research of mutual interest and by providing NCAR scientific staff with the opportunities to participate in graduate student research and education. Through this program, NCAR increases its contribution to the education of the next generation of scientists, researchers, and faculty. In turn, the graduate students help invigorate NCAR and their home institutions. Finally, the Graduate Visitor Program provides opportunities to partner with universities and engage Ph.D. students from underrepresented groups in NCAR research activities. The ASP anticipates that the program will help diversify the future workforce at NCAR and in the geosciences professoriate and research communities.

Student Comments

The graduate visitor program gave me unparalleled access to some of the leading scientists in my area of research. This collaboration allowed me both to fortify my confidence in understanding the background theory of my work and to speedily and accurately make practical advances toward useful results. I now have an extensive network of collaborators and advisers from NCAR who are more than happy to comment on and help me as my graduate career continues. In addition, the GVP itself made living away from home for four months very enjoyable--the assistance provided through helping to find housing, a living stipend, access to the NCAR computers and other resources and events to socialize and get to know fellow graduate students all made my time in Boulder a joy. I highly recommend the program to any other graduate students looking to expand the horizons of their research and enjoy some time in Boulder.

-**Luke Madaus**, *University of Washington*

The Graduate Visitor Program was an overall great experience for me. Getting the opportunity to work with scientists that were originally only a name at the top of every journal article I read, and becoming close collaborators on my research was something I could not value more. The atmosphere at NCAR was very conducive to quality research while staying relaxed and clear minded. I accomplished so much within my short, three month period in the GVP that I am sure I could not have done anywhere else. Between the knowledge and skills gained, collaboration opportunities and friendships made, I can not decide what was the best about this experience. I strongly believe that being a part of the GVP will help me in my career after graduate school.

-**Pat Hawbecker**, *Texas Tech University*

Having granted a graduate visitor program is, without a doubt, the best thing in my PhD journey to date…

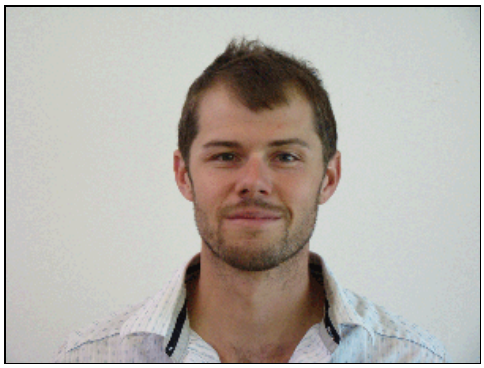
I credit meeting many of my research goals this year to my host, Stephen Sain. We, together with Dan Cooley, had a fruitful discussion that later on become a basis by which to expand my research.

In my opinion, Graduate Visitor Program is the best and most beneficial program you'll ever experience. I would definitely recommend participating in this program and considering it as part of a research journey. It is a great way to build research skills, to broaden horizons, and most importantly to build a network.

-**Indriati Bisono**, *University of Melbourne*

The NCAR Graduate ASP program is a highly rewarding opportunity for graduate students. While there are many great aspects of the program, perhaps the greatest of all is the chance to collaborate with a plethora of scientists who are experts in your field of study. Through this collaboration, I gained a significant amount of insight into how these scientists have addressed similar problems in the past, as well as garnered fresh ideas to better approach the problems I was addressing through my research. Now back at my home institution, I am applying new tools and ideas I gained through my ASP experience towards finishing my Ph.D. The ability to speak face-to-face on a daily basis and the accompanying instantaneous feedback I found to be more constructive than traditional means of email collaboration, and much less rushed than, for example, personal communication in-between talks at a conference. Every NCAR employee I spoke with was enthusiastic about discussing my research project and offering suggestions. Everyone at NCAR, including staff and the other ASP students, was super friendly and accommodating - an added bonus!

-**William A. Komaromi**, *University of Miami*



This summer the graduate visitor program gave me the opportunity to work with Dr. Piotr Smolarkiewicz at the National Center for Atmospheric Research. I had a wonderful experience studying at a national laboratory, focusing on my research, and forming deep friendships with the other graduate students whom were part of the graduate visitor program.

One of the most common questions for graduate students is "what are your plans once you finish?" My summer at NCAR gave me an opportunity to experience what life would be like if I worked at a national laboratory after I complete my PhD. In reflection, my time at NCAR was most positive. The atmosphere at NCAR was causal in attire, but serious when it came to science. It was clear that the groups at NCAR have a goal of learning together and using their individual strengths as a team. I had lunch with many staff scientists and most of them enjoyed their positions and the scientific freedom it provided.

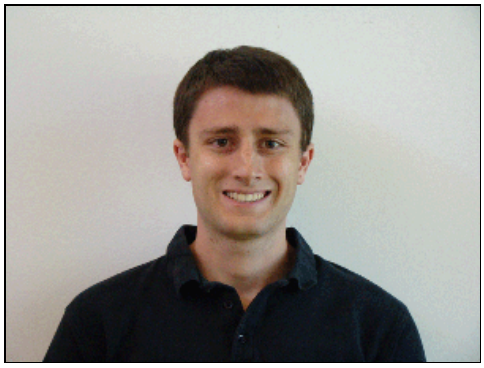
For the past two years Dr. Smolarkiewicz has been an unofficial advisor for my primary dissertation research of modeling microscopic fluid flow in porous media. Prior to my visit, we would exchange several emails each week. My time at NCAR allowed us to meet often and expedite the completion of two papers, one of which was recently

published. During my primary advisors visit, we came together, focused as a team, and made extraordinary progress on the difficult problems we were studying. This experience showed me how important and productive in person meetings are even in a world with Skype.

-**Jeffrey Hyman**, *University of Arizona*

The NCAR Graduate Visitor Program provided growth opportunities in many aspects of my research, career, and even my life. The interaction with my supervisor was definitely the best part of my experience; he would take substantial time each week to discuss my findings with me, and not just provide feedback, but also an opportunity to discuss and share ideas about things I can do to enhance my research. This type of leadership style allowed for a substantial amount of creativity in my research, which not only made the work rewarding and substantial, but fun! The work done during my visit has become a central point of my Master's Thesis, as well as potentially a publication, which is exciting for a Masters student. In addition to the substantial benefits to my research, my visit provided excellent networking and career-enhancing opportunities; being able to sit in on (and even present in!) working group meetings allowed me to get to know some of the top research occurring in my field, as well as some of the top scientists in the field… an extremely valuable experience! I will always fondly look back on my time at NCAR as a turning point in many aspects of my research, career, and life!

-**Terrence Mullens**, *San Jose State University*



I found the time that I spent engaged in the NCAR Graduate Visitor program very rewarding and highly valuable to the progress of my PhD dissertation. There were many aspects of the GVP that I liked; however, one thing that was very important to me was the fact that it allowed me to work with world class scientists in a new research setting. This was valuable to me because it broadened my outlook on scientific research by exposing me to new and interesting styles of research that I was not aware of prior. Also, the GVP helped me solidify my dissertation topic and identify the specific problems that I wanted to address in my PhD research. By working on the project assigned to me at NCAR, I was able to realize new and exciting areas of research which aligned with the broad scope of my dissertation. These areas will be addressed in the various chapters of my dissertation. Additionally, I built a stronger professional network which has promoted my ability to communicate research ideas among researchers in my field. Finally, I learned a plethora of new tools and methods for analyzing and interpreting data which has expanded my ability to make meaningful conclusion about my research results.

-**Christopher Nunalee**, *North Carolina State University*

Advisor Comments

The graduate visitor program by ASP represents a unique opportunity for doctoral students to work in one of the leading institutes in atmospheric science. One of my students, Luxi Zhou, joined this program in autumn 2012, and during my three-week visit to Boulder, her first question was if there was any chance of extending her time at NCAR beyond the three months. It was the friendly, always helpful and fruitful atmosphere at the institute in scientific discussions and also private issues which impressed her and encouraged her to step deeper into certain topics which were not part of her interests before. The structure of inviting the supervisor for a shorter period together with the student makes this program outstanding.

-**Michael Boy**, *University of Helsinki, Finland*

My Ph.D. student, William Komaromi, spent 3 months on the ASP Graduate Visitor Program in summer 2012. The timing was good since he was due to submit his thesis proposal after the visit …
The graduate visitor program appears very well-organized to me (and this comes from someone who is often highly critical of disorganization!). My own week-long visit was very well set up by NCAR and I also derived great benefits from the interactions with NCAR scientists. It also demonstrated to me first hand how well William was branching out as a young scientist during his time at NCAR. Due to this positive experience, I recommended that another of my students apply this year.

Sharon Majumdar

I think the graduate program was good for Ms. Thompson for several reasons. I think that the program promotes exposure to different viewpoints as to how to solve problems. In our case, Ms. Thompson is working on a rather complicated technical problem associated with numerical weather prediction of convection. As with any cutting edge work like this, there are various "camps" as to how to approach the problem, what are the critical issues, and what are the best methods to solve these issues. Appreciation of these often subtle details cannot (and does not) occur via a seminar or email collaboration - it requires the student to get deeply involved with another group's approach and ideas and this requires weeks and months of intense effort and discussion. Secondly, in her case, Ms. Thompson will be obtaining all three degrees from the University of Oklahoma. We both agree this is a weakness, so again the exposure to a new group of scientists is very helpful in forcing a student to defend his (or hers) points of view, etc. I know from my own experience that moving schools between my M.S. degree and Ph.D. degree was a period of growth for me some years ago (too many!). So our intent here was for Ms. Thompson to at least be embedded in another scientific culture, like NCAR's, to help her grow and mature as a scientist. Finally, as part of their professional development, students like Ms. Thompson need to develop their own network of collaborators with their peers or other more senior scientists so that they have a base of intellectual support when they graduate and move on with their careers. Programs like the one at NCAR are invaluable for that purpose.

-**Louis Wicker**, *NOAA* (Ms. Thompson is at the University of Oklahoma)

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ASP Summer Colloquium

For several decades, the ASP has hosted at least one 2-week colloquium every summer on an emerging science topic of interest to the NCAR community. The colloquia are designed for graduate students in new or rapidly developing areas of research for which good course materials may not yet be available. In recent years, the colloquia have had both a lecture component and a hands-on tutorial component. NCAR Scientific staff members in partnership with one or more university collaborators write proposals for colloquia topics, and in the event that their proposal is selected,

Profiles in Science
Supporting Diversity in the Atmospheric Sciences
ECSA Junior Faculty Forum on Future Scientific Directions

organize the colloquium curriculum with logistical support provided by the ASP.

In 2012, the summer colloquium was titled The Weather-Climate Intersection: Advances and Challenges.

Climate and weather are inextricably linked. Weather happens on the scales of minutes to weeks, while climate characteristics are the effects of weather averaged over the longer term – weeks to years or decades or more. Weather forecasting has evolved to be remarkably accurate, however forecasts created for periods beyond seven to 10 days get increasingly less reliable. To a large degree, prediction difficulties come down to deficiencies in the quality or quantity of observational data and computer modeling capabilities. Even more than in other regions of the world, predictions and forecasting of tropical climate and weather are made difficult due to the less complete understanding of how tropical convection couples to the large-scale atmospheric dynamics.

In recent years, buoyed by improvements in numerical modeling and more and better observational data, forecasting of longer term weather and climate has improved. These improved forecasts have both improved scientific understanding and expanded current forecasting accuracy. This reality has made possible a more informed study of where and how weather and climate influences and dynamics intersect. In addition to scientific advances, new understanding will inform economic and societal issues related to weather and climate. For example, an improved understanding of what weather extremes might be expected further into the future and how to best prepare for these will benefit the public, as well as those working in industry, such as insurance, finance, energy, and transportation.

“Among the topics that fall within this weather-climate intersection is the Madden-Julian Oscillation (MJO) – a 30- to 60-day pattern of eastward moving precipitation and convection that occurs along the equator,” explains George Kiladis, a research meteorologist in the Earth Systems Research Laboratory at the National Oceanic and Atmospheric Administration (NOAA). “This ‘holy grail’ of tropical weather systems was in fact discovered at the National Center for Atmospheric Research (NCAR) by Rol Madden and Paul Julian back in 1971, and researchers are still working hard to understand it completely.”

When active, the MJO accounts for about a quarter to a third of the resulting precipitation in the tropics, and also strongly affects the weather and the climate of global regions beyond the tropics. If the current models get the MJO right, it might be possible to extend accurate medium-range weather forecasts out another several days, Kiladis says.

Students studying atmospheric science are well aware of atmospheric phenomena such as the MJO and El Niño, and understand that these events have both weather and climate effects, but few move beyond this recognition to consider the interaction between climate and weather in greater detail. Additionally, many students focus on climate and weather phenomena occurring in regions beyond the tropics (i.e., the extratropics) rather than looking at tropical weather and climate in depth. With the recent advances in understanding and technical and observational capabilities, these areas of study offer exciting new research frontiers, not least because atmospheric events happening within the boundaries of the weather-climate intersection have significant impacts on the ocean-atmosphere system over a wide range of space and time scales.

Recognizing these gaps in student experience, Lance Bosart, a distinguished professor from the University at Albany, Kiladis, and Mitch Moncrieff, a senior scientist at NCAR successfully proposed running a three-week program for graduate students that covered these topics for NCAR’s annual Advanced Study Program (ASP).

“We’d been thinking about this topic as an ASP colloquium for at least five years,” says Bosart. “We have all benefited from ASP colloquia when we were students and early career scientists – as have many of the speakers at the 2012 colloquium. Not only is this a topic that we’re all interested in – it’s the way forward for both synoptic meteorology and climate research – but it gives us an opportunity to give back to the ASP program and the science community.”

Titling the program, “The *Weather-Climate* Intersection: Advances and Challenges,” the first week consisted mostly of foundational lectures on climate and weather, with discussions on the final project, a course requirement, beginning at the end of the week. The second week brought together scientists specializing in the weather-climate intersection who work on related phenomena such as the MJO, El Niño-Southern Oscillation, and midlatitude jet streams and blocking. In addition to lecturing, they had a rare opportunity to talk to their peers for a prolonged span of time, with many of the researchers staying for more than just the middle week. The third week featured lectures from recent PhD graduates on relevant topics, and saw students pushing to finish and present their final projects. Speakers were not limited to those working in government-funded labs or academia; several speakers came from private industry, an area that stands to benefit from the increased understanding of weather and climate.

“We designed the program intentionally to maximize the time that students had with the world-class researchers in this field, while also giving them an opportunity to meet and spend time with the cohort they are likely to work with throughout their careers,” Moncrieff says. “In addition, by inviting early-career speakers, we hoped to show students a variety of future possible job options – the challenge of melding weather and climate certainly requires bright new minds.”

“The students enjoyed the colloquium, but the researchers also enjoyed it because they had a chance to catch up on the state of others’ research,” Bosart says. “The students pushed these discussions further by asking questions of the scientists on topics that often hadn’t been considered for decades, or on stuff we generally take for granted, which gave all of us things to think about.”

An innovation added to this year’s colloquium that Kiladis saw as extremely useful were “map discussions.” A tradition in the University at Albany’s atmospheric sciences department, the colloquium’s morning lectures covered weather characteristics from a theoretical perspective, while afternoon map discussions led by Bosart or other lecturers offered an opportunity to show real-time weather maps illustrating the type of phenomena discussed in the morning. Looking at the maps helped continue the discussion, offering a way of cementing the theoretical ideas with reality, Kiladis explains.

By all accounts, the 2012 ASP colloquium on the weather-climate intersection was a success,enjoyed by organizers, speakers and students alike.

“These ASP colloquia provide a real service to the community by training the next generation of students,” Bosart says. “Organizing and running colloquia is a difficult thing for a university to do – NCAR has the resources, and experiences, they know how to do it, and how to do it right, and it is an obvious priority for both them and the National Science Foundation.”

Story courtesy of Rachel Hauser, NCAR Research Relations

Pictures courtesy of George Kiladis, NOAA-PSD

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Profiles in Science

Zhensong Cao - High precision measurements of CO_2 isotope using difference frequency spectrometer

Katherine Dickinson - Human Behavior in the Face of Environmental Risks

Gülnur Dogan - Exploring our sun by looking at the other stars

Matthew Hayman - Detecting Oriented Particles with Polarization Lidar

Alexandra Jahn - Changes in the Arctic sea ice

David Richter - Sea spray in the turbulent, near-surface boundary layer

Vanessa Schweizer - Systematic Exploration of Socioeconomic Conditions Affecting the Mix of Mitigation, Adaption, and Suffering

Brian Tang - A global, long-term tropical disturbance database

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Advanced Study Program | ASP
2012 Annual Report

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ASP Annual Report 2012

Supporting Diversity in the Atmospheric Sciences

The ASP continued its ongoing efforts to better serve diverse communities in FY2012 primarily through its postdoc exchange initiative.

In FY2008, a Memorandum of Agreement (MOA) was signed between NCAR and four Historically Black College and University (HBCU) partner universities:

Profiles in Science
Supporting Diversity in the Atmospheric Sciences
ECSA Junior Faculty Forum on Future Scientific Directions

* Howard University
* North Carolina Agricultural and Technical University
* Hampton University
* Jackson State University

The MOA focuses on these areas of mutual agreement:

* Graduate student research and internship opportunities
* Faculty exchange and internship opportunities and faculty training.
* NCAR scientists serving as visiting faculty to increase instructional capacity and curricular breadth/
* Participation of NCAR scientists on graduate student committees.
* Collaborative research that results in proposal submission

In support of the Memorandum of Agreement referenced above, the ASP recruited two of its postdoctoral fellows to spend time teaching, conducting research, and collaborating with faculty and students at Hampton University and Howard University. Alexandra Jahn spent two weeks at Howard University last fall and Jia Yue completed his 4-month teaching assignment at Hampton university teaching “Principles of Atmospheric Physics”.

The visit established a scientific relation where none previously existed between NCAR and this HBCU. Students at Hampton became aware of the research at NCAR and Jia’s visit could dramatically increase the chances of one or more Hampton students visiting NCAR, especially now that Jia has accepted a full-time faculty position at the university. Finally, Hampton University plans to join UCAR as a member university as a direct result of this initiative.

At the very end of FY12, Sean Moore began his semester-long residence at the Minority Serving Institution (MSI) The University of New Mexico, Albuquerque. Sean will also be conducting research at nearby Navajo Reservations along with teaching and collaborating with UNM faculty and students.

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2012 Annual Report

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ECSA Junior Faculty Forum on Future Scientific Directions

In 2003, the Advanced Study Program and the Early Career Scientist Assembly (ECSA) began hosting an annual forum at NCAR on future scientific directions. The objective of this forum is to bring together early career faculty and NCAR scientific staff to discuss selected topics in the Geosciences. This forum is open to non-tenured faculty at universities who are within five years of their first professorial academic appointment and to Level I and Level II NCAR scientific staff. In addition to promoting scientific discussion, an intended goal of the forum is to encourage development of

Profiles in Science
Supporting Diversity in the Atmospheric Sciences
ECSA Junior Faculty Forum on Future Scientific Directions

professional relationships between members of the ECSA and UCAR institutions.

ECSA-WCRP Workshop: Regional Climate Issues in Developing Countries

The Early Career Scientists Assembly hosted a special Junior Faculty Forum before the WCRP's Open Science Conference in Denver. ASP sponsored 35 early-career scientists from nearly 20 countries to participate in the 3-day workshop October 19-22, 2011. The workshop focused on examining the diversity of regional climate issues with an emphasis on developing countries. Topics included droughts, floods, heat waves, severe storms, sea level rise, water supplies, agricultural yields, and the survival of native species, pollution and human health. According to the article summarizing the workshop in Eos (Vol 93, No. 14, 3 April 2012), "The workshop fostered new ideas and collaborations between early-career scientists from around the world. The discussions underscored the importance of establishing partnerships with scientists located in typically underrepresented countries to understand and account for the local political, economic, and cultural factors on which climate change is superimposed."

The Junior Faculty Forum on Future Scientific Directions is funded by the NSF.

Participants of the 3-day workshop at the NCAR Mesa Lab.

Participants of the 3-day workshop at the+ NCAR Research Aviation Facility at the Rocky Mountain Metropolitan Airport.

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2012 CISL Annual Report

CISL Annual Report Table of Contents

‹ CISL Director's Message

CISL Services ›

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CISL ANNUAL REPORT 2012
COMPUTATIONAL & INFORMATION SYSTEMS LABORATORY

CISL Services

CISL has a proud tradition of providing world-class supercomputing and data services to its user community. The quality of these services is and will remain a core value of the laboratory. However, the makeup of these services is not static: they continually change in concert with rapid changes in the underlying technologies and scientific demands of our users. CISL:

- Maintains and operates the physical facilities and cyberinfrastructure needed to support the atmospheric

and related sciences

- Curates, manages, and archives a rich set of data collections to which it provides free and open access
- Creates essential widely used software cyberinfrastructure such as data analysis and visualization tools and frameworks for modeling and science gateway construction
- Provides user support and training on all of these
- Strives to better integrate its resources and services with regional and national cyberinfrastructure and services, and with the organizations that maintain them, such as the Front Range GigaPoP (FRGP), the Front Range Consortium for Research Computing (FRCRC), and NSF's eXtreme Science and Engineering Discovery Environment (XSEDE).

From CISL's web page for services and support, users can access CISL's help desk and consulting services, as well as complete information about HPC systems, storage systems, data analysis and visualization systems, data collections, user documentation, and training.

At the end of FY2012, CISL was positioned to realize its dream of creating a data-centric, petascale supercomputing environment for our community at the NWSC. The centerpiece milestone in 2012 was the delivery, construction, and acceptance testing of the 1.5-petaflops IBM iDataPlex supercomputer system Yellowstone, along with the related high-speed networking, central disk storage, tape archive, and data analysis and visualization systems. These resources will be critical tools enabling scientists to push back the research frontiers of weather phenomena, climate change, space weather, solar physics, and more. Consistent with NCAR's mission, the NWSC has begun to demonstrate the energy efficiency promised by its design and the use of the newest and most efficient technologies available. Finally, 2012 saw the construction and installation of the NWSC Visitor Exhibit, which provides an interactive, self-guided tour of the science goals and technology employed to deliver scientific discoveries at the NWSC.

CISL's software CI capabilities made important advances in FY2012 as well, including ones that enable our tools to work with larger data sets, or integrate better, or operate with new kinds of scientific data. For instance, FY2012 saw the on-time publication of NCAR's contribution to the Fifth Climate Model Inter-comparison Program (CMIP5). Over 140 terabytes of this data will be used by the climate community to study areas of agreement and divergence in the predictions of future climate made by the world's best Earth System models.

This work is funded as specified in the following individual reports.

‹ CISL Annual Report Table of Contents

CISL facilities ›

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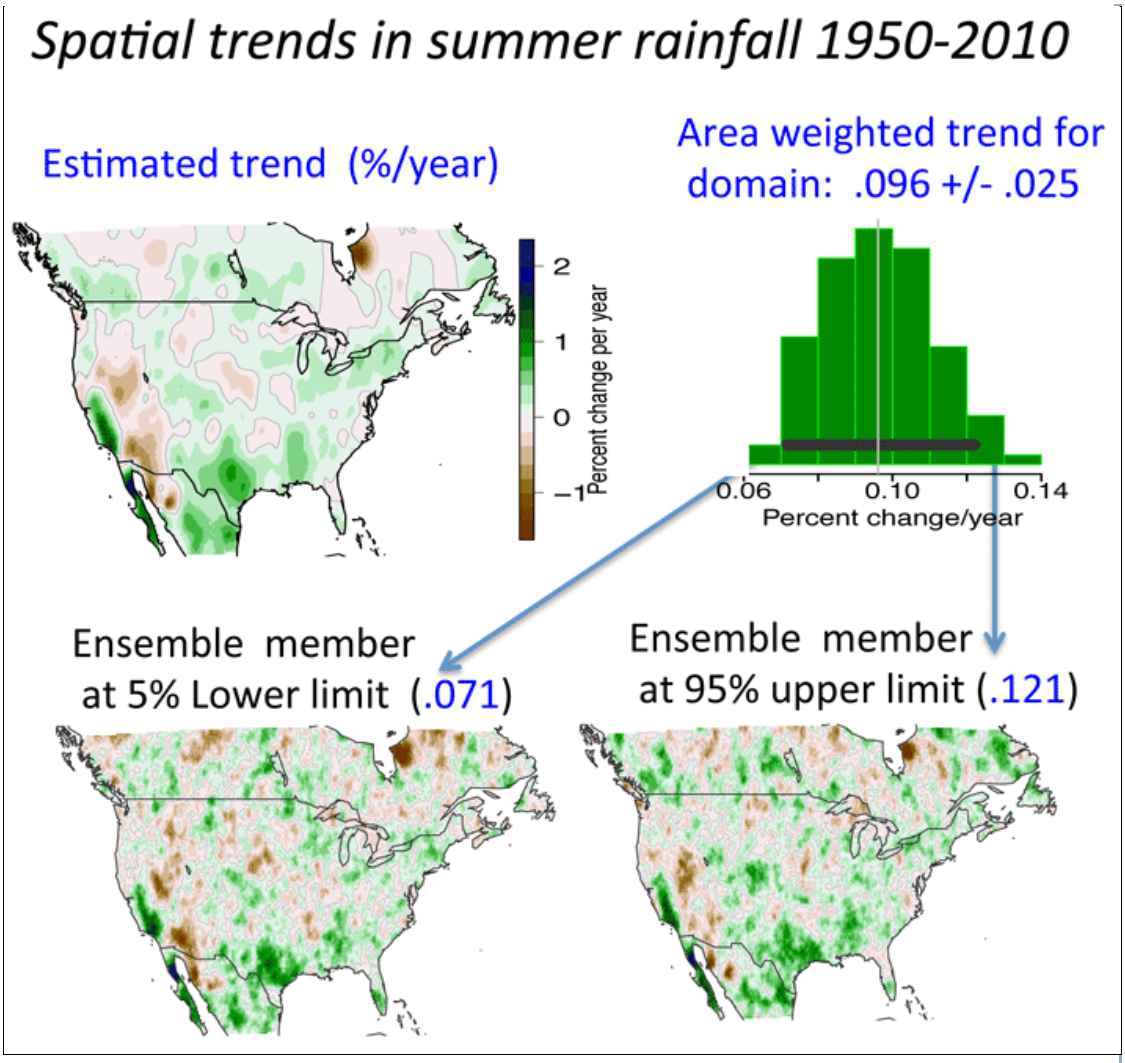
CISL Science

CISL research activities support scientific computation, numerical methods, geophysical modeling, and the analysis of geophysical data and model experiments. These activities are chosen to lead the geophysics community in adopting new computational methods and mathematical tools to improve research. Diverse scientific disciplines often share common tools and numerical methods. The kind of mathematical, computational, and physical sciences housed in CISL focus on general mathematical tools, models, and algorithms that have broad application across NCAR. Hallmarks of this research are innovative and standout contributions that not only have relevance for the overall NCAR scientific program, but also are significant in their specific area of mathematical, physical, or computational science.



The trend surface in summer rainfall (in percent change per year) was found using spatial statistics methods and Monte Carlo simulation to generate an appropriate ensemble. Part of this method is to estimate how the correlation between the trends of two stations decreases as a function of separation distance. This correlation function is the main statistical ingredient to estimate the value of the trend at locations where station data is not available. This surface is given in the upper left. Note some drying across the Southwest and increasing amounts in Texas and Southeast. But the spatial patterns are not smooth. A 100-member ensemble is used to represent the uncertainty in the trend surface. The interpretation is that each member of the ensemble is equally plausible given the 1,700+ stations and the spatial correlation function. (The mean of the 100 ensemble members is the same as the estimate in the upper left plot.) The spatially averaged trends across this region are found for the mean surface and for each member of the ensemble and are represented as a histogram in the upper right. Here the dark gray bar contains 95% of the values. This is an estimate of the uncertainty of the average trend across this region based on having an irregular station network. The lower left and lower right plots show the ensemble members with trends at the limits of this uncertainty range. These lower plots give an impression of the spatial variability in the trend that is plausible based on the data. Note that the patterns of drying and increasing wetness are still visible, but there is much more variability in the extent of each. The variation in the ensemble suggests which features can be taken seriously and which are due to spatial noise. This is just one example of how the ensemble members can be used to summarize the variability in the estimate. They could also be used to determine the uncertainty in the regions where the trend is negative. In addition, the ensemble fields can be aggregated up to the size of the model grid cells to give estimates with uncertainty at the resolution of a particular model.

The figures above provide an example of the challenges for discerning patterns in climate from observational data. In this case, sparse and irregular trends derived from individual stations are used to estimate a trend surface using methods from spatial statistics. The uncertainty in this surface can be represented as an ensemble of fields that are equally plausible given the data, and the ensemble is used to set uncertainty ranges on the average trend over this domain.

From this specific example, one can trace some more general themes of research in CISL. Creating statistical tools for the analysis of climate data along with characterizing the uncertainty in any analysis is one research activity in CISL. The ensemble method used here is also a central statistical feature of CISL's assimilation research and is implemented in the Data Assimilation Research Testbed (DART). Equally telling in terms of a scientific perspective is what is omitted from this figure. The observational record serves as motivation and validation for geophysical models that simulate the Earth's climate system. Numerical experiments over this period using regional climate models are one way to assess the ability of geophysical simulation to reproduce the kind of trends that are observed. This activity is represented in CISL through leadership of the North American Regional Climate Change

and Assessment Program (NARCCAP). It is widely acknowledged that climate models are challenged to simulate precipitation at local scales. At a more basic level CISL scientific research supports the construction and running of models that support higher resolution with the intent of more accurately simulating geophysical processes such as rainfall. Of course one litmus test for this research in numerical methods and computational science is to compare the resulting models to reality. This point brings us back to considering the historical record of climate exemplified in the figure.

These are some notable FY2012 accomplishments and examples of the diversity of CISL science:

- An ensemble ocean reanalysis from 1998-2010 has been completed using the atmosphere and ocean components of CESM.
- DART was successfully applied to the NOAH land surface model to assimilate observations of soil moisture.
- A statistical approach was developed that allows comparison of different resolutions to calibrate the Lyon-Fedder-Mobarry magnetosphere model.
- An overview analysis of the NARCCAP experiments was completed that considered future changes in seasonal temperature and precipitation.
- An examination of high-resolution dynamical downscaling for the U.S. Southwest was initiated.
- In an idealized rotating and turbulent system, it was demonstrated that there is a return to isotropic turbulence at small scales.
- Development of advanced numerical algorithms for transport were shown to scale to hundreds of tracers without impeding parallel efficiency.
- Radial basis function methods were succefully combined with GPU coprocessors for efficient and accurate computation without assuming a fixed numerical mesh.

The activities outlined in this report advance the imperatives and frontiers of CISL's research strategy. The breadth of this research aligns with CISL's strategic imperative of scientific excellence. For CISL's interactions with the scientific community, a robust visitor program and a popular summer internship program provide numerous strategic benefits. Another scientific imperative addressed by CISL research is meeting the challenges of Earth System modeling as it moves to the petascale and exascale. Thus, research is pursued on adaptive numerical methods and multiscale models, both areas addressing the need for higher-resolution geophysical simulations. A companion to this effort is work in computational science for taking advantage of massively parallel supercomputers and new kinds of processors. Set against these computational goals is the creation of new analysis tools to interpret complex multifactor geophysical simulations and heterogeneous observational data. These are addressed in CISL research by the focus on the impacts of regional climate change and data assimilation.

This work is funded as specified in the following individual reports.

‹ Science gateway cyberinfrastructure development

Interdisciplinary contributions ›

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CISL Education, Outreach, and Training

CISL designs education programs to integrate research and education and teach the technical skills that students and faculty need to make effective use of advanced cyberinfrastructure. These programs also promote diversity, enhance a culture of teaching and mentorship within CISL, and provide opportunities for collaboration with the university community. These objectives are accomplished through visitor, internship, workshop, and training programs.

A supercomputing laboratory in a national research center is a unique place to help integrate research and education between disciplines. CISL focuses on the computational and atmospheric sciences, and has a math institute dedicated to education and advancing research using applied mathematics and statistics. CISL's educational efforts are designed to complement and supplement programs at universities and other centers.

CISL manages two principal training thrusts: one for HPC systems and another for CISL-developed data analysis and visualization tools. NCAR and CISL also provide cyberinfrastructure resources and user support for community workshops, tutorials, and summer schools in the atmospheric and related sciences.

This work is supported by NSF Core funding, with supplemental funding supplied by other sources as noted in the following reports.

‹ Scientific data compression and visualizing large datasets

Integrating research and education ›

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Broader Impacts

CISL engages in a spectrum of activities designed to broaden the laboratory's impact through outreach, collaboration, and community engagement, and through capacity building at regional, national, and international scales. These activities have two main thrusts. First, CISL does outreach and provides training and education opportunities aimed at broadening participation and encouraging the development of the trained and diverse workforce necessary to continue advancing the scientific use of high performance computing resources. Second, CISL encourages collaboration and exchanges of information and expertise for developing shared cyberinfrastructure and standards that will advance high-performance computing, not only in the atmospheric and related sciences, but also in the general HPC community.

Clear examples of how CISL's education efforts broaden the laboratory's impact on the U.S. STEM workforce arise yearly from CISL's internship program SIParCS. Numerous interns have redirected their career plans in response to their positive research experiences in CISL. Students have come to IMAGe for a specific project, then returned as postdocs, taken jobs as university faculty, then sent their students here. This process keeps refreshing our workforce with new talent, it reinvigorates others at the universities, and it is a healthy model for a national center

This work is supported by NSF Core funding.

‹ NWSC visitor center exhibits

Diversity-focused activities ›

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2012 Annual Report

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ISP Annual Report 2012

Table of Contents

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Frontiers and Imperatives

The work of ISP addresses frontiers and supports the imperatives of the NCAR Strategic Plan:

Two ISP projects are focused on NCAR Frontier 1: To advance modeling and analysis focused on informing climate change adaptation and mitigation.

- The **Integrated Assessment Modeling** (IAM) project is focused on developing and applying integrated socio-economic and biophysical models of the climate system to investigate how changes in human systems are coupled with the Earth's climate system.
- The **NCAR Vulnerability, Impacts, and Adaptation** (NVIA) project is focused on interdisciplinary basic research that integrates climate, weather, social, ecological and heath sciences to investigate the effects of climate change and extreme events on human populations at local, regional and global scales.

One ISP project is focused on the NCAR Imperative to **Develop and transfer scientific applications, technology, and information products that address societal needs**.

- The **Weather Communication and Warning** (WCW) project is conducting research intended to improve understanding of how people react to weather information and enhance communication of weather, climate, and hydrological forecast information to the public and decision makers.

Two of the ISP projects are focused on elements of NCAR's imperatives, "prediction and attribution" and "model development":

- **Climate Change and Marine Ecosystems** is focused on modeling, understanding and projecting the impacts of climate change on marine ecosystems.
- Carbon Cycle Observations and Modeling is focused on comparison of carbon cycle observations to simulation results from **Community Earth System Model** (CESM) and other biogeochemical modeling systems.

In its first three years of operations, ISP has provided full or partial support to seventeen different postdoctoral researchers and fellows. In some cases, postdocs are being shared with other institutions, including the areas of climate and health (in collaboration with RAL, ASP, and the Centers for Disease Control), climate and terrestrial ecosystems (in collaboration with the National Ecological Observatory Network), and climate and marine ecosystems (in collaboration with Rutgers University). In other cases, ISP is collaborating with the NCAR Advanced Study Program to support interdisciplinary postdoctoral fellows who have proposed research projects on topics of interest to ISP.

All ISP activities are defined and undertaken in cooperation with other NCAR organizations and collaborators in the university community and other research institutions.

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2012 Annual Report

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Program Activities

In FY12, ISP conducted 3 ongoing research projects, each of which was initiated in FY10.

- The **Integrated Assessment Modeling** (IAM) project is focused on developing and applying integrated socio-economic and biophysical models of the climate system.

- The **NCAR Vulnerability, Impacts, and Adaptation** (NVIA) project is focused on conducting interdisciplinary basic research on social, economic, and political activities related to climate at local, regional and global scales.
- The **Weather Communication and Warning** (WCW) project is focused on improving communication of weather, climate, and hydrological forecast information to the public and decision makers.

ISP initiated development of 2 new projects during FY11:

- **Climate Change and Marine Ecosystems** is focused on modeling, understanding and projecting the impacts of climate change on marine ecosystems.
- Carbon Cycle Observations and Modeling is focused on comparison of carbon cycle observations to simulation results from **Community Earth System Model** (CESM) and other biogeochemical modeling systems.

ISP also hostedthe scientific support office for **Analysis, Integration, and Modeling of the Earth System** (AIMES), which is one of the core projects of the **International Geosphere Biosphere Program** (IGBP). AIMES is focused on achieving a deeper and more quantitative understanding of the role of human perturbations to the Earth's biogeochemical cycles and their interactions with the coupled physical climate system. This activity concluded at NCAR in 2012.

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PostDoctoral Themes at ISP

The Integrated Science Program (ISP) sees the support of postdoctoral research at NCAR as an effective means of seeding new, crosscutting research themes in the institution with short-term and collaborative funding. These new activities employ enthusiastic young researchers in building research programs that will remain relevant at NCAR and collaborating institutions well into the future.

ISP is collaborating with the Advanced Studies Program (ASP), the Research Applications Laboratory (RAL), and the Centers for Disease Control (CDC) to bring postdoctoral researchers to NCAR to study issues at the intersection of climate and health. Housed at RAL, these CDC-funded researchers represent the first of what is hoped to be a series of activities oriented to understanding the critical links between climate change and human health. This program is highlighted in the **NCAR Annual Report.**

ISP is collaborating with the National Ecological Observatory Network (NEON) to house two NSF-supported postdoctoral researchers who will conduct research on the interactions of climate change with terrestrial ecosystems. Such interactions will be an important factor in determining the evolution of ecosystems and the services they provide to human societies, the rate and magnitude of climate change, and the severity of climate change impacts during the next century. The co-location of NCAR and NEON in Boulder allows these new researchers to collaborate with scientists from both institutions and develop a well-integrated approach. This program is highlighted in the FY10 **NCAR Annual Report**.

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2012 Annual Report

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High Altitude Observatory | HAO
2012 Annual Report

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HAO Annual Report 2012

Director’s Message

It is my pleasure to introduce the HAO annual report for 2012. It has been another successful year that is reflected in the high quality of the research output of HAO scientists and the service of HAO colleagues to the solar-terrestrial physics community. I am

Michael Thompson – HAO Director

pleased to be able to take this opportunity to acknowledge publicly the outstanding efforts in 2012 of HAO staff, postdocs, students, and visitors. It is my privilege to lead such a dedicated and talented group of people.

Several colleagues have been recognized during the year with prestigious awards or promotions. Last December, BC Low was presented with the UCAR Outstanding Achievement Award for Mentoring. Not only is this a very fitting recognition of BC's outstanding service to colleagues of all ages over many years, it is also the second consecutive year that an HAO staff member has won this award (the previous recipient being Art Richmond). I think this is a true testament to the dedication of my HAO colleagues to the development and support of students and early-career researchers who are the life-blood of our field.

The HAO John W. Firor Award for 2011 went to Bruce Lites and co-authors for their 2008 paper in *The Astrophysical Journal*, "The horizontal magnetic flux of the quiet-Sun internetwork as observed with the HINODE spectro-polarimeter". The HAO Walter Orr Roberts Award went to a team led by Qian Wu, principal investigator (PI), for the HiWind Balloon-Borne Observatory, which had a very successful first flight in 2011. The HAO Director's Award was presented to Ben Foster in recognition of his dedicated work making possible the community release of the TIE-GCM and his engagement with and support of the TIE-GCM user community.

In addition, two HAO colleagues, Sarah Gibson and Hanli Liu, were very deservedly promoted to Senior Scientist.

Congratulations to all the above colleagues on their success.

I would like to mention a number of other personnel developments in the Observatory and in NCAR. Keith MacGregor moved to Washington DC to take up a secondment to NASA as program officer for astrophysics theory. Joanne Graham moved from the NCAR Earth Systems Laboratory (NESL) to take up the position of HAO Administrator. And internal to the Observatory, Scott Sewell became manager of our Instrumentation Group and Joan Burkepile, who remains in Boulder, became manager of the Mauna Loa Solar Observatory (MLSO). One other personnel development that will be of interest to friends of HAO is that Tom Bogdan, a long-time former colleague and HAO senior scientist, moved from the National Oceanic and Atmospheric Administration (NOAA) where he was director of the Space Weather Prediction Center to become UCAR president in succession to Rick Anthes.

HAO's Visitor Program continues to thrive and is an important element of our service to the community. As usual, the summer was busy with visitors to the Observatory. In 2012, we hosted 106 visitors, and many of these visits occurred during the summer. We are really pushing the limits of how many visitors we can accommodate during the summer months, and I would like, particularly, to encourage colleagues from the USA and overseas to visit at other times of the year when we can accommodate still more visitors!

An exciting development this year has been the inauguration of the HAO engineering undergraduate internship scheme, under Scott Sewell's leadership. We have had three enthusiastic interns working with members of our engineering group primarily on the drive system for the spar in our new test observational dome facility at the Mesa Lab in Boulder. This facility will enable us to test instrumentation locally before it is deployed to Mauna Loa or elsewhere. During the summer we were also pleased to have an excellent cadre of undergraduates on our Research Experience for Undergraduates (REU) program, which we run jointly with our colleagues at the University of Colorado. Exceptionally, this year all six of the HAO REU students were women, and we hope that many of them will go on to earn PhDs and enjoy careers in solar-terrestrial physics.

Our highest instrumentation priority is the Coronal Solar Magnetism Observatory (COSMO) that will be comprised of three instruments: a white light coronagraph ("K-Cor"), a chromospheric and prominence magnetometer ("ChroMag"), and a large coronagraph. There has been excellent progress on the COSMO concept and more specifically on all three COSMO components this year. The K-Cor is now in build phase, under the PI-ship of Joan Burkepile, and should be mounted on the Mesa Lab spar for testing this spring before being deployed and commissioned at Mauna Loa in the summer of 2013. A ChroMag prototype is also well advanced under the leadership of PI Scott McIntosh and instrument scientist Alfred de Wijn: this should take first light on the Mesa Lab spar in the first weeks of 2013. Finally, the large coronagraph design has made substantial progress during the year with funding support from the NCAR directorate and the National Science Foundation (NSF), and with engineering collaboration from international partners. This progress has been further cemented with the first Coronal Magnetism Workshop that was held in Boulder in early summer of 2012, and the formation of an international COSMO Steering Committee that held its first meeting on the occasion of the workshop. Much credit for the progress on COSMO goes to HAO assistant director for instrumentation, Steve Tomczyk, who continues to promote and progress COSMO very effectively. These efforts have been further motivated in the community by the progress of the Coronal Multi-channel Polarimeter (CoMP) whose data products are now being served daily (subject to observing conditions) on the HAO/MLSO web site. CoMP can be regarded as a "baby-COSMO", since it is a small-aperture prototype for the COSMO large coronagraph. It is noteworthy that a

number of the above developments were strongly mandated by the 2011 science review of HAO conducted by NSF. K-Cor and the ChroMag prototype will be the first instruments to use the Mesa Lab spar developed by our interns and engineers.

A number of other developments during the year are also worthy of mention. Our newly constituted HAO External Advisory Committee met in August, under the chairmanship of John Leibacher. We thank this outstanding and incredibly busy group of national and international colleagues for giving so willingly of their time and sage advice. This year also saw the launch at the Mesa Lab of a new Sun-Earth Connections exhibit, featuring the scientific activities of HAO past and present. This exhibit is now one of the highlights of public tours at the Mesa Lab. Many people have contributed to its success, but I feel justified in calling out for special mention four people who have contributed particularly to the success of the exhibit: Becca Hatheway of UCAR's education and outreach program, "Spark", and HAO's Don Kolinski, Joan Burkepile, and Mark Miesch. Thanks to all of them, and to the many other colleagues who contributed ideas and material to the final exhibit. On a personal level, since assuming the directorship of HAO I have prioritized the development of connections to the US university community. In the past year I have made visits and given colloquia to three universities with significant presence in our research field: the University of Michigan, the University of Alabama in Huntsville, and George Mason University.

Finally, a noteworthy external development at the beginning of fiscal year 2012 was the announcement by the Association of Universities for Research in Astronomy (AURA) that they had selected the University of Colorado as the future host of the National Solar Observatory (NSO). Although still to be ratified by NSF through the award of the next cooperative agreement for the management of NSO, this is a significant development for US solar physics and a huge fillip for solar-terrestrial physics research and activity in Boulder. It raises a number of questions for the future about the relationship between HAO and NSO, and how our two organizations should best serve the national and international community. We look forward positively to the co-location of our two institutes, and to seeing how this development can work in the best interests of the community we serve and of the dedicated staff of the two observatories.

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- 2012 HAO Annual Report
- Director's Message
- Table of Contents
- Executive Summary
- Scientific Discovery and Innovation
- Capabilities for Prediction in Solar Variations and Their Impacts
- Community Model Development
- Observational Facilities and Data Service

Table of Contents

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Executive Summary

As part of the National Center for Atmospheric Research (NCAR), the High Altitude Observatory (HAO) leads and supports a comprehensive research program in solar-terrestrial physics. Our research program is guided by the HAO 2011-2015 Strategic Plan, which focuses on six Imperatives. Our imperatives are 1) promote innovation and creativity within HAO and across the solar-terrestrial physics community; 2) provide capabilities for more accurate prediction and attribution of changes in solar output and impacts of such changes; 3) advance and support world-leading

numerical models of the atmosphere and Sun-Earth System and make them widely available, 4) develop and provide state-of-the-art observational facilities that meet the needs of NSF, NCAR, and the solar-terrestrial physics community; 5) develop and transfer scientific applications, technology, and information products that address societal needs; and 6) attract a diverse group of university students and early-career scientists and engineers to solar-terrestrial physics, and provide them with exciting opportunities for educational and professional development.

This report highlights the scientific activities of the Observatory during the fiscal year (FY) 2012, which covers the period from 1 October 2011 to 30 September 2012. Among the major activities are numerical modeling of solar dynamo and magnetic flux emergence that are mainly responsible for long-term solar variability; observational and theoretical studies of mass and energy transport, both at the smallest granular convective scale in photospheric process and at the large super-granular scale in chromospheric spicules or jets and coronal mass ejections; investigations of dynamical response of the Earth's upper atmosphere, ionosphere, and magnetosphere to solar forcing from above and to lower atmospheric forcing from below, using state-of-the-art numerical models. Other highlights include major milestones in community model development, facility and data service to the community, as well as efforts in transferring scientific knowledge and technology for the benefit of society.

HAO is committed to fostering the training and education of graduate and undergraduate students. In FY2012, HAO supported 5 graduate research assistants (GRAs) to carry out their Ph.D. research projects under the supervision of HAO scientific staff. In addition, HAO staff also mentored six undergraduate students under NSF's Research Experiences for Undergraduates (REUs) program, two students from UCAR's Significant Opportunities in Atmospheric Research (SOARS) program, and three undergraduates under HAO's newly established Engineering Internship. Our students are excelling in solar-terrestrial research areas. It is particularly worth mentioning that Maria Weber, a GRA from Colorado State University, continued her thesis work on modeling the dynamic rise of active region flux tubes in the turbulent solar convective envelope by embedding a thin flux tube model in a rotating spherical shell of turbulent convective flows computed separately from a global convection simulation. Her excellent work won AGU's Outstanding Student Paper Award at the 2011 fall AGU meeting. Congratulations as well to Chihoko Yamashita and Donald Schmit, our Newkirk Graduate Fellows, who successfully defended their PhD theses during the past year.

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Scientific Discovery and Innovation

HAO conducts a comprehensive program of solar-terrestrial physics, encompassing solar physics, physics of the heliosphere, study of geospace and space weather, and the physical processes of Earth's magnetosphere and upper atmosphere. The main research areas include: investigations of long-term solar variability using state-of-the-art numerical models; theoretical and observational studies of transient solar phenomena; and research into terrestrial upper atmosphere's response to variable solar output and its coupling to the lower atmosphere.

Long-term Solar Variability

The long-term variability of the Sun's magnetic field takes place over the course of weeks, months, years, decades, and even centuries. Such changes have profound consequences for the Earth's space environment and the upper atmosphere, and, to a lesser extent, for its climate system. The origins and impacts of these changes have deep relevance to related variability in stars and stellar systems. During the period covered by this report, HAO scientists have used a combination of observations, theory, and numerical models to probe outstanding questions on magnetic dynamos, convection and shear, magnetic flux emergence and sunspots, the evolution of the Sun's corona and the heliosphere, and solar cycle variations. Each of these can be studied as a distinct subject by itself; however, investigations of the coupled Sun-Earth system as a whole offer new insight into how these processes are interrelated.

An example of how a single topic may be viewed through a multidisciplinary prism can be found in the recent (2008-2010) solar minimum. This minimum extended longer and was quieter than any previous minima in more than 50 years, and it challenged theoretical and numerical models ranging from the solar dynamo and solar wind to the Earth's space environment and upper atmosphere. HAO scientists have been involved in research into this minimum spanning all of these regimes. One study showed that strong heliospheric periodicities during the recent solar minimum were unusual on timescales of the geomagnetic record (~150 years). This is ascribed to a combination of low activity and warped heliospheric magnetic structures, a longitudinal asymmetry that is likely rooted in the solar interior. Such asymmetries may arise from persistent, long-lived convective cells in the lower convection zone, from the coupled action of rotational shear and turbulent intermittency that lead to the buoyant rise of magnetic flux loops at localized longitudes, or, alternatively, from the nonlinear evolution of a quasi-3D hydrodynamic (HD) instability at the bottom of the solar convection zone. In another study, an explanation was found for unexpectedly weak poleward-directed solar interior flows. As shown in Figure 1, simulations from a dynamo model demonstrated that the weakness of the current solar cycle as indicated by a broad range of solar and helioseismic observations would affect the mean solar rotation rate most significantly at high latitudes, temporarily masking the helioseismic signals in these regions. Observed properties of sunspots, such as spot size, contrast, and group area are affected by processes in the solar interior and at the solar surface. These properties are being scrutinized for evidence of changes in the current cycle relative to prior cycle behavior. Since the historical sunspot record is often used to constrain models of total solar irradiance (TSI) used in global climate simulations, it is vital that this record is well calibrated and understood. Another avenue for calibrating TSI models is to study the behavior of a collection of Sun-like stars over extended time periods in order to gauge the expected range of variability for the Sun.

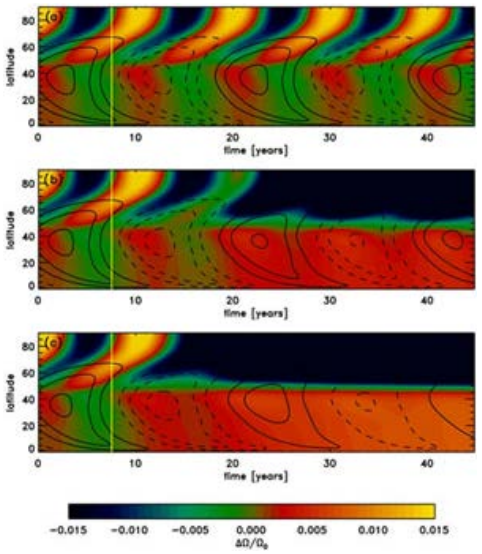

Figure 1. *Simulated high-latitude torsional oscillation pattern (color shades) together with the toroidal magnetic field (contours) near the base of the convection zone as proxy for a magnetic butterfly diagram. The torsional oscillation amplitude is clipped off at 1.5% of the core rotation rate, corresponding to an amplitude of about 6.5 nHz. The peak toroidal magnetic field strength is about 14 kG, the contours indicate the 30%, 60%, and 90% levels, with solid and dashed line styles separating the polarity. From top to bottom the panels show three dynamo solutions that differ in the value of the α-effect after t = 7.5 years. Panel (a) presents the reference solution with a constant α-effect of 0.15 m s–1 throughout the simulation run. In panels (b) and (c) the α-effect was reduced to 75% and 50% after t = 7.5 years, respectively. In panels (b) and (c) the high latitude branch of torsional oscillations becomes hidden since the mean rotation rate drops in high latitudes.*

The Sun's activity cycle is driven by its magnetic dynamo, which is powered by the complex interplay of flows in the solar interior including differential rotation, convection, flux emergence, and meridional circulation. The meridional flow acts as a conveyer belt whose non-local nature links the near-surface shear layer (NSSL) and the Polar Regions to the rest of the convection zone. This is evident from photospheric observations and local helioseismic inversions, which indicate poleward flow in the NSSL that reverses sign at high latitudes and a tight link between the maintenance of zonal and meridional flows by convection. Hydrodynamic modeling demonstrated that the Sun's typical state consists of a two-cell circulation profile with a high-latitude reversal, which occasionally turns into a single-celled state. This has important implications for the operation of the solar dynamo and the length of the activity cycle. Other work suggests that there may be two meridional circulation cells at low latitudes but centered at different radii as indicated by some recent helioseismic inversions, which could have a profound impact on dynamo theory. Variations of the meridional flow with time are a key factor in solar cycle variability. Flux-transport dynamo models found that the

response time to such flow variations is about six months, and is independent of the model's magnetic diffusivity.

The origin of global-scale mean flows such as meridional circulation and differential rotation lies in the dynamics of convection, and thus mean flow properties inferred from helioseismology can provide fundamental constraints on the convection that drives them. Such constraints are consistent with convection models but do not rely on them, providing an independent probe of subsurface dynamics with important implications for mean-field dynamo models. The interactions between convection and magnetic flux emergence are of fundamental importance to understanding how dynamos can generate cyclic behavior. One recent approach to address the problem was to introduce the standard Babcock-Leighton flux emergence source term into global convection simulations, resulting in cyclic magnetic fields and global flows reminiscent of solar observations. Another approach explicitly considered the interaction of rising magnetic flux through the convection zone by assuming thin flux tubes, eliminating artificial diffusion present in numerical simulations. It was found that the best match with solar surface observations is for flux tubes possessing more than 40 kG initial field strength. Another complementary approach is to seek fully self-consistent couplings between convection, flux emergence, mean flows and thermal gradients by utilizing sophisticated numerical modeling techniquesto conduct 3D global simulations of the rise of buoyant toroidal flux structures. Such simulations are often applied to other stars since abundant observational data on differential rotation and convection as obtained via astroseismology provide key model validation, and, in the process, elucidate the underlying fundamental physics to all stars.

Transient Solar Phenomena

During the period covered by this report, HAO scientists studied transient solar phenomena using both observations and numerical modeling. The processes under study ranged from the smallest spatial scales of the outer solar atmosphere to the largest energetic events in the solar system, namely, coronal mass ejections (CMEs). While CMEs are violent, episodic manifestations of magnetic energy release that drive space weather near the Earth, the small-scale magnetic, thermal, and radiative phenomena in the photosphere and chromosphere are responsible for the mass and energy transport processes throughout the Sun and into the solar system via solar irradiance and solar wind.

The relentless stirring and heating/cooling processes of the plasma trapped in the smallest “granular” convective scales of the photosphere likely generate and sustain the vertical and horizontal fields as observed. Photospheric magnetic field and its evolution provide the observational basis for our efforts to study the mass and energy transport to the outer solar atmosphere. Observations from Hinode spectro-polarimeter (SP) provide a means to characterize the distributions of the magnetic field at the smallest observable scales that is currently available. These observations reveal the presence of a locally, self-sustaining feedback or dynamo process, offering supporting evidence to the predictions by numerical simulations.

Episodic energy release on the supergranular scale, which is the fundamental length scale of the quiet solar atmosphere, is observed in the form of slender fast jets or “spicules” that appear to contain a mixture of both hot and cold materials. These ubiquitous jets supply hot material to the corona and solar wind and, as such, provide a large portion of the mass input to the corona and heliosphere. Naturally, the material injected into the corona does not stay there indefinitely as new observations have shown the formation of a rapidly-heated upflow associated with spicules, together with a much slower, almost persistent, downflow of material in the same or closely neighboring structures. These observations reveal that the counter-streaming materials are readily visible at temperatures below about 1 million K, indicating that the downward moving material is the signature of the cool return flow from the corona back to the surface. The timescales of heating and cooling in the “mass-cycle” of the solar atmosphere are crucial in establishing the photon flux in emission lines that affect the chemistry in the Earth’s atmosphere.

The spicules take place in the regions of strong magnetic flux concentrations, and they likely play a part in mass supply to the active region of the corona. Indeed, in times of rapid energy release, such as during flares and CMEs, the plasma at the chromospheric-coronal interface dynamically responds to topological changes of the enclosing magnetic field. Figure 2 displays the observations by the Solar Dynamo Observatory (SDO) spacecraft in the left panel and by Hinode in the right side panel. Rapid plasma upflows from the chromosphere were seen to be induced following the release of a CME and lasted for several hours before the corona relaxed to its pre-eruption state. These observations suggest that our knowledge of the thermodynamic state of the coronal plasma following a CME is far from complete. Observations of this kind also put forth strong scientific requirements on the next generation of instrumentation such as ChroMag.

While there is a long way for numerical models to fully capture the complete physical picture of transient phenomena, these models are now reaching an incredible degree of sophistication. One

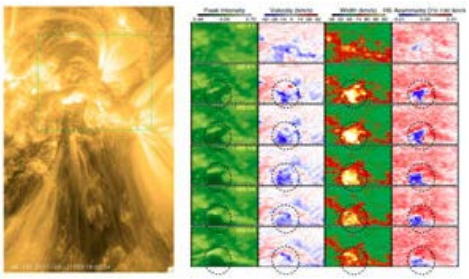

Figure 2. *Induced high-speed flows from an active region following a CME. The left panel shows a CME in progress as observed by the Atmospheric Imaging Assembly (AIA) 171Å channel of SDO while the right set of panels show spectroscopic measurements from the Extreme-ultraviolet Imaging Spectrograph (EIS) on the Hinode spacecraft which was sampling the region in the green rectangle every 20 minutes. The columns on the right side show the line brightness, line-of-sight (Doppler) velocity, the broadening of the line profiles, and the degree of line*

profile asymmetry measured between 70 and 130km/s. The color of the Doppler velocity and asymmetry indicate the direction of the material flow – blue is pointed at the observer, red is away. The region enclosed by the dashed circle shows the CME induced high-speed outflow that lasted for at least one hour following the release of the CME.

such example is the magneto-hydrodynamic (MHD) simulations with improved thermodynamics that incorporates heating produced by the current sheet formation and thermal conduction along the magnetic field lines. The simulations showed that, during the quasi-static rise phase of the coronal magnetic flux rope, a current sheet develops underlying the flux rope, and reconnections in the current sheet produce a central hot, low-density channel containing the reconnected and twisted field lines on top of the current sheet. This is consistent with the observed feature of an elevated central cavity enclosed by a U-shaped dense shell on top of the dense prominence sheet often seen in coronal prominence cavities just prior to their eruption. The simulations help interpret such features as the result of "tether cutting" reconnections which reduce the anchoring of the flux rope and build up the twisted flux of the flux rope until it erupts due to the onset of the torus instability.

Atmosphere-Ionosphere-Magnetosphere Dynamics

The mesosphere, thermosphere, ionosphere, and magnetosphere encompass the uppermost layers of the Earth's atmosphere. The solar influences on these layers are profound. The absorption of solar EUV and X-ray fluxes can affect the thermal, ionization, and compositional states of the upper atmosphere, while the appropriate magnetic and plasma conditions in the solar wind can produce episodes of geomagnetic storm activity that can alter the structure and dynamics of the entire region. These layers are also coupled to the lower atmosphere through the generation and propagation of atmospheric waves and tides. The primary goals of our research are to understand the processes that affect the dynamical, electrodynamical, thermodynamical, and chemical conditions in the Earth's upper atmosphere, ionosphere, and magnetosphere, and to understand the couplings of these regions to both the lower atmosphere and the interplanetary medium, and their response to the Sun's variable radiative, particulate and magnetic outputs. To achieve these goals, HAO has developed a series of hierarchical numerical models for the coupled upper atmosphere-ionosphere-magnetosphere system, including the Thermosphere-Ionosphere Electrodynamics General Circulation Model (TIEGCM), the Thermosphere-Ionosphere-Mesosphere Electrodynamics General Circulation Model (TIMEGCM), the Coupled Magnetosphere-Ionosphere-Thermosphere (CMIT) model, the Whole Atmosphere Community Climate Model (WACCM), and its upward extension or WACCM-X.

The sudden increase of X-ray and extreme ultra-violet irradiance during solar flares increases the density of the ionosphere through enhanced photoionization. The TIEGCM is suitably designed to investigate the detailed effects of flares on the upper atmosphere and ionosphere. Using numerical simulations from TIEGCM, HAO scientists have shown how enhanced solar heating alters the thermosphere through enhanced ionization during flares. It was found that sudden injection of localized heating, together with preexisting traveling atmospheric disturbances (TADs) excited by moderate geomagnetic activity prior to the flare can cause TADs to intensify and to transport energy and momentum to the equatorial region. Geomagnetic storms are often triggered by solar disturbances such as CMEs. One such event took place on 9 November 2004 when a fast-moving interplanetary CME plunged to the Earth, exerting a strong interplanetary electric field on the magnetosphere and ionosphere. A comprehensive modeling investigation based on the TIMEGCM was carried out to investigate ionospheric and thermospheric variations associated with the prompt penetration of electric field from high latitudes to the equator. The study showed that the TIMEGCM is able to successfully reproduce the large vertical ion drift of about 120 m/s as observed by the Jicamarca incoherent radar in Peru, and to reveal dramatic changes in ionospheric density that occurred during the storm.

Numerical experiments were also conducted to elucidate the mechanisms of solar wind and IMF forcing. Changes in the thermosphere-ionosphere system caused by high-speed streams in the solar wind, and the co-rotating interaction regions they engender, were studied using a combination of CMIT and TIEGCM simulations and data analysis. It was found that the interplanetary magnetic field (IMF) is more important than solar wind speed and density *per se* in controlling magnetosphere-ionosphere coupling. The CMIT model was used to evaluate how changes in the orientation of the geomagnetic field with respect to the Sun-Earth line, as the Earth rotates and revolves around the Sun, affect the coupling of the solar wind with the magnetosphere and ionosphere. Furthermore, the possible effects of geomagnetic-field changes over periods of millennia on solar wind/magnetosphere/ionosphere/thermosphere coupling were examined, by altering the strength or orientation of the geomagnetic dipole in CMIT. These changes affect ionospheric conductivity and the attack angle of the solar wind with respect to the Earth's dipole, and therefore affect magnetosphere-ionosphere coupling and ionospheric dynamo effects, and they also change the manner in which winds redistribute ions, leading to complex ionospheric variations.

Extensive analyses of COSMIC data for 2007-2010 have revealed a number of features concerning seasonal and solar-cycle variations. Low-latitude N_mF_2 was dominated by the semi-annual anomaly, the equatorial anomaly and the annual asymmetry. The second equinoctial maximum is not centered on the September equinox, but occurred in October. There is an annual variation at high latitudes in which maximum values of N_mF_2 occur in summer, in

contrast to analyses of earlier periods that showed a winter anomaly. Elevated height of the peak density, h_mF_2, also occurs in summer at high latitudes, with a distinct seasonal and hemispheric asymmetry. An important scientific advance was the first observation of high-latitude thermospheric winds during the day obtained with a balloon-borne Fabry-Perot Interferometer named HiWind. Figure 3 shows the comparison of the HiWind data with the neutral winds predicted by the TIMEGCM. It was found that some of the wind characteristics predicted by the TIMEGCM at high latitudes were observed, but that the model did not predict the persistent equatorward winds that were observed.

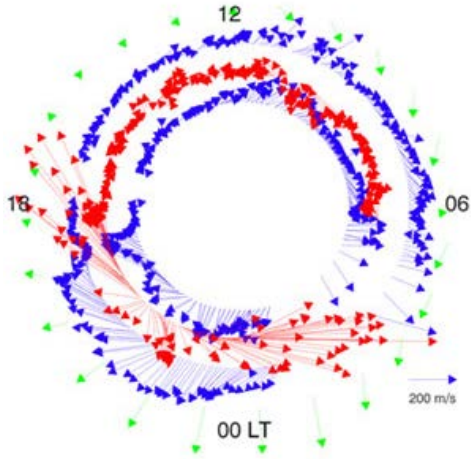

Figure 3. *Neutral winds observed by HiWind (blue) in both the poleward and equatorward look directions, together with ion velocities observed by EISCAT (red) and neutral winds predicted by the TIMEGCM (green), as a function of local time (LT).*

HAO scientists made a number of major advances in understanding the sources and consequences of variability in atmospheric tides and planetary waves. Analysis of a 20-year climate simulation using WACCM-X showed that the migrating diurnal and semidiurnal tides (DW1 and SW2) and the non-migrating diurnal eastward propagating wave 3 component (DE3) in the mesosphere and lower thermosphere (MLT) are modulated by the quasi-biennial oscillation (QBO), and that the migrating tides vary with winter stratospheric temperature anomalies. The short-term variability of these tidal components has time scales of several days, much shorter than the typical time scales of stratospheric planetary wave variability (10-20 days). The magnitude of the day-to-day tidal variability is significant and is persistent throughout the year. In a separate study using WACCM, an analysis of the momentum budget of the DW1 found that momentum advection makes a dominant contribution to the phase change of DW1 in the zonal wind compared with the effects of gravity-wave forcing. Other studies showed how tides are modulated by the two-day wave, generating two-day variations in ionospheric electric fields and electron densities, and how tidal amplitudes in the upper atmosphere are affected by the El Nino Southern Oscillation (ENSO). A TIEGCM simulation of geomagnetic perturbations led to the important finding that the hemispheric asymmetry of the SW2 in the ionospheric dynamo region of 90-140 km in altitude changes strongly during stratospheric sudden warming (SSW) events, which is a clear indication of the influence of atmospheric forcing on ionospheric dynamics. Simulations with the TIMEGCM also showed how large-scale secondary waves can be generated, which have strong influences on the ionosphere. Investigations of gravity waves associated with tropical deep convection found that these waves can propagate into the thermosphere and deposit large amounts of momentum locally as they break.

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Capabilities for Prediction in Solar Variations and Their Impacts

Another HAO Imperative seeks to enhance capabilities for the study and more accurate prediction and attribution of changes in solar output and their impacts on the Earth, from short-term space weather to long-term solar-cycle modulation. To this end, HAO scientists collect critical measurements of solar disturbances and develop appropriate diagnostic and inversion tools, and work toward creating a comprehensive model of interactive processes throughout the Earth's upper atmosphere.

Community Model Development
Observational Facilities and Data Service
Research to Application
HAO Visitor Program
HAO 2012 Profiles In Science

HAO scientists are heavily involved in the spectro-polarimetric diagnostics of the solar atmosphere, from the photosphere, through the chromosphere, and into the corona. This work is fundamental for the investigation of solar magnetism, and its effects on the space environment, including the Earth's magnetosphere, both in the short- and long-time scales. These objectives of our research require a concerted effort that bridges many disciplines. HAO scientists participate in spectro-polarimetric investigations in the U.S. and around the world, both ground-based and space-borne (e.g., Spectro-Polarimeter for Infrared and Optical Region (SPINOR), Prominence Magnetometer (ProMag), and Hinode Spectro-Polarimeter (SP)). Acquisition of new spectro-polarimetric data from a variety of solar structures and their interpretation in terms of fundamental physical processes occurring on the Sun are in fact a necessary step towards understanding the causes of solar variability.

The Coronal Multi-channel Polarimeter (CoMP) is a coronal spectro-polarimeter installed at the Mauna Loa Solar Observatory (MLSO) in Hawaii. CoMP is a prototype for the Coronal Solar Magnetism Observatory (COSMO) large coronagraph to observe the magnetic and thermodynamic state of the corona. CoMP has the unique ability to measure the properties of ubiquitous magnetic or Alfvénic waves in the corona. It is capable of imaging the coronal magnetic fields in a cadence of a few seconds, making it a valuable tool to monitor CMEs. In the past year a considerable effort has been taken to make the CoMP data accessible to the community. The CoMP data pipeline is now completed, and provides routine daily observations to the community. Data are ported nightly to HAO where the level-0 (raw data) to level-2 (polarization, intensity, Doppler velocity, line width) data products are being developed and archived by the Community Spectro-Polarimetric Analysis Center (CSAC). The associated level-2 images and image sequences (movies) are available online through the MLSO web page where users can also access the complete level-1 and level-2 FITS images for any day(s) of interest to them. In addition to maintaining the Hinode/SP data analysis pipeline that serves the wide community users, the CSAC team has begun to push forward with Frontier 1 in the HAO Strategic Plan, that is, to investigate the onset and development of magnetic flux transport through the chromosphere and the impact of its short-term variability on the Sun-Earth system. This effort focuses on the use of pattern recognition techniques to investigate fundamental questions concerning the analysis and inversion of spectropolarimetric data with regard to the complex spectral lines formed in the upper photosphere and chromosphere where multi-component line profiles and large line-of-sight gradients have significant impact on the line formation. The new inversion technique will be implemented on data obtained by the NASA Marshall Space Flight Center Solar Ultraviolet Magnetic Imager (SUMI) rocket payload, and by the NASA Interface Region Imaging Spectrograph (IRIS) small explorer mission (scheduled for launch in early 2013), and by the ProMag instrument which is currently under development.

In working toward a more comprehensive model of interactive processes throughout the Earth's upper atmosphere, a significant effort was undertaken to develop additional capability for the TIEGCM to specify the electro-dynamical coupling of the ionosphere with the magnetosphere by using observations of geomagnetic-field-aligned currents from the Active Magnetosphere and Planetary Electrodynamics Response Experiment (AMPERE), a multi-satellite project. This was shown to drive ionospheric currents in the TIEGCM that produce magnetic perturbations at the ground comparable to observations in the auroral regions for specific events. Furthermore, a new parameterization of soft-electron precipitation in the CMIT model was shown to give CMIT the capability to reproduce observed enhancements in thermospheric mass density observed by the CHAMP spacecraft at 400 km altitudes in the cusp and pre-midnight auroral region, caused by increases in Joule heating. Assimilation of the FORMOSAT-3/COSMIC electron density profiles into the TIEGCM using the NCAR Data Assimilation Research Testbed (DART) was also completed. This is a major step forward because data assimilation is critical to accurate specification and forecast of ionosphere and thermosphere densities that affect space communications and satellite drag.

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  - Integrated Science Program
  - Budget & Planning Office
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  - Staff Directory
  - Scientific Visitors
- Locations/Directions
  - Maps, Directions, Help
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High Altitude Observatory | HAO
2012 Annual Report

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Community Model Development

HAO leads and develops large-scale numerical models that support community research in the upper atmospheric, ionospheric, and magnetospheric physics. Community models include the NCAR TIEGCM, the CMIT model, and the upward extension of the WACCM-X. The CMIT development is a joint effort with the Center for Integrated Space Weather Modeling (CISM), led by Boston University; WACCM is part of the Community Earth System Model, and is a joint effort among three divisions at NCAR (i.e., the Atmospheric Chemistry Division (ACD), Climate and Global

Community Model Development
Observational Facilities and Data Service
Research to Application
HAO Visitor Program
HAO 2012 Profiles In Science

Dynamics (CGD) Division, and HAO). The TIMEGCM is widely used by the upper atmospheric community. In particular, university researchers and students collaborate with HAO staff to use it for basic research, because the model incorporates comprehensive aeronomical, dynamical, and electrodynamical processes that are appropriate for the mesosphere-thermosphere-ionosphere regions.

The TIEGCM version 1.94.2 was released in January, 2012, and updates to the TGCM website and download page are completed. Development of the CMIT model has concentrated on improving the auroral parameterization utilized to couple the magnetosphere to the ionosphere and on coupling with the Rice Convection Model (RCM) of the inner magnetosphere. In collaboration with a graduate student visitor from Dartmouth College, a new version of the empirical model for auroral electron fluxes was developed and tested. This new version of precipitation model will be included in the next release of the CMIT model to the community. We also completed the major milestone by successfully coupling the RCM inner magnetosphere model to the Lyon-Fedder-Mobarry (LFM) global MHD model, and a new version of the coupled model is currently being developed which incorporates dipole tilts and asymmetric hemispheric conductance. Another major focus of the CMIT model was its utilization by NCAR staff and community members to examine the response of geospace to high-speed solar wind streams during the most recent solar minimum.

The CMIT model was updated to use the latest version of the TIEGCM as its thermosphere/ionosphere component, and the variable critical latitude method for calculating ionospheric electric potentials introduced in the TIEGCM v. 1.94 was tested using the CMIT inputs. Testing and validation of the double-resolution (2.5 degree) version of the TIEGCM was performed in preparation for its release. Furthermore, a memory accumulation bug that affected the Intel compiler was identified and fixed, enabling better performance. For the TIMEGCM, the use of stratospheric analysis fields to specify meteorological variability was advanced, initially employing WACCM/GEOS5 histories to nudge the lower boundary and the lower levels of the high-resolution TIMEGCM. Work on the parallel dynamo solver continued, including the use of the Earth System Modeling Framework (ESMF) v. 5.2.0 interpolation routines for geographic to geomagnetic, magnetic-to-grid transformation and regridding dynamo outputs. The dynamo simulation now executes in parallel, with the exception of the stencils and the partial differential equation (PDE) solver.

WACCM-X is now one of the three atmospheric modules of the NCAR Community Earth System Model (CESM), and the CESM1.0.4 that includes WACCM-X has been released for community use. A five-year controlled simulation of CESM/WACCM-X under solar maximum conditions is part of the release. A tutorial at the annual Coupling, Energetics, Dynamics of Atmospheric Regions (CEDAR) workshop was organized by HAO staff to introduce CESM/WACCM-X to the community. The vertical plasma transport module has been implemented in WACCM-X recently and is currently undergoing testing.

The efforts described above facilitate the further development of HAO's first principles physics models, making them more efficient and accurate. These developments help scientists to explore predictive capabilities in order to meet the challenge of space weather application. They also help government agencies to adopt better national strategies toward space weather prediction and mitigation.

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2012 Annual Report

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Observational Facilities and Data Service

Observational research is central to HAO's vision and mission. To fulfill this Imperative, HAO will maintain its observing facilities and seek opportunities to develop and upgrade existing observational technology and instruments. Major efforts in FY2012 include completing transition of CoMP to routine operations in its synoptic mode, constructing the K-coronagraph as a component of the COSMO project, and enhancing HAO's data service capability for the community.

Coronal Solar Magnetism Observatory (COSMOS)

Driven by society's need to understand the origins of space weather, HAO scientists, along with colleagues at the University of Hawaii and the University of Michigan, have proposed to build the COSMO instrument suite. The facility will take continuous synoptic measurements of the entire corona in order to understand solar eruptive events that drive space weather and to investigate long-term and solar-cycle phenomena. The primary instrument will consist of a 1.5-meter coronagraph with two detector systems: a narrow-band filter polarimeter and a spectro-polarimeter. Supporting instruments are a white-light coronagraph to record the evolution of the electron-scattered corona (K-corona) and a chromosphere and prominence magnetometer (ChroMag).

The COSMO project has advanced considerably during the past year. The design phase of the large coronagraph has started with support from the NSF and in partnership with an international team of engineers. The work towards a preliminary design review is undertaken in parallel with the construction of the K-Coronagraph and the ChroMag prototype. These first two components of the COSMO suite are expected to be built in early 2013. A community-wide workshop on coronal magnetism was held at NCAR in May, 2012, and was attended by more than 100 scientists from the community. The conference papers will be featured in a special edition of the *Solar Physics* journal. It is worth pointing out that, in the recently published Solar and Space Physics Decadal Survey report by the National Research Council (NRC), COSMO has been recommended as one of the high-priority and cost-effective ground-based projects for the NSF.

K-Coronagraph (K-Cor)

The first element of COSMO to be realized, the new K-Coronagraph is being built with the support of NSF special funding. It will be used for synoptic observation of CMEs and the large-scale structure of the corona. K-Cor passed its critical design review in summer 2012 and is now being under construction. The newly completed Mesa Lab spar will be used to test the instrument in Boulder in the Winter or early Spring of 2013 K-Cor is scheduled to be deployed to the Mauna Loa Solar Observatory in Summer 2013, where it will replace the old Mk4 white-light coronagraph.

Chromospheric Magnetograph (ChroMag)

Another element of COSMO, ChroMag is an imaging spectro-polarimeter with a six-stage tunable Lyot filter at its core. The filter/polarizer is capable of observing many chromospheric spectral lines in the 500-1100nm wavelength range across the whole solar disk, with almost uniform and very high polarimetric sensitivity. The prototype ChroMag filter is currently under construction at HAO, and will be deployed to the refurbished Mesa Lab spar in late 2012. The ChroMag instrument is specifically designed to study the dynamic evolution of the Sun's chromosphere as well as the onset of the large-scale solar eruptions that episodically impact the near-Earth environment. As such, it is a vital component of HAO's Program Frontier 1, which aims to investigate the onset and development of magnetic flux transport through the chromosphere, and the impact of its short-term variability on the Sun-Earth system. ChroMag will complement existing (and near-future) space-based assets while filling a critical observational gap of the solar outer atmospheric system. ChroMag is thus of broad strategic importance, providing vital data to the community as well as an invaluable opportunity to train the next generation of instrumentation researchers at HAO.

Community Data Service

The Community Spectro-Polarimetric Analysis Center (CSAC) is an HAO imperative activity that provides the worldwide community with resources for analyzing the Stokes polarimetry measurements of remote sensing magnetic fields in the lower solar atmosphere. The tools provided by CSAC allow users not only to perform data reduction and calibration in order to extract the magnetic field vector and associated thermodynamic properties from the observed data, but also to display and manipulate the derived vector magnetic fields. Over the past year CSAC has focused on maintaining the Hinode/SP data archive, distributing the reduced data and "inverted" vector magnetograms through its own web interface and through several community/mission archives. CSAC has published the IDL interactive data analysis tool to the community, which permits the user to explore the information-rich SP datasets. CSAC has produced documentation on the Hinode/SP instrument and on the data reduction package of its Hinode/SP effort, and it is now in the process of documenting the inversion algorithm named the Milne-Eddington gRid Linear Inversion Network (MERLIN). The code is designed to invert the SP measurements into the vector magnetic field.

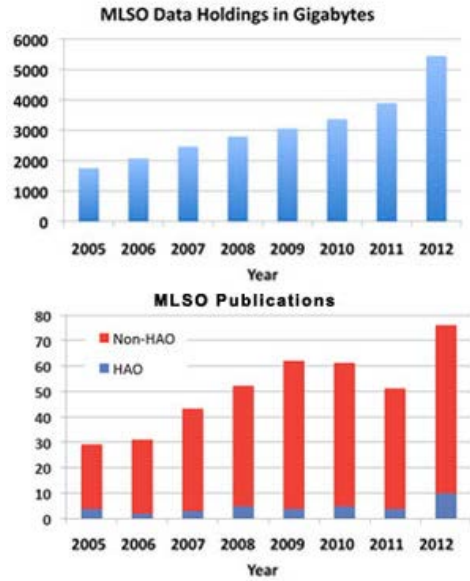

Figure 4. *(top) MLSO data holdings in gigabytes. (bottom) MLSO publications led by scientists at HAO (blue) and in other organizations (red).*

The Mauna Loa Solar Observatory (MLSO) is a facility of the National Center for Atmospheric Research

(NCAR) funded by the National Science Foundation (NSF) and operated by HAO. MLSO currently houses five instruments that observe the solar photosphere, chromosphere and low corona: (1) the CoMP instrument; (2) the Mk4 K-Coronameter; (3) the Chromospheric Helium-I Imaging Photometer (CHIP); (4) the Precision Solar Photometric Telescope (PSPT); and (5) the Coronado Ha imager. All MLSO observations dating back to 1980 are available online via the **MLSO web site**. The MLSO database serves the broad solar community both nationally and internationally. As of October, 2012, there are a total of 530 registered users, 40% of whom are from universities. Figure 4 shows the MLSO data holdings and publications led by HAO staff and scientists in other organizations, respectively.

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High Altitude Observatory | HAO
2012 Annual Report

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Research to Application

HAO's mission includes fostering and transferring knowledge and technology from its origins in fundamental research for the benefit of society. In partnership with NASA's Community Coordinated Modeling Center (CCMC), the Space Weather Prediction Center (SWPC) at NOAA, and CISM, HAO will continue to develop, test, and transfer our numerical models for space weather applications.

Community Model Development
Observational Facilities and Data Service
Research to Application
HAO Visitor Program
HAO 2012 Profiles In Science

The first version of the CMIT model was transferred to the CCMC in 2011. During the last year HAO supplied the CCMC with an updated version of the model that incorporates a number of new features and operational enhancements. HAO staff has been actively working with CCMC staff to ensure operation of the model as they are transitioned to a new computational platform. So far, the models have been used to conduct 92 simulations that are available for download by the entire space physics community from the CCMC website. In addition, CMIT and its subcomponents are now available for routine usage at the CCMC via its run-on-request system. As part of the CCMC validation efforts, we have continued to participate in their metric challenges conducted in coordination with NSF's GEM and CEDAR programs. Furthermore, we continue to be actively engaged in the Space Weather Prediction Center (SWPC) sponsored competition to select a geospace model for transition into operations. HAO also began a collaborative partnership with SWPC to identify the most pressing questions for how we can transfer our expertise in space-weather related research to application.

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High Altitude Observatory | HAO
2012 Annual Report

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HAO Visitor Program

HAO is committed to a vibrant visitor program, allocating sizable base funds to the program despite the very tight FY12 budget. HAO supported 14 postdocs and 5 graduate research assistants (GRAs) to carry out their research under the supervision of

Community Model Development
Observational Facilities and Data Service
Research to Application
HAO Visitor Program
HAO 2012 Profiles In Science

HAO scientific staff during FY12. HAO staff mentored six REU students and two SOARS students during last summer, and hired three undergraduate student interns who have worked at HAO since summer 2012 under the newly established HAO Engineering Internship. HAO also hosted six affiliate scientists and 100 other visiting scientists (of which 31 were student visitors). Figure 1 shows the numbers of visitors hosted by HAO from 2008 to October 2012.

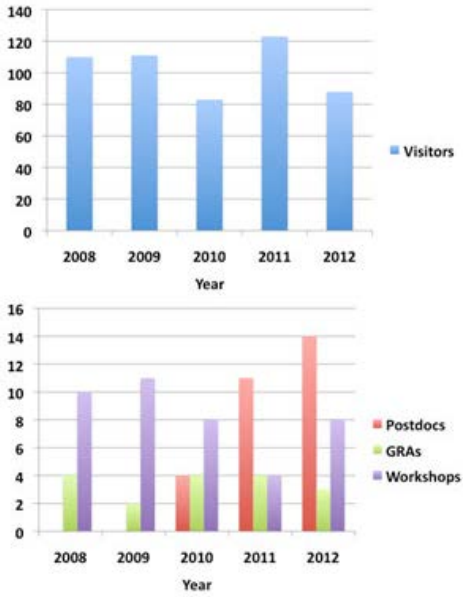

Figure 5. *HAO Visitor Program statistics from 2008 to October 2012.*

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Earth Observing Laboratory | EOL
2012 Annual Report

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Executive Summary

For over 50 years, NCAR has been charged by the National Science Foundation with providing observing facilities and associated services for the community of university atmospheric scientists. A significant portion of this charge to NCAR now rests with the Earth Observing Laboratory (EOL), which defines its mission to be:

To develop and deploy observing facilities and provide data services

needed to advance scientific understanding of the earth system.

When we wrote our Laboratory Strategic Plan in 2009 we framed our activities as a lab in the context of our mission statement, which is further encapsulated in our "Four Ds": Deployment, Development, Data Services and Discovery. This annual report describes the efforts we undertook in Fiscal Year (FY) 2012 to carry out the objectives described in our Strategic Plan.

Deployment

Deployment activities in EOL are encompassed by two separate Imperatives in our Strategic Plan: **Imperative I**, to *"Maintain the EOL facilities that are deployed using NSF "deployment pool" funds so that they are ready for reliable and safe operation in anticipated field programs;"* and **Imperative II**, *"Support observing needs of research programs at a level that serves NSF, university, and NCAR program needs."*

EOL works continuously to maintain and improve the NSF Lower Atmospheric Observing Facilities (LAOF) resources with which we are entrusted, and to ensure their safe and reliable operation for deployment. Several of these activities are described below in **Imperative I**.

EOL's deployments of the NSF LAOF in FY 2012 are described in **Imperative II**. Seven field campaigns were conducted in FY 2012, including the Dynamics of the Madden-Julian Oscillation (DYNAMO) project, a complex international project conducted in the Indian Ocean that included a six-month field deployment of our facilities. Another complicated FY 2012 campaign was Deep Convective Clouds and Chemistry (DC3), which was a multi-agency, multi-aircraft campaign carried out in the central U.S.

Development

Most of EOL's Development activities are described by **Imperative III** of our Strategic Plan: *"Anticipate future needs resulting from changing priorities, aging equipment or emerging opportunities, and develop new technology (instrumentation, software, and infrastructure) to meet those needs."* EOL's FY 2012 developments included: the design and construction of the Airborne Vertical Atmospheric Profiling System (AVAPS) Dropsonde system for the NSF/NCAR GV; the 449 MHz wind profiler system; CentNet, the multi-station, multi-sensor network; the HIAPER Cloud Radar (HCR); the Front Range Observational Network Testbed (FRONT); a water vapor Differential Absorption Lidar (WV DIAL); and the Airborne Phased Array Radar (APAR). These developments ensure that EOL is well-positioned to meet immediate and near-term community needs.

Other, longer-term EOL development efforts are contained in our Frontiers, which focus on emerging opportunities or developing needs in the atmospheric science community that EOL could address. In FY 2012 EOL addressed some of our Frontiers through continued exploratory work on the feasibility of developing an Airborne Phased-Array Radar (APAR), envisioned to replace the ELDORA airborne radar, and by fostering a new partnership with Montana State University to develop a WV DIAL instrument that can be used in the field.

Data Services

EOL is committed to data processing, quality control, and archival for field projects – all major aspects of the end-to-end services that EOL provides to the community – as expressed in **Imperative IV**: *"Provide comprehensive data services, open access, and long-term stewardship of data."* This includes efforts to update and improve the Field Catalog, development of remote operations software for several EOL systems, and advances in observing systems software. EOL is also participating in several data services endeavors, including development of DOIs for data sets, and participation in Earth Science Information Partners (ESIP) and the NSF-sponsored EarthCube.

Discovery

EOL strives to promote curiosity about Atmospheric and Earth sciences and to inspire development of the next generation of observational scientists and engineers. This is integral to **Imperative V**: *"Attract and inspire new generations of scientists, engineers and the general public to atmospheric science, conveying the excitement and intrinsic value of observational research."* In FY 2012 EOL was active in a number of Education and Outreach activities, including eight educational deployments, two major field campaigns, school and school group visits, and support for secondary school teachers. EOL also continued our undergraduate engineering internship program, now renamed the Summer Undergraduate Program for Engineering Research (SUPER). This internship program focuses EOL's outreach efforts on the engineering community in a manner analogous to what UCAR/NCAR currently does for young scientists (e.g. SOARS). EOL also undertook Phase II of our pilot Technical Internship Program (TIP II), to establish and increase interactions with two-year college and technical school faculty and students in order to spark interest in technical and support careers in the geosciences.

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Earth Observing Laboratory | EOL
2012 Annual Report

sponsored by NSF

Table of Contents

Maintain the EOL Facilities that are Deployed Using NSF "Deployment Pool" Funds so that they are Ready for Reliable and Safe Operation in Anticipated Field Programs

1. **S-Pol Radar**
2. **HIAPER Airborne Instrument Solicitation (HAIS) instrumentation**
3. **GV optical windows**

Imperative II

Support Observing Needs of Research Programs at a level that Serves NSF, University and NCAR Program Needs

1. **Instrument Development and Education in Airborne Science (IDEAS IV)**
2. **ICEBRIDGE**
3. **Dynamics of the Madden-Julian Oscillation (DYNAMO)**
4. **Tropical Ocean Troposphere Exchange of Reactive Halogen Species (TORERO)**
5. **AgI Seeding of Clouds Impact Investigation (ASCII)**
6. **Deep Convective Clouds and Chemistry (DC3)**
7. **Hurricane and Severe Storm Sentinel (HS3)**

Imperative III

Anticipate Future Needs Resulting from Changing Priorities, Aging Equipment or Emerging Opportunities to Develop New Technology

1. **HIAPER Airborne Vertical Atmospheric Profiling System (AVAPS) Dropsonde System**
2. **449 MHz wind profiler**
3. **CentNet**
4. **HIAPER Cloud Radar (HCR)**
5. **Front Range Observational Network Testbed (FRONT)**
6. **Water Vapor Differential Absorption Lidar (WV DIAL)**
7. **Airborne Phased Array Radar (APAR)**
8. **DLR Collaboration**

Imperative IV

Provide Comprehensive Data Services, Open Access, and Long-Term Stewardship of Data

1. **Field Catalog 2.0**
2. **Catalog Maps**
3. **Lidar Radar Open Software Environment (LROSE)**
4. **Data Citations and Digital Object Identifiers (DOIs)**
5. **NCAR membership in the Federation of Earth Science Information Partners (ESIP)**
6. **EarthCube**
7. **Advances in Observing System Software**

- ***Mission Coordinator (MC) Display***
- ***Software Defined Digital Down-Converter (SD3C)***
- ***Remote instrument control***
- ***High Spectral Resolution Lidar (HSRL)***
- ***Compact Atmospheric Multi-species Spectrometer (CAMS)***

Imperative V

Attract and Inspire New Generations of Scientists, Engineers and the General Public to Atmospheric Science

1. **Educational Deployments**

- ***Careers in Science (CiS)***
- ***Storm Chasing Utah Style (SCHUSS 2011)***
- ***DOW Observations of New England Storms (DOWNEWS 2012)***
- ***DOW Observations of Lake-Effects (DOLE 2012)***
- ***Doppler on Wheels Research Radar at Purdue (DROPS 2012)***
- ***University of Illinois DOW Education, Research, and Outreach Project (UIDOW 2012)***
- ***Polarimetric Radar for Examining Streamflow and Soil Erosion Studies (PRESSES 2012)***

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Earth Observing Laboratory | EOL
2012 Annual Report

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Imperative I

Maintain the EOL Facilities that are Deployed Using NSF "Deployment Pool" Funds so that they are Ready for Reliable and Safe Operation in Anticipated Field Programs

Robust performance of weather, climate, and chemistry models depend on accurate observations and measurements. EOL's central mission, and our first Imperative, is the maintenance of NSF-funded Lower Atmospheric Observational

Facilities (LAOF) for research in atmospheric science, with emphasis on systems that are beyond the capabilities of most universities or smaller groups.

The fulfillment of Imperative I drives countless day-to-day efforts to preserve and consistently improve the NSF LAOF with which we are entrusted, and to maintain their readiness for our vigorous deployment schedule (see **Imperative II**). In preparation for each field campaign, all EOL instrumentation slated to deploy undergoes exhaustive testing by our engineers and technicians to ensure optimal performance during the campaign. During the field phase it often becomes necessary to make adjustments to overcome difficult or unforeseen environmental conditions in order to meet the Principal Investigators' (PIs') scientific objectives for the experiment. Finally, when the instrumentation returns from the field, calibrations, maintenance and repairs are performed so that the facilities can be ready to perform in their next deployments.

S-Pol Radar

Deployed for the first time in 1996, the S-band Dual Polarization Doppler (S-Pol) Radar's flexible design makes it unique in that it can support different operating modes and advanced waveforms from which researchers may choose. This dual-polarimetric, 10-cm weather radar, housed in eight standard-sized sea containers, is transportable and can be deployed to remote locations around the world; previous deployment locations include Brazil, Italy, Barbuda, Taiwan, and most recently the Republic of Maldives in the Indian Ocean. S-Pol provides measurements of cloud and precipitation microphysics and dynamics, ultimately leading to improved forecasting of cloud and precipitation formation and severe weather events.

In FY 2012 S-Pol was deployed to the Republic of Maldives for the Dynamics of the Madden-Julian Oscillation (DYNAMO) field campaign. Several improvements to S-Pol were made in preparation for its deployment, including remote status monitoring software. This software allowed technicians to monitor the antenna, transmitter, data, and hardware from a remote location, and was designed to page off-site staff in the event any of the operating modes were performing outside expected parameters. The radar was also deployed with new remote operations capabilities where operators could modify the radar scanning mode.

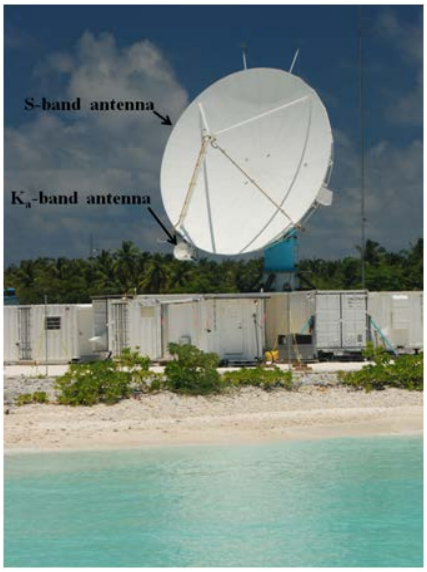

Figure 1: *The SPolKa radar set up at DYNAMO.*

A recent major upgrade was the development of a K_a-band (0.86 cm) wavelength radar for SPol, which is called SPolKa when the K_a-band is installed. The dual-wavelength radar measurements enabled by this upgrade can be used to estimate the near cloud humidity profiles in the lower troposphere (Ellis and Vivekanandan, 2010) and the total liquid water content of cloud and precipitation drops within clouds (Ellis and Vivekanandan, 2011). Estimates of these quantities are not possible with single wavelength radars but are important to many different types of studies, including addressing the DYNAMO hypotheses.

The S-Pol radar is currently being prepared for operations as part of the Front Range Observational Network Testbed (FRONT). Discussion of this activity can be found in **Frontier IV.**

NSF/NCAR GV HAIS Instrumentation

HIAPER Airborne Instrumentation Solicitation (HAIS) was a special NSF solicitation to identify key measurements and develop instruments for the HIAPER aircraft. Fourteen state-of-the-art instruments have been developed through this solicitation. These instruments are now available to, and in high demand by, the research community. They are providing key atmospheric chemistry, dynamics and microphysical measurements that are vital for many field studies, as indicated by the table below.

HAIS Instrument	Field Campaign(s) that used this instrument (2009-2012)
Advanced Whole Air Sampler (AWAS)	HIPPO I - V

Chemical Ionization Mass Spectrometer (CIMS)	DC3
Three View-Cloud Particle Imager (3VCPI)	DC3, ICE-T, IDEAS IV, PREDICT
Fast Ozone Instrument	DC3, PREDICT
HIAPER Airborne Radiation Package (HARP)	DC3, TORERO
High Spectral Resolution Lidar (HSRL)	TORERO
Microwave Temperature Profiler (MTP)	HIPPO I - V, PREDICT, TORERO
Quantum Cascade Laser Spectrometer for HIAPER (QCLS)	HIPPO I - V
Small Ice Detector, Version 2 (SID-2H)	ICE-T, IDEAS IV, PREDICT
Trace Organic Gas Analyzer (TOGA)	DC3, TORERO
Vertical Cavity Surface Emitting Laser Hydrometer (VCSEL)	DC3, HIPPO I - V, IDEAS IV, PREDICT, TORERO

Table 1: *HAIS instruments and the field campaign(s) that have used them, 2009-2012.*

Figure 2: *The CIMS instrument, developed by Georgia Tech University.*

CIMS, developed by Georgia Tech, measures sulfur dioxide, nitric acid, pernitric acid, and nitrous acid and is configurable for others species as well. The instrument is compact and certified for the GV. It was operated unattended during DC3 in summer 2012, its first deployment, and provided reliable measurements, with no known problems during the campaign.

The VCSEL instrument provides routine measurements of humidity from the surface to the stratosphere. It has a fast response, is externally mounted, and requires no internal cabin space except for a small box inside the roof of the GV. VCSEL is now included in all projects.

Figure 3: *The Vertical Cavity Surface Emitting Laser Hydrometer (VCSEL).*

An example of three other wing-mounted HAIS instruments is shown below.

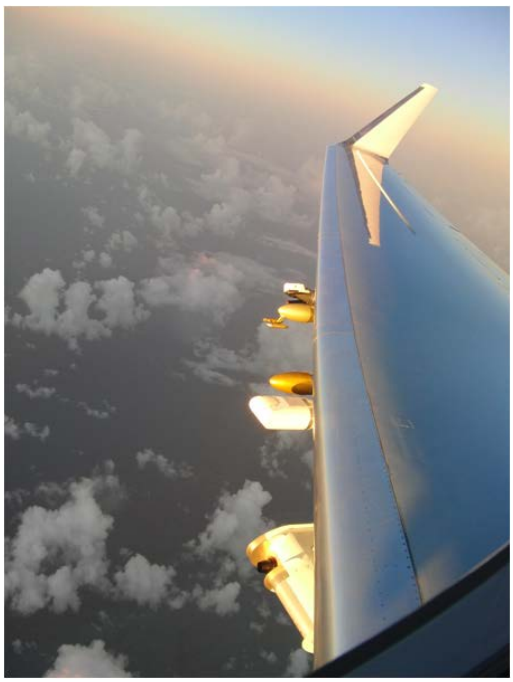

Figure 4: *SDI (top), MTP (center) and the 3V-CPI (bottom) instruments mounted on the wing of the NSF/NCAR HIAPER aircraft.*

The HSRL was deployed for the first time in the Tropical Ocean Troposphere Exchange of Reactive halogen species and Oxygenated VOC (TORERO) project in January 2012. Use of HSRL on the HIAPER required construction and certification of the optical windows. An innovative strategy, where personnel from EOL and the University of Wisconsin

worked collaboratively in preparing for and deploying the instrument, was effectively employed to meet the required deadline. Substantial software and hardware changes to HSRL were required and successfully made, and EOL personnel were both science-team members and involved in the field for the campaign.

Measurements from HSRL provided important operational information for TORERO, including location of aerosol layers and the depth of the boundary layer, which was used for adjustment of flight plans. In addition, HSRL gave quantitative information on aerosol scattering and differentiation of ice from aerosol layers from the depolarization measurements. Finally, HSRL was used to identify the top of the troposphere and sub-visual cirrus, and to measure the stratospheric aerosol layer.

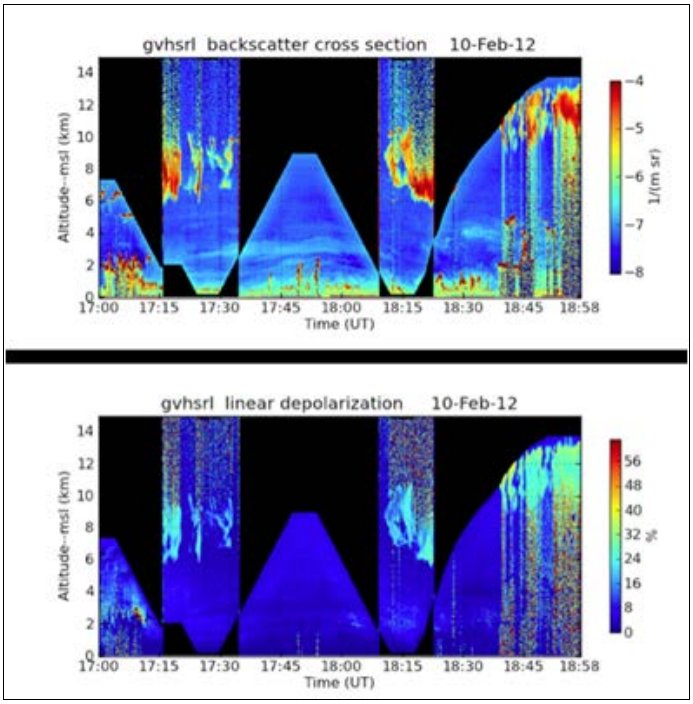

Figure 5: *During flight operations, HSRL located aerosol layers, the top of the boundary layer, and other features relevant to the measurement strategy.*

Post-project analyses are focusing on examination of the backscatter returns for identification of the top of the boundary layer; the location of aerosol layers, including those in the stratosphere; and the presence of ice clouds, including sub-visual examples, and how the depolarization signal can help identify such layers.

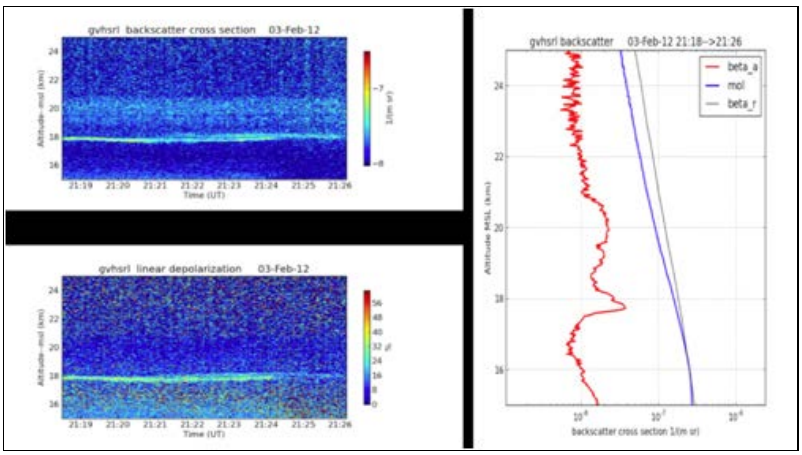

Figure 6: *HSRL backscatter measurements.*

NSF/NCAR GV Optical Windows

The use of the large optical windows for the GV during ICEBRIDGE (see **Imperative II**) and TORERO was the final utilization of the original GV/HIAPER infrastructure provisions. The optical windows enable use of the zenith and both nadir view ports and are required for complex optical remote sensing instruments, such as the HSRL and NASA's Land, Vegetation, and Ice Scanner (LVIS), used during ICEBRIDGE. The windows are optical quality fused silica manufactured to high tolerances and they provide 17"diameter clear apertures. Each window has two 1" thick panes to provide redundancy for fail-safe operation with no flight restrictions. After construction, final tasks completed in FY

2012 included pressure testing of the windows and interface structures and FAA certification of the windows for use on the aircraft.

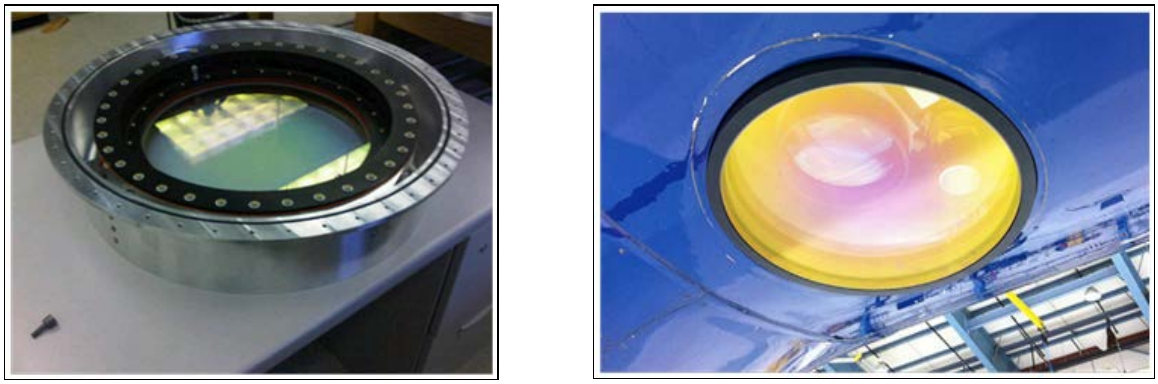

Figure 7: *The optical windows for the NSF/NCAR GV, before (left) and after (right) installation.*

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Imperative II

Support Observing Needs of Research Programs at a level that Serves NSF, University and NCAR Program Needs

Field-program planning and implementation is a critical community service, and EOL's efforts here tie to the NCAR Strategic Imperative to *"develop and provide state-of-the-art observational facilities that meet the needs of NSF, NCAR, and the atmospheric and related sciences community."* EOL employs and trains project staff, assists PIs with

project planning and preparation, operates facilities and instruments for observing programs, and preserves the quality of collected data for decades in support for research and field programs worldwide. In FY 2012, EOL supported seven research missions: Instrument Development and Education in Airborne Science (IDEAS) IV (October, 2011); NASA's ICEBRIDGE project (October-November 2011); Dynamics of the Madden-Julian Oscillation (DYNAMO) (September 2011-January 2012); Tropical Ocean Troposphere Exchange of reactive halogen species and oxygenated VOC (TORERO) (January-February 2012); AgI Seeding of Clouds Impact Investigation (ASCII) (January-February 2012); Deep Convective Clouds and Chemistry (DC3) (May-June 2012); and Hurricane and Severe Storm Sentinel (HS3) (August-September 2012).

Instrument Development and Education in Airborne Science (IDEAS) IV

IDEAS IV provided testing opportunities on the NSF/NCAR C-130 for airborne instrumentation created for geosciences research. Operated from the Rocky Mountain Metropolitan Airport (RMMA) in Broomfield, CO in October 2011, the campaign was designed to strengthen the ties between NCAR and the university instrument development community by providing test flight opportunities for new or modified instruments. The flights were also important for EOL to test and improve our airborne instrumentation, such as SID-2H, VCSEL and CPI, and provided a unique opportunity to train students in observational science.

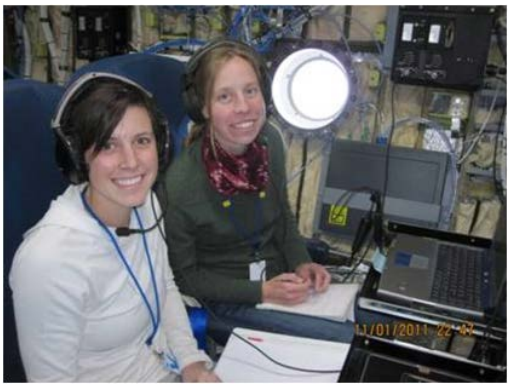


Figure 8: *Students from the University of Colorado-Boulder on the NSF/NCAR C-130 testing an inlet and isotope measuring instrumentation during IDEAS IV.*

ICEBRIDGE

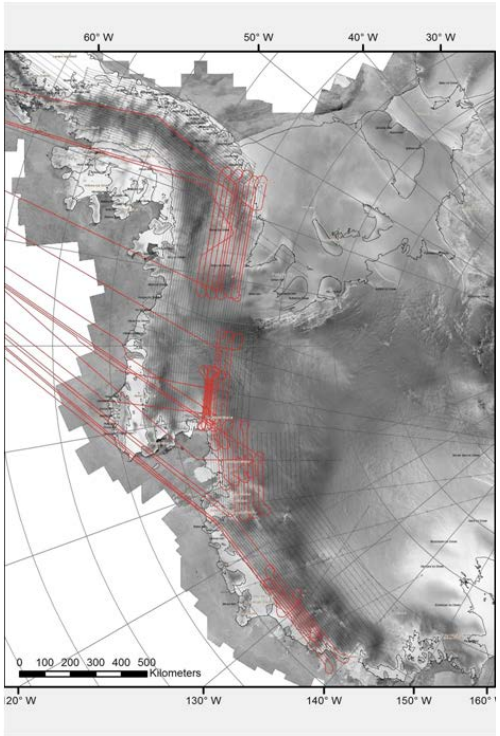
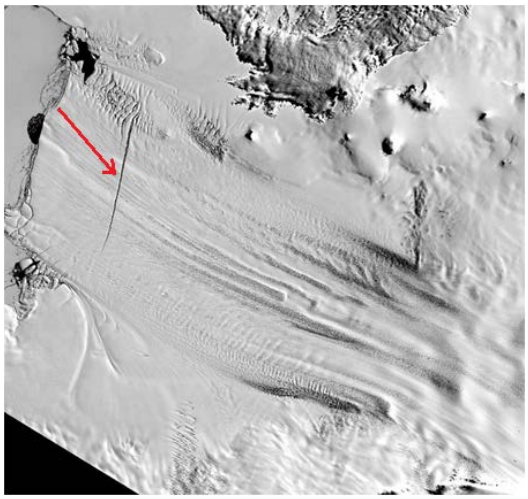
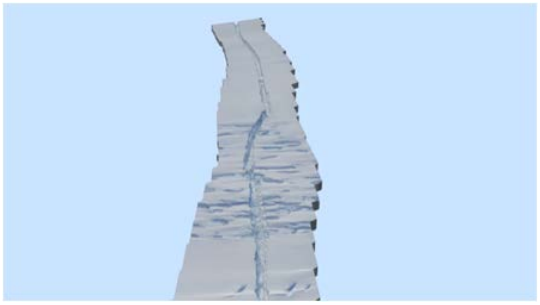


Figure 9: *Flight tracks of the NSF/NCAR GV over Pine Island Glacier for ICEBRIDGE.*

ICEBRIDGE was a NASA-funded project that included the NASA DC8 and NSF/NCAR GV (HIAPER) aircraft with laser mapping, ice-penetrating and gravity instruments to monitor and characterize Earth's cryosphere. The campaign operated out of Punta Arenas, Chile in November 2011 and the flights were over West Antarctica (see Figure 9). The main goal was to survey the thickness and depth of polar ice sheets and glacial movement in order to fill gaps between NASA's now defunct ICESat satellite (2009) and its replacement ICESat 2 (launch planned for 2016). The NSF/NCAR GV carried the NASA LVIS instrument, a scanning laser altimeter that has a 35 m footprint and a 2.5 km wide swath from 13 km flight altitude. The NSF/NCAR GV 20" optical viewport was used for LVIS. A primary target was the Pine Island Glacier, which drains about 10% of the West Antarctic Ice Sheet. Satellite measurements have shown that the Pine Island Glacier Basin has a greater net contribution of ice to the sea than any other ice drainage basin in the world and this contribution has increased due to recent acceleration of the ice stream. A major crack in the ice developed in October 2011 as shown in Figure 10, and the aircraft flights allowed detailed mapping of the physical characteristics of the crack as shown in Figure 11. The crack was 18 mi long, 180 ft across, 150 ft deep as of ICEBRIDGE operations in late 2011.





Figures 10 & 11: *A major crack in the ice, which developed in October 2011 and was observed during ICEBRIDGE (left, red arrow); Detailed mapping of the physical characteristics of the crack in the ice (right).*

Dynamics of the Madden-Julian Oscillation (DYNAMO)

The goals of the Dynamics of the Madden-Julian Oscillation (DYNAMO) experiment were to improve understanding of MJO initiation processes and expedite efforts to improve simulation and prediction of the MJO in global models. DYNAMO was designed to test the hypothesis that there are 3 essential factors for MJO initiation: (1) interaction between convection and its environmental moisture; (2) distinct roles of different types of convective clouds at each MJO stage; and (3) upper ocean processes and air-sea interaction. The scientific motivations for DYNAMO included: (1) the MJO serves as a bridge between weather (e.g., tropical cyclones) and climate (e.g., El Niño); (2) the MJO tests the fidelity of global climate models that are used to predict the future climate change, including the speed of the sea level rise; and (3) the MJO provides potential improvement of weather and short-term climate prediction.

Participating countries included Australia, France, Korea, India, Indonesia, Japan, Kenya, the Republic of Maldives, the Republic of Seychelles, Sri Lanka, Taiwan, the U.K., and the U.S. A number of U.S. agencies were involved, including NSF, the Department of Energy (DOE), the Office of Naval Research (ONR), the National Oceanic and Atmospheric Administration (NOAA), and National Aeronautics and Space Administration (NASA). Futhermore, 24 U.S. universities participated in the campaign. The deployed facilities included NSF/EOL SPolKa radar and ISS/GAUS as well as university and agency facilities, including the Texas A&M SMART-R radar, Colorado State University TOGA Radar, DOE AMF2 radar, NOAA P-3 aircraft, French Falcon aircraft, Scripps Research Institute R/V Revelle, soundings, drifters, moorings, and various other instruments.

With research-quality dual-polarization and dual-wavelength observations, S-PolKa provided important information of precipitation and clouds including hydrometeor classification, liquid water content estimates, cloud and precipitation population distribution, near cloud humidity profiles, precipitation rates and kinematic information (Doppler). Three MJO events were observed (Figure 12).

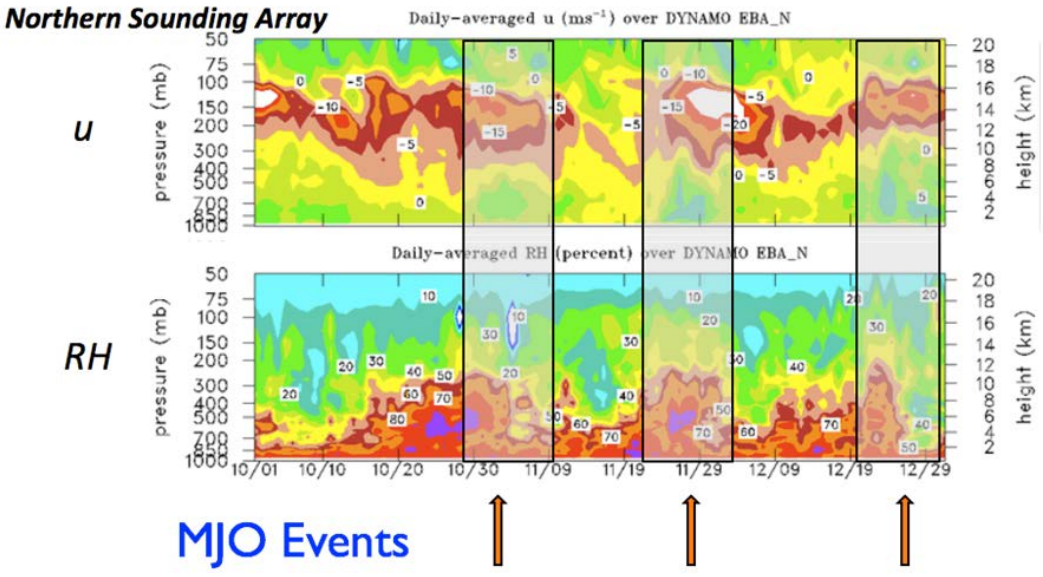


Figure 12: The Madden-Julian Oscillation is a planetary scale wave with a period of 30 to 60 days that is

characterized by large regions of organized, enhanced precipitation, increased westerly winds, and humidity at mid-levels in the atmosphere. The movement of MJOs is typically about 5 m s^{-1} to the east and they originate in the western Indian Ocean. The MJO is the dominant component of intraseasonal variation in the tropics and impacts global weather and climate. Three episodes of the MJO event observed during DYNAMO are seen in this figure.

EOL scientists used atmospheric attenuation at Ka-band for radar humidity retrievals, which are high temporal resolution and possible at different azimuth angles. These humidity retrievals fill in gaps in sonde data and monitor clouds/precipitation contribution to humidity (Figure 13). Scanning in the various quadrants allowed the radar to expand the spatial coverage of the measurement of relative humidity. The radar retrieval captured much of the variability in relative humidity (RH), which a single sonde is unable to represent.

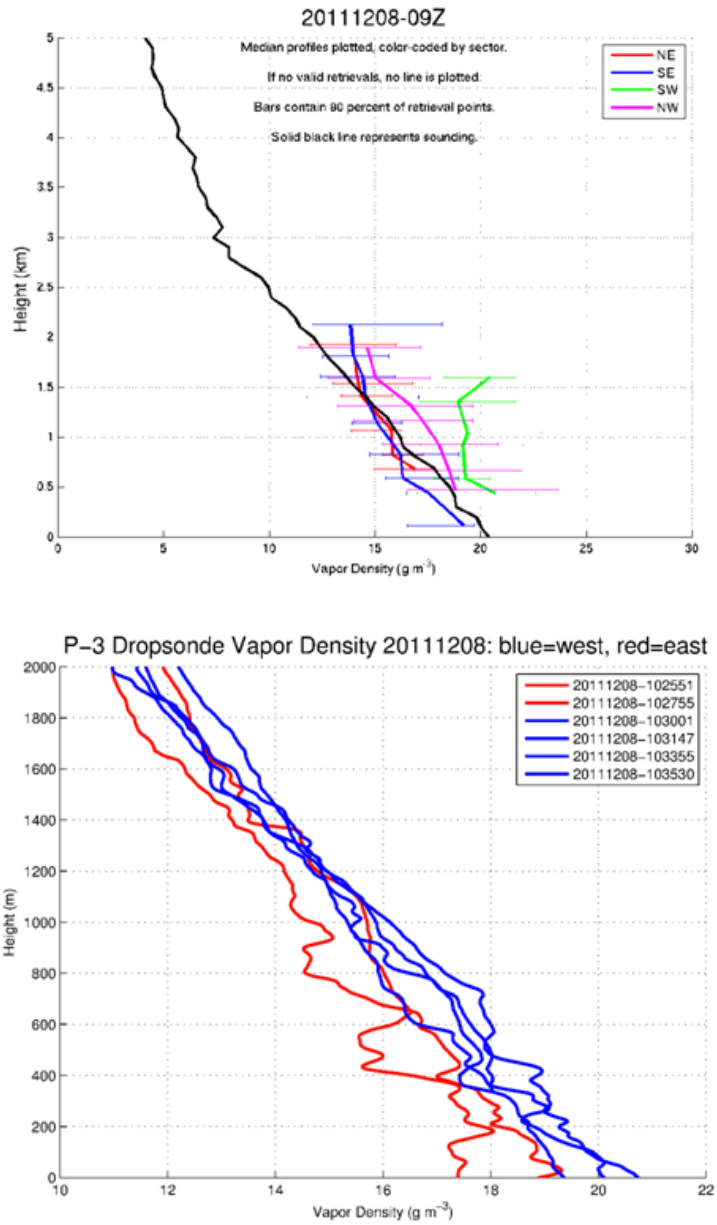


Figure 13: Real-time DYNAMO radar humidity profiles (top) compared to dropsondes (bottom). (Figures courtesy of Scott Powell, University of Washington.)

Tropical Ocean Troposphere Exchange of Reactive halogen species and Oxygenated VOC (TORERO)

The TORERO field campaign was designed to study the release, transport and fate of reactive halogen species (RHS) and oxygenated volatile organic carbon (OVOC) from marine sources and their effect on the atmospheric oxidation capacity in the Eastern Tropical Pacific Ocean. The basic hypotheses were: (1) ocean sources of OVOC and RHS impact atmospheric composition in the marine boundary layer (MBL) and in the free troposphere (FT) as a result of deep convective transport; (2) the gas fluxes across the air-sea boundary vary between the oligotrophic and mesotrophic

ocean and coastal upwelling; and (3) reactive gases released from the ocean are relevant to chemistry and climate.

TORERO was supported by NSF and NASA and had 17 participating institutions from the U.S., Germany, Japan, and the U.K. The campaign was conducted in January-February 2012 and utilized the NSF/NCAR GV and the NOAA R/V Ka'imimoana platforms.

TORERO measured, for the first time simultaneously, bromine and iodine oxide radicals and organic precursor molecules. The inorganic halogens destroy heat trapping tropospheric ozone, modify the oxidative capacity of the atmosphere, and oxidize mercury. Preliminary results showed bromine oxide increasing with altitude, indicating a vertical gradient in the breakdown of organic halogens, which is the source of the inorganic halogens.

Several HAIS instruments were included in the TORERO payload and played key roles in the experiment. During flight operations the High Spectral Resolution Lidar (HSRL) measurements were used to locate aerosol layers, the top of the boundary layer, and other features that were used to adjust flight plans. Backscatter measurements from HSRL provided quantitative information on aerosol scattering (also affecting other key measurements) and depolarization measurements allowed differentiation of ice from aerosol layers. HSRL measurements were also used to identify the top of the troposphere, sub-visual cirrus, and the stratospheric aerosol layer (cirrus cloud may bias measurements of key trace gases, including IO, from satellite).

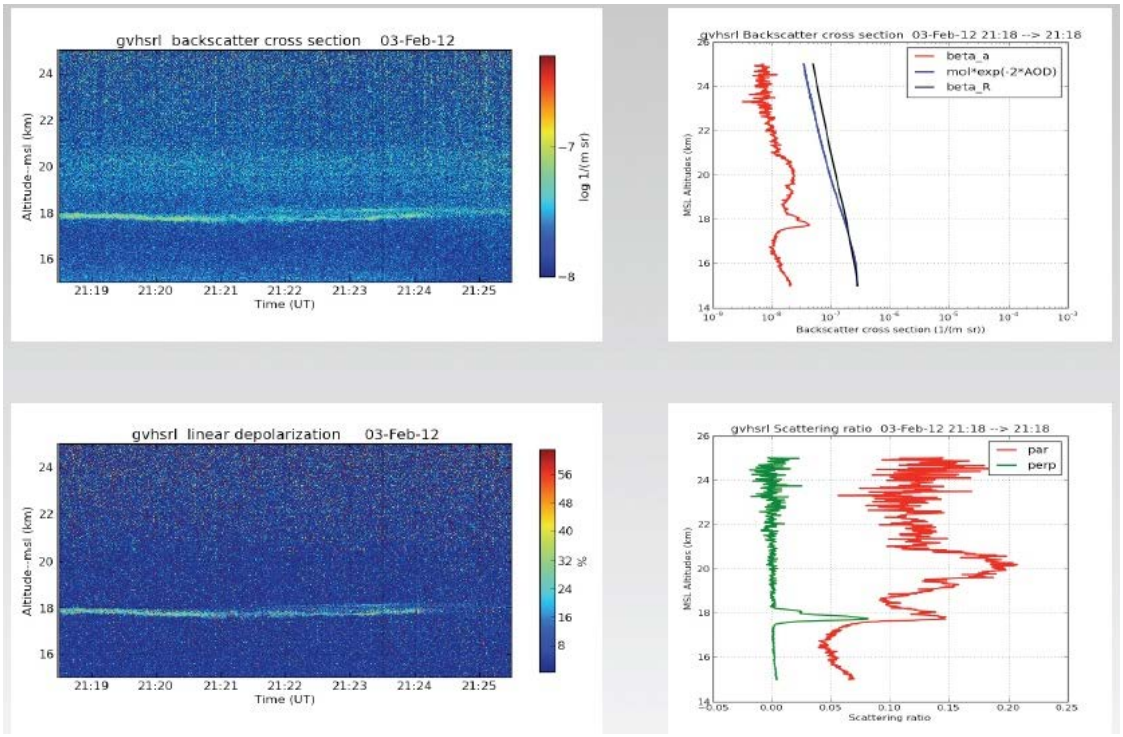


Figure 14: Observations of stratospheric aerosols and sub-visible cirrus clouds using HSRL in TORERO. Data from one approximately five minute zenith observation from a flight level above 13 km is shown above. Depolarization was used to discriminate between the non-spherical ice cyrstals of the cirrus clouds and the spherical stratospheric aerosols.

Another HAIS instrument, the Trace Organic Gas Analyzer (TOGA), was critical in understanding the chemistry of reactive halogen species by providing measurements of the organic source gases of many of these reactive species. As an in situ measurement it complemented the remotely sensed measurements from the PI-provided Airborne Multi-AXis-Differential Optical Absorption Spectroscopy (AMAX-DOAS) instrument and so supplied important support for those critical remote measurements.

A third HAIS instrument, the HIAPER Airborne Radiation Package (HARP), provided measurements of actinic flux that were central to determination of photolysis rates for trace-gases in TORERO. These photolysis rates are required to predict the oxidative capacity of the tropical troposphere, the ozone concentration, and the lifetimes of many of the measured trace gases. The spectral irradiance also helps determine the column concentrations of various species and the net effect of aerosols and clouds on the short-wavelength radiation budget.

Finally, the HAIS Microwave Temperature Profiler (MTP) instrument was used to determine vertical distributions of temperature. The measurements were also used to identify the tropopause location and provided useful information for adjusting important measurements of the sea-surface temperature. In addition, MTP provided information to help determine temperature profiles for use in HSRL analyses (where the calibration to molecular backscatter depends on temperature). This remote sensing of temperature added to available profiles in oceanic regions where routine soundings are sparse.

AgI Seeding of Clouds Impact Investigation (ASCII)

Figure 15: The Center for Severe Weather Research (CSWR) Doppler on Wheels (DOW) radar set up at ASCII.

Conducted in January-February 2012, the primary goal of the AgI Seeding of Clouds Impact Investigation (ASCII) field campaign was to investigate how ground-based glaciogenic seeding affects supercooled droplets and ice particles in orographic clouds using new instruments (especially radar and lidar) not available previously during weather modification studies. The Wyoming King Air aircraft, Wyoming cloud radar, Wyoming cloud lidar, and NSF/NCAR ISS/MGAUS NSF LAOF were deployed for this campaign.

The campaign's investigators modeled ASCII cases using high-resolution cloud- and aerosol resolving simulations in order to evaluate the model using composite radar/lidar observations, and to assess how upstream conditions influence the effect of seeding in terms of cloud properties and surface precipitation. Preliminary scientific results show snow storms over a continental divide range tend to be more stratified than those over an adjacent mountain range east of the divide. But a well-mixed turbulent Planetary Boundary Layer (PBL) layer is generally present over both ranges. This layer, draped over the rather gentle terrain, appears important in natural snow growth.

The depth of the well-mixed PBL was also important in the vertical mixing of artificial ice nuclei (AgI dust) injected into storms from the ground during ASCII, and thus the effectiveness of glaciogenic cloud seeding. This is one important criterion that operational seeding programs (which have existed for decades) ignore. Such programs have traditionally released soundings as part of their seeding decisions, the criteria for which include temperature, humidity, and wind speed near mountain ridge level. However, their soundings have lacked the vertical resolution near the ground to determine PBL depth. The finding is enabled by fine vertical resolution of MGAUS's soundings.

Figure 16: The ISF-provided met tower set up in Dixon, Wyoming for ASCII.

Deep Convective Clouds and Chemistry (DC3)

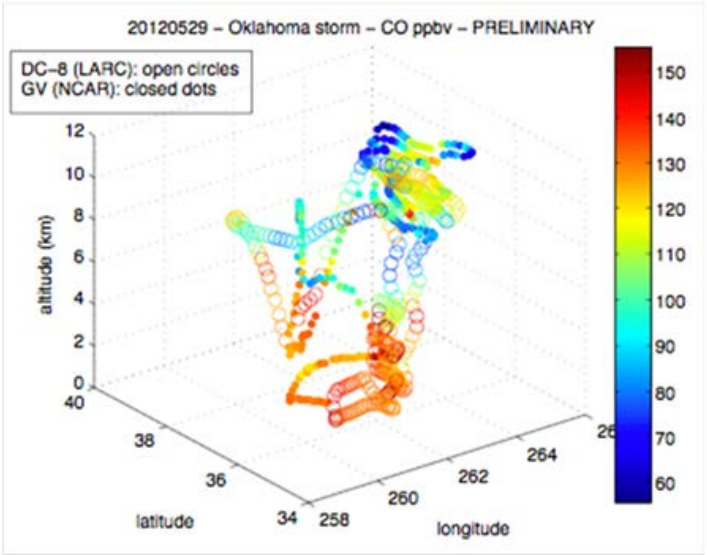
The Deep Convective Clouds and Chemistry (DC3) field campaign, operated from Salina, KS in May-June 2012, investigated the impact of mid-latitude, continental thunderstorms, including their dynamical, physical, and lightning processes, on upper tropospheric composition and chemistry. Participating U.S. agencies were NSF, NASA, NOAA, and DOE, and facilities included the NSF/NCAR GV aircraft, NSF/NCAR ISS/GAUS, NASA DC-8 aircraft, CHILL radar, CSU_PAWNEE radar, SMART-R radar, MAX radar, Lightning Mapping Arrays, Soundings, and Precipitation collection. Germany also participated with the DLR Falcon aircraft. 25 U.S. universities were involved in the campaign, which had approximately 350 total participants.

Figure 17: The three DC3 aircraft with DC3 participants in front. The NSF/NCAR GV is on the left, the NASA DC-8 is in the middle, and the DLR Falcon is on the right.

Forecasting of storms was a critical element of the campaign, so NCAR Weather Research and Forecasting model (WRF)-tracer simulations were conducted at 3 km grid resolution to forecast convection and the convective outflow plume the next day. These simulations were very successful and helpful in forecasting, as were chemical transport models and a trajectory model.

The Mission Coordinator Display, developed by EOL and available via Internet and on the GV and DC8, was initially developed as a safety aid, yet it has become critical for science direction on the ground and in the air. Displayable items for DC3 included: NEXRAD Radar, constant altitude plan position indicator (CAPPI) at Flight Level, Research Radars, Satellite (IR/vis), Lightning (North American Precision Lightning Network (NAPLN)/ Lightning Mapping Array (LMA), Camera from GV, Flight Track with Wind for the GV and DC8, Flight Plan, VHF Omnidirectional Ranges (VORs), and other navigational points. The Mission Coordinator Display was a key real-time decision making tool utilized by PIs on the ground and in the aircraft during flights.

Preliminary CO measurements (Figure 18 top) show transport from near surface to the anvil region. NO measurements (Figure 18 bottom) show high values in the anvil as a result of generation from lightning.



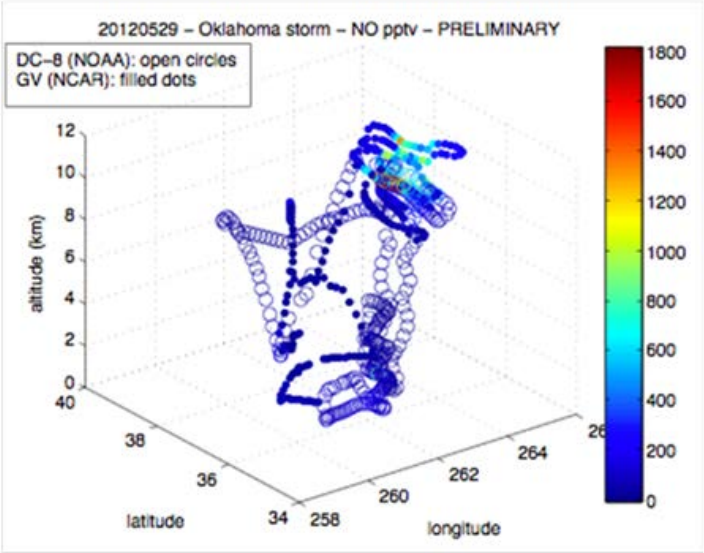


Figure 18: Three-dimensional plots of CO (top) and NO (bottom) plotted by latitude, longitude, and altitude, from DC3. (Plots courtesy of Bill Brune, Pennsylvania State University.)

Hurricane and Severe Storm Sentinel (HS3)

The Hurricane and Severe Storm Sentinel (HS3) is a five-year NASA-sponsored mission designed to investigate the processes that lead to hurricane formation and intensity change in the Atlantic Ocean basin. EOL deployed the dropsonde system on the Global Hawk (GH) during this campaign in August-September 2012 (Figure 19). HS3 included 7 flights, 5 of which were during various stages of Hurricane Nadine. EOL released 343 sondes from the GH during the campaign (Figure 20). The data was relayed through the Global Telecommunications System after QC processing and was incorporated into the National Hurricane Center forecasting. The dropsonde measurements were critical to this mission; and, while some unexpected technical difficulties were encountered, the system performed well enough to meet the primary goals of the mission.

Figure 19: The NASA Global Hawk during the HS3 campaign.

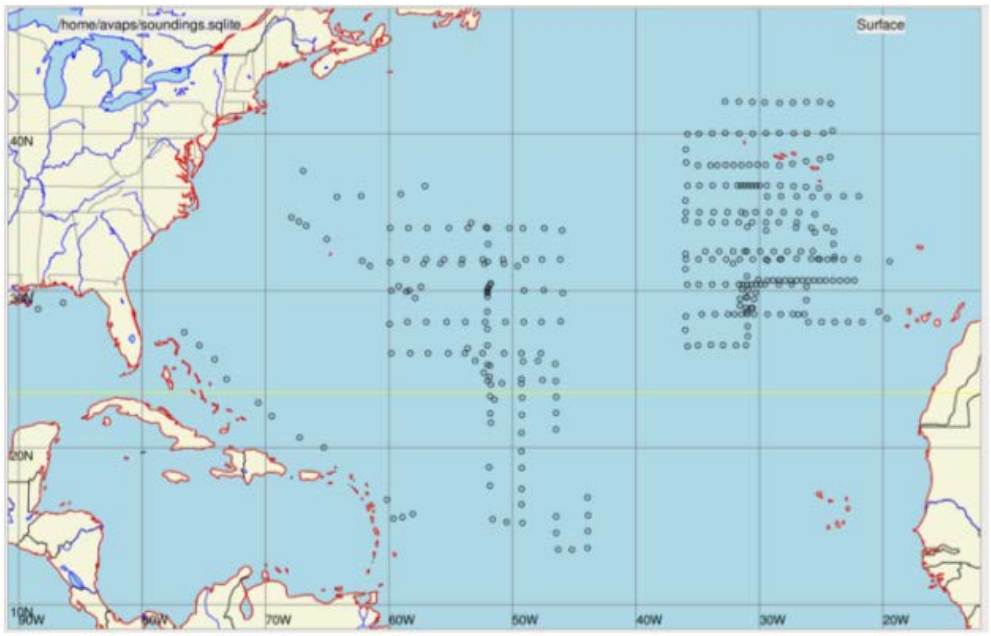


Figure 20: HS3 dropsonde flights and drop locations.

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Imperative III

Anticipate Future Needs Resulting from Changing Priorities, Aging Equipment or Emerging Opportunities to Develop New Technology

The set of facilities and instruments assembled and maintained by NCAR and EOL serve the community well; however, there is a constant, ongoing process of acquiring new capabilities and retiring and replacing those that become

outdated. Community priorities and technological opportunities call for continuing development so that the available observing systems remain matched to scientific needs and advancements. EOL must also be sensitive to changes in priorities and needs of the atmospheric science community and must adjust its capabilities as required to meet those needs. In addition to such evolutions, systems become obsolete or too costly to maintain, and it is therefore necessary to plan for their replacement or end-of-life. Thus, Imperative III calls upon EOL's scientific and engineering leadership and expertise for a healthy development effort and for the retention and training of staff who can conduct that research and development. It also requires the development of life-cycle and end-of-life plans for major facilities, instruments and software (see **Imperative IV** for more information on data services and software developments).

Development efforts in FY 2012 included continued work on the new dropsonde system for the NSF/NCAR GV, construction and testing of a prototype mid-troposphere 449 MHz profiler consisting of 7 antenna/transmit/receive modules, and work to advance the development of CentNet, an expandable network of up to 100 ground-based stations with flux-measuring capabilities. The HIAPER Cloud Radar (HCR), Front Range Observational Network Testbed (FRONT), Airborne Phased Array Radar (APAR) and Water Vapor Differential Absorption Lidar (WV DIAL) also figured prominently in EOL's development work in FY 2012. The longer-term plans for several of these developments are also discussed in our Frontiers. We have also strengthened and expanded our partnership with DLR, the German Aerospace center, in hopes of pursuing joint development of critical-need new instruments that could fly on both the DLR HALO and NSF/NCAR HIAPER aircraft.

AVAPS Dropsonde System for HIAPER (NSF/NCAR GV)

A new and improved Airborne Vertical Atmospheric Profiling System (AVAPS) remains a high priority instrument so that HIAPER can meet the scientific community's needs for high altitude dropsonde operations. The current AVAPS system, located in the baggage compartment, requires that the dropsonde be manually loaded into the launcher. As a result, the AVAPS operator is required to move between the console and the aft baggage compartment to load active dropsondes into the launcher. Safety procedures limit the number of times per hour the baggage compartment can be opened during the flight, thus limiting the number of sondes that can be dropped during flight. During turbulent conditions, all cabin personnel are required to remain seated for safety, and dropsonde operations are suspended.

The new HIAPER AVAPS system will implement remote features for safe operations above 40,000 feet, reducing the amount of time the operator needs to spend in the aft baggage compartment, and therefore significantly reducing exposure to hazardous conditions. This will also serve to increase the total sonde capacity during a single flight. The new system design is leveraged from the development of the fully automated dropsonde system for the NASA/NOAA Global Hawk (GH). The GH AVAPS system was successfully deployed in January 2011 during the Winter Storms and Pacific Atmospheric Rivers (WISPAR) campaign, and in August 2012 during the HS3 campaign. Building on this work, the system for HIAPER will be automated, will use the mini-dropsonde, and will allow 8 sondes in the air simultaneously. The increased safety of operation and doubling the number of sondes that can be in the air simultaneously are major improvements over the current system. This added capability will allow finer scale evaluation of rapidly evolving mesoscale systems.

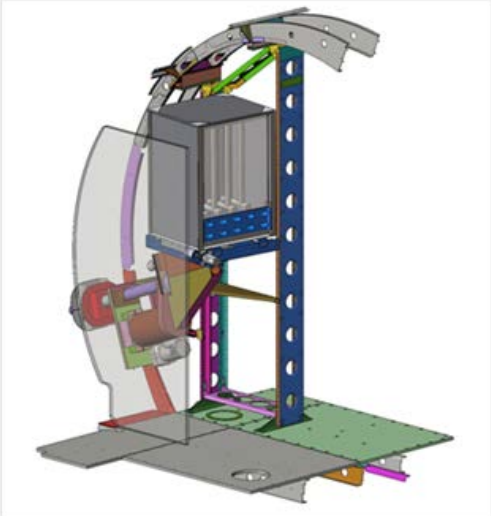

Figure 21: NSF/NCAR GV AVAPS system schematic

The development of the AVAPS for HIAPER satisfies the following EOL priorities:

(1) Support observing needs of research programs at a level that serves NSF, Universities and NCAR program needs.

(2) Improve observing capabilities for weather and climate phenomena with high socio-economic impact. Specifically develop a new dropsonde system for HIAPER and use its capabilities to support studies that bridge the gap between mesoscale weather and climate studies.

(3) Continue and complete the acquisition of the HAIS and other instruments that were developed as part of the HIAPER acquisition and plan for their operation in support of the research community.

(4) Develop capabilities that implement new technologies and lead to smaller size instrumentation.

(5) Develop remotely controlled and operated instrumentation to eliminate the need for onboard operators, allowing for additional aircraft payload and/or extended mission range.

(6) Develop capabilities that emphasize safe facility operations.

(7) Collaborate and cost share development efforts with other agencies.

EOL has several decades of experience developing dropsonde hardware and software for use on high-altitude balloon and aircraft platforms, and is therefore especially well suited for this task. In FY 2012, EOL made progress in the design and fabrication of the launcher for the HIAPER AVAPS system, which was built but has not yet been tested. Updates were also made to the mini-sonde, and progress was made on the design of the control and communication, which determine how the HIAPER AVAPS system will interface with the HIAPER data system, and how ground-to-air control will take place.

449 MHz Wind Profiler

EOL is developing 449 MHz wind profiler technology to improve measurements within and above the atmospheric boundary layer, improving height coverage and measurement frequency for wind and temperature profiles. The new 449 MHz network will eventually replace the current 915 MHz wind profilers, increase the deployable network size (number of systems), and provide more deployment flexibility for investigators.

The 449 MHz wind profiler development incorporates a modular and flexible design based upon individual panels that are combined in various configurations. Advanced signal processing techniques are an integral part of the new profiler and are critical to its combination of high sensitivity, high vertical resolution, and ground-clutter cancellation. The 2011 tests of our prototype 3-antenna wind profiler showed that its sensitivity and altitude coverage exceeded that of our collocated 915 MHz profiler. In FY 2012, EOL began construction and testing of a prototype mid-troposphere profiler consisting of 7 antenna/transmit/receive modules. The goal is to have this system tested in early FY 2013, with plans to have a more deployable (hardened) capability of one 7-antenna or two 3-antenna 449 MHz profilers available in 2013. A future goal is to expand to a 19-antenna (full troposphere) capability, also providing two 7-antenna (mid-troposphere), and six 3-antenna (boundary layer) options. Upcoming algorithm development will take full advantage of the flexibility of this modular system.

The modular wind profiler development is well aligned with broader needs identified by national workshops. The 2009 National Research Council report *Observing Weather and Climate from the Ground Up: A Nationwide Network of Networks* identifies vertical profiles of wind and temperature and boundary layer height as among high priority measurement needs. A 2003 workshop by the U.S. Weather Research Program (Dabberdt et al., BAMS 2005) includes measurement of the three-dimensional wind field in the lower troposphere among the most needed observations. The 449 MHz wind profiler advances create improved options for these national needs.

Figure 22: A 3-panel 449 MHz profler system during PCAPS

CentNet

There is now broad recognition within the geosciences that the multi-scaled features characterizing landscapes present unique challenges that hinder progress in multiple fields connected to climate, air quality, atmospheric composition, surface hydrology, and ecology. Flows over complex terrain or within the rough sublayers of vegetative or urban canopies have obvious physical inhomogeneities. Fragmentation in landscapes introduces roughness, albedo and soil moisture gradients that can in turn introduce complexity in seemingly simple situations. To make scientific progress when these features are present requires measuring and modeling spatial gradients in state variables and their concomitant fluxes at unprecedented spatial scales.

The consensus of an EOL-convened 2008 Adaptive Sensor Array workshop was that a large network of ground-based sensors would facilitate research in the biogeosciences, hydrology, and urban meteorology, in addition to the mesoscale meteorological research traditionally supported by tower networks. Measurements of turbulent fluxes and radiation were among those listed as essential by workshop attendees. The workshop participants' research interests included understanding turbulent flow over complex terrain, predicting convective initialization, characterizing the

exchange of trace gases within a vegetative canopy, understanding above and subsurface water pathways, and the effect of the planetary boundary layer on pollution transport in an urban environment. These perspectives were reiterated at a Discussion Forum in 2010, scheduled during joint American Meteorological Society Symposia on Boundary Layers and Turbulence, Agricultural and Forest Meteorology, and Urban Environment. All of these groups have endorsed the concept of a large network and provided valuable guidance on needed capabilities.

EOL plans to address this challenge by constructing a new surface network facility of up to 100 self-contained flux systems to be deployable at a broad range of spatial scales (1m to100km) in support of a wide variety of biogeophysical field studies. Called CentNet, this system at its core would allow direct research-quality measurements of all components of the surface energy and water budgets. This would be complemented by measurements of key elements of the carbon budget, including eddy-covariance measurements of the fluxes of momentum, carbon dioxide, sensible and latent heat, soil heat flux, and incoming/outgoing visible/infrared radiation.

Scalable up to 100 stations, CentNet is designed to minimize the staff time required for deployment, operation, and data handling. Radio Frequency (RF) communications will be utilized as much as possible to reduce cabling, which in turn reduces set-up time, failure modes, and weight. Each station will have two-way communication via the Internet for real-time data display and control. The data system will run EOL's NIDAS software, which time-tags and archives every sample so that users have the largest choice of data analysis methods. This system also has the ability to cycle power on any sensor, e.g. one that is not reporting. In FY 2012, EOL continued work to develop automatic cleaning systems to minimize field maintenance of sensors. We also designed new tower infrastructure to be lightweight, easily deployed, and have a minimal footprint. The development effort so far has focused on sensor evaluation and infrastructure design with the goal of completing prototype station construction by the end of 2012.

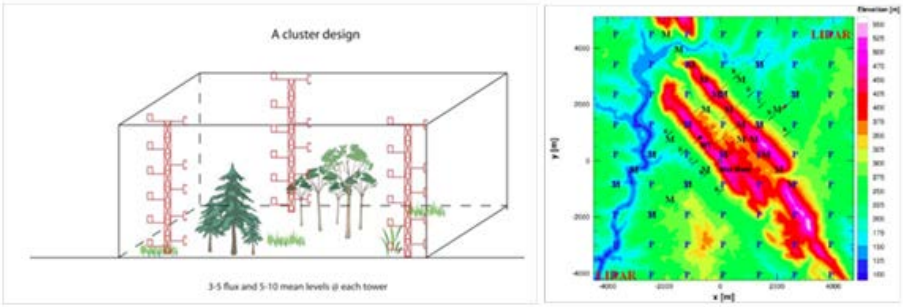

Figure 23: Two possible experiemental designs that could use CentNet. The design on the left would study CO_2 advection within a sparse forest canopy using the box budget method with several clusters of multiple-level CO_2 flux towers. The design on the right would employ an extensive array of multiple-level towers to produce a flow map over complex terrain. This map would be used as a validation data set for wind turbine siting models.

HIAPER Cloud Radar (HCR)

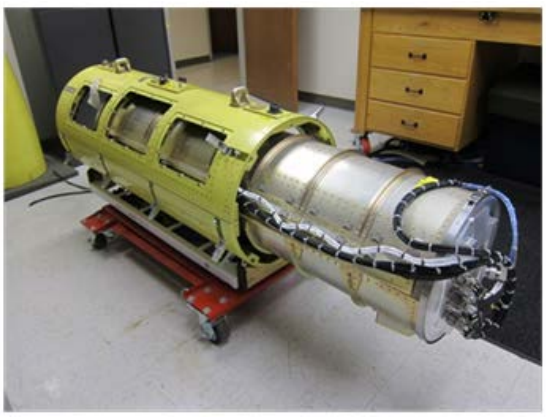

Figure 24: The HIAPER Cloud Radar in its pod configuration.

To complement the HAIS projects, EOL is developing the HIAPER Cloud Radar, which will be mounted in a wing-pod on the GV, and will provide high resolution, research-quality data not previously available to the atmospheric research community. In FY 2012 EOL transitioned the HIAPER Cloud Radar (HCR) from a ground-based instrument to an airborne configuration. As part of this process, we completed a thermal evaluation of the data system and relocated the data system inside the pressure vessel to ensure that integrity of the data system is maintained in all flight conditions. Essential airborne components such as the pressure vessel, the pod mounting hardware, the antenna reflector, the antenna controls, and an inertial navigation system (INS) have been configured and integrated on the GV. EOL also upgraded the data acquisition system to handle the HCR's high data rate, and we tested the real time B-scan and Ascope displays as well as the radar control GUI software.

The transmitter/receiver (T/R) switch network and the installation of the second receiver channel provide HCR with polarimetric capability. With the extensive electrical and mechanical efforts in transitioning the HCR to an airborne platform in FY 2012, and the front-end electronics and transmitter validation performed in FY 2011, HCR is ready and scheduled for its first electrical and mechanical integration with HIAPER in October 2012. The first test flights for HCR

will follow in February 2013.

Front Range Observational Network Testbed (FRONT)

The Front Range Observational Network Testbed (FRONT) is an observational infrastructure for the collection of comprehensive mesoscale and climate process study data sets and for the testing of new observational technologies and retrieval methods. The backbone of the network is the unique dual-polarization, multi-wavelength and Doppler remote sensing capabilities of the Colorado State University (CSU) CHILL National Radar Facility near Greeley, CO and the NCAR EOL S-PolKa Radar Facility near Firestone, CO. While these two radars provide the foundation, there is vast scientific and engineering potential in the integration and testing of other research and operational instruments within the FRONT coverage domain.

In addition to CHILL and S-PolKa, data from the CSU Pawnee radar (located near Nunn, CO) and the KFTG (Denver International Airport) and KCYS (Cheyenne, WY) WSR-88D radars will be integrated into FRONT and their measurements routinely archived. This expansive radar coverage will provide dual-Doppler wind retrievals extending from Cheyenne to south of Denver. The dual-polarimetric radar capabilities will be used to assess microphysical characteristics of storms. S-PolKa (when not deployed remotely) and CHILL at FRONT will be operated daily during the convective season and during significant weather events. FRONT will also be available through the NSF Lower Atmospheric Observing Facility (LAOF) request process, thereby expanding the utilization of the NSF facilities.

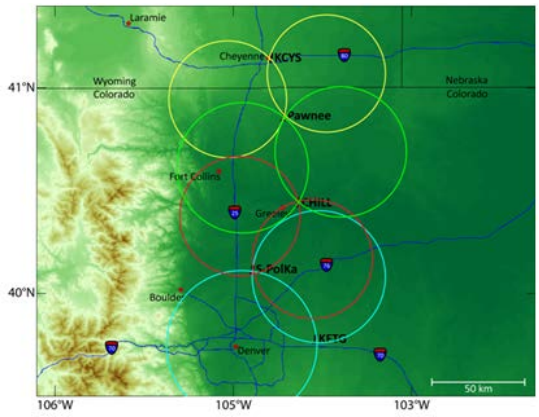

Figure 25: The FRONT domain, showing the layout of radars for FRONT overlaid on Front Range topography. Colored circles indicate dual-Doppler lobes between nearby radar pairs.

The FRONT network is ideally suited to provide Front Range observational datasets to advance the knowledge in hydrometeorology, mesoscale weather and climate process studies and to test new observational technologies and retrieval methods. The establishment of this readily-available infrastructure will provide a dual-polarization, multi-Doppler, multi-wavelength radar network for hydrometeorology and climate process studies; for developing and testing new algorithms; for testing and validating new instruments; for studying sensor integration technologies; for applied data assimilation activities; for validating numerical models; for testing advanced networking concepts; and for enhanced educational opportunities.

It is envisioned that the existing ground-based instruments maintained and operated by the two organizations, such as the Integrated Surface Flux Systems (ISFS), Integrated Sounding System (ISS), GPS ground-based receivers, High-Spectral Resolution Lidar (HSRL), HIAPER Cloud Radar (HCR) operated by EOL, and LMA (Lightning Mapping Array) operated by CSU, could be made available in conjunction with FRONT through the NSF LAOF request process. New instruments, such as the joint Montana State University-EOL Water Vapor DIAL (WV DIAL) venture, are expected to be tested and to become available for request, and could also be used in conjunction with FRONT. The combination of satellite data, Front Range observing networks of surface stations, precipitation gauges and stream flow observations, operated by various public and private entities, provide a data-rich environment for FRONT. The combination and integration of these diverse and complementary datasets will allow the NSF research and education communities, as well as the National Weather Service (NWS) and other interested parties, free and open online access to rich datasets that will address a multitude of scientific and educational objectives.

Preparations for the FRONT Firestone site continued in FY 2012 and will be completed in FY 2013. S-PolKa will be moved once the site is completed and FRONT operations will begin after setup and testing of the radar at Firestone.

Figure 26: Research radars serve as anchors for FRONT. The Colorado State University CHILL radar is on the left and the EOL S-PolKa radar is on the right.

Water Vapor Differential Absorption Lidar (WV DIAL)

Engineers from Montana State University (MTU) have developed a lab-based, low-cost, eye-safe, diode-based water vapor Differential Absorption Lidar (WV DIAL) system for remote sensing of water vapor in the atmosphere. EOL is partnering with MTU to enhance the system for operating in the field and for long periods of time that would be required for use in a field campaign. The goal of this effort is to evaluate the technology and, if appropriate, build and deploy a network of WV DIALs for the NSF community.

Work on the WV DIAL system in FY 2012 included a 6-week test period in Boulder, CO; radiosonde and microwave profiling radiometer (MWR) intercomparisons; a 3-week test period at Howard University (Beltsville, MD); radiosonde, Raman lidar and MWR intercomparisons; a 1-week demonstration at the Dallas - Fort Worth, TX National Weather Service Forecast Office; and radiosonde, infrared spectrometer (AERI) and MWR intercomparisons.

In the future, work on this system will include: lowering the minimum range from ~800 m to ~100 m; improving its daytime range to 2-3 km; stabilizing/ruggedizing the system to account for temperature variations; packaging the system into a temperature-controlled container for unattended operations; developing software for subsystem automated control; and analyzing the potential for scanning.

The figure below shows the first continuous observations from by the WV DIAL system operated at the NCAR Foothills campus. By operating it continuously, EOL is learning a great deal about tuning, aligning, operating, and analyzing data from the system. These “first look” data are preliminary but show great promise in providing continuous moisture profiles in day and night.

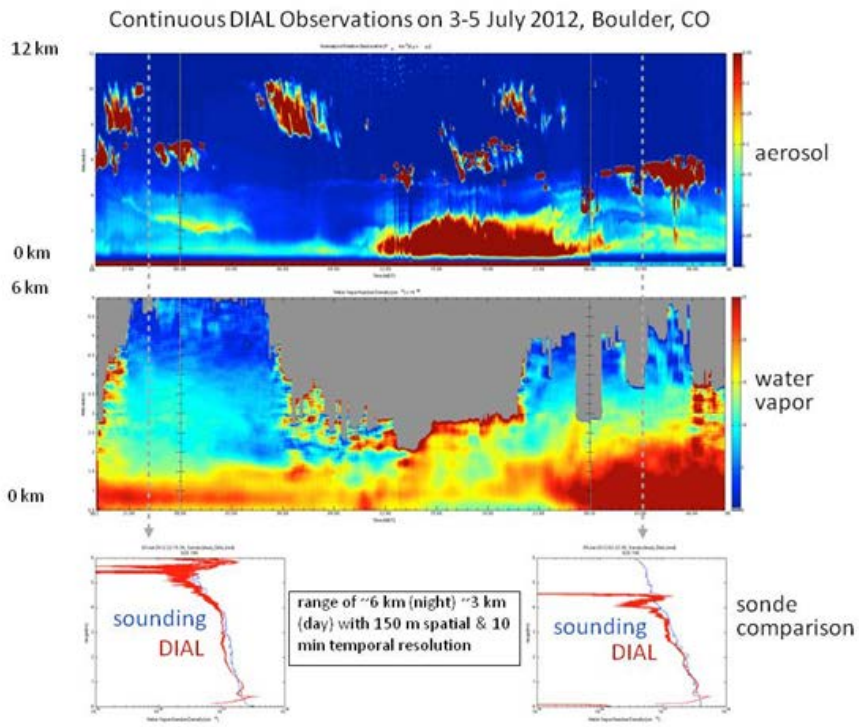

Figure 27: The first continuous observations of the WV DIAL, from NCAR's Foothills Lab.

Airborne Phased Array Radar (APAR)

EOL is in a unique position to play a leading role in airborne phased array radar technology, specifically with respect to the airborne antenna. The availability of and direct access to the C-130 combined with in-house scientific and engineering expertise create an exceptional opportunity for EOL to make significant contributions to such a next-generation radar capability.

As a result, the development of an APAR with dual-Doppler and dual-polarimetric capabilities to replace the Electra Doppler Radar (ELDORA) has

Figure 28: The NSF/NCAR C-130 with a model (styrofoam panels) of the Line Replaceable Units (rectangular elements) and the full sized aperture (the four by four matrix) for APAR.

been identified as a specific action for **Frontier I** in the current EOL Strategic Plan. At X-band, ELDORA has experienced severe attenuation in heavy rain situations, and its lack of dual polarization capability severely restricts its scientific usefulness in advancing quantitative precipitation estimates and water cycle research in those regions not covered by ground-based operational radars. APAR will address these issues. APAR design envisions it being flown on the NSF/NCAR C-130, and would consist of four distinct apertures strategically located about the fuselage. This APAR design could also be adapted to C-130s in the U.S. Air Force hurricane reconnaissance fleet. The potential to improve hurricane track and intensity forecasts by continuously assimilating APAR data from those reconnaissance missions into operational numerical models may provide even greater societal impacts for the general public beyond the benefits to be gained by the scientific research community.

Development of APAR requires substantial effort and resources. As such, EOL has taken a phased approach to APAR development and is partnering with MIT/Lincoln Laboratory and V. Chandrasekar (EOL Affiliate Scientist from Colorado State University) on this effort. In FY 2012, this partnership worked to develop a small, low cost, prototype, dual-pol phased array antenna. The antenna will serve as a building block for a larger sub-panel, designated as a Line Replaceable Unit (LRU).

The next phase would be development of an APAR LRU, as several LRUs can be combined to form a full sized aperture. This is a multi-disciplinary effort, requiring the skills of scientists, technicians, instrument makers, and mechanical, electrical, antenna, RF and software engineers. Input from the community is a critical part of APAR development and EOL is currently developing an APAR white paper to outline the full project. EOL will seek collaborative partners for the full APAR project when the full proposal is developed.

DLR Collaboration

DLR, the German Aerospace center, is Germany's national research center for aeronautics and space. Its extensive research and development work in aeronautics, space, transportation, energy, defense and security research is integrated into national and international cooperative ventures. One of the cooperative ventures is working with EOL on a variety of complementary topics associated with aircraft and airborne instrumentation. DLR operates HALO, the High Altitude and Long Range Research Aircraft, which is a Gulfstream G-550 that is similar to the HIAPER, NSF/NCAR Gulfstream V aircraft. Below are some key areas of collaboration that EOL and DLR are exploring.

NCAR's capabilities in airborne radar and DLR's in airborne lidar are complimentary, and EOL's extensive experience in instrument flight certification would also be helpful to this collaboration. The timing for developing joint projects between EOL and DLR is excellent, as EOL is in the process of planning for the next round of instrument development activities. Leveraging expertise from both EOL and DLR would reduce the time and cost associated with developing new, critical-need instruments, and would allow EOL and DLR to pursue joint development of such instruments that could fly on both HALO and HIAPER.

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Imperative IV

Provide Comprehensive Data Services, Open Access, and Long-Term Stewardship of Data

One of NSF's core expectations in the NSF - UCAR Cooperative Agreement focuses on data issues, specifically calling for NCAR to *"serve as stewards of high quality scientific data on behalf of the community through maintenance, enhancement and curation."* For EOL, this charge falls on the Computing, Data and Software Facility (CDS). CDS is

responsible for developing and maintaining EOL's computing infrastructure, data and metadata services, collaborative tools, and software engineering, all of which are integral to Imperative IV. CDS serves as the umbrella for all data management activities in EOL, and takes a proactive approach in working with PIs to meet **NSF's requirement** that, beginning in January 2011, grant proposals include comprehensive data management plans.

Field Catalog 2.0

Development work continues on the Field Catalog 2.0, a major upgrade of the software that has served the lab and the scientific research community for the last 17 years. During FY 2012, major components of the new software were developed, tested and used to support field campaigns, including Catalog Maps (described below), product ingest and synchronization, and monitoring components. These new developments supported the DYNAMO, TORRERO and DC3 field campaigns. New ingest and synchronization software allowed us to reduce the latency in field catalog products availability to less than 30 seconds from reception. It also included for the first time an ability to ingest products according to a defined priority system, ensuring that vital products needed for real-time decision-making were available without delay. For DYNAMO, the synchronization component allowed CDS to set up two-way mirroring between a local catalog set up in the Maldives and one running in Boulder, and using a user-defined set of products that were based on priorities halfway around the world. This system provided fast access with minimal delays to catalog products for users at the field site while ensuring robust collection of all project related products. Also in FY 2012, we worked to develop monitoring software with the assistance of an EOL Summer Undergraduate Program for Engineering Research (SUPER) intern. This software will allow CDS to automatically watch all field catalog product feeds and related system services, and to immediately detect problems and notify support staff. This monitoring component has been demonstrated and will be completed and implemented prior to the next supported field campaign.

Catalog Maps

The Catalog Maps tool, a component of the field catalog, was developed during 2012 to provide real-time access to geographic information system (GIS) information and overlay capabilities for the broad spectrum of project participants, particularly those using mobile devices or using cellular networks to access the internet. This tool was rapidly developed ahead of the Deep Convective Clouds and Chemistry (DC3) campaign and was first used in the field for that project. Based on OpenLayers technology and taking full advantage of Web Map Service (WMS) protocols, Catalog Maps is designed to work across all major computer operating systems and to support a large number of users efficiently. It provides access to major operational and research products from a campaign, including satellite, radar and lightning data as well as aircraft and research instrument locations, tracks and data plots. Development work continues on Catalog Maps to incorporate replay capabilities and to refine the interface for touch screen devices.

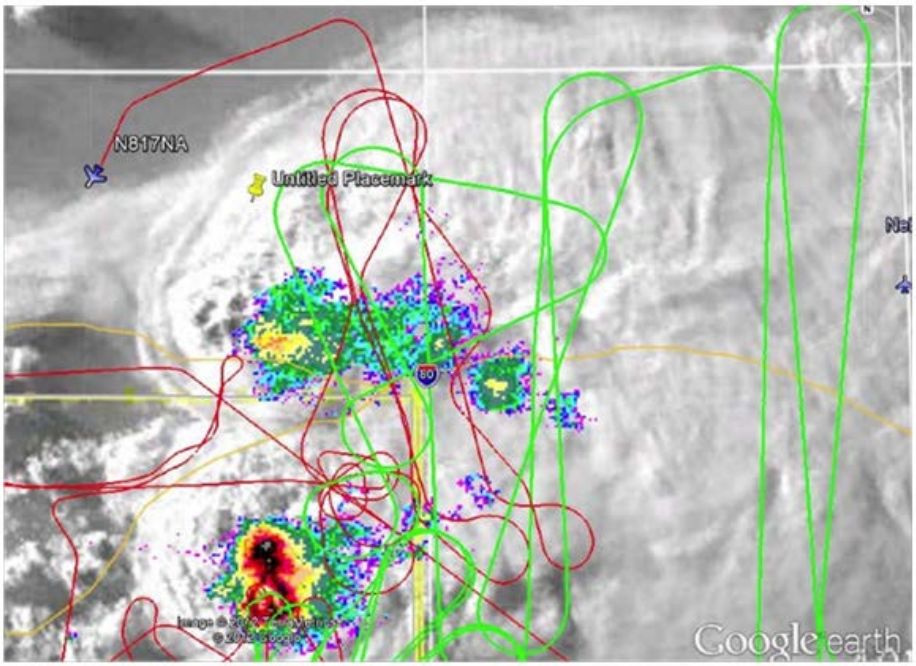

Figure 29: The Mission Coordinator (MC) display during DC3, showing radar based location of storms, satellite overlay of clouds, the GV flight track in green, and the NASA DC8 flight track in red. Items that can be displayed include NEXRAD radar, CAPPI at flight level, research radards, satellite (IR/vis), lightning, (NAPLN/LMS), camera from the GV, flight track with winds, flight plan, and VORs and other navigational points.

Lidar Radar Open Software Environment (LROSE)

Atmospheric researchers make extensive use of scanning and profiling remote sensors, including microwave radars, wind profilers, lidars and sodars. However, extracting the full value from measurements made with these sophisticated instruments depends on having good software tools, and on shared analysis among the community of users. NCAR has a long history of such software and community format development for scanning radars. Capitalizing on this history, and appropriate for a National Center, LROSE will create a core software and open-source software exchange. This exchange will be facilitated by NCAR, but software development and maintenance will occur throughout the user community. This exchange would function well beyond the scanning radar community to benefit users of wind profilers, some lidars, and possibly other remote sensors. Such a shared approach could be used for all software used by NSF's LAOF community.

Developed in FY 2012, the LROSE proposal would build on 25 years of software and standards created by NCAR and UNIDATA. This software has been a foundation for the weather radar research community, but it has become clear in recent years that NCAR cannot expand or even continue to maintain the existing suite of software in the rapidly changing technological environment. LROSE's NCAR-Community hybrid calls for NCAR to develop data formats and core software, and then enables and encourages the user community to participate by developing application modules and algorithms. These modules would extend the core software to meet developer needs for specialized data quality control, scientific analysis, display, and data integration, and ideally would be useful to others in the community. This hybrid approach is analogous to the successful approach used by the Weather Research and Forecasting model (WRF) in which NCAR designs and develops data formats and core software, while the user community develops modules written in efficient high-level languages, such as MatLab® , IDL®, NCAR Command Language (NCL), and Python.

The LROSE approach would extend beyond scanning weather radar research software to also facilitate wind profiler and other remote sensor research. For instance, converters for common commercial wind profiler formats could greatly broaden the use of non-LOAF wind profiler datasets. The LROSE hybrid model will allow flexibility in addressing, and timely response to, changing needs in today's world of quickly evolving software and instrument development.

Data Citations and Digital Object Identifiers (DOIs)

Federal agencies, professional societies, and research organizations in the geosciences are moving towards requiring researchers to formally cite data (or digital resources) that lead to a given research result. However, before digital resources can be cited, they must be designated as citable objects with unique identities. The most common type of unique identifier used within current global scholarly communication systems is Digital Object Identifiers (DOIs). DOIs provide unique identifiers/locators for web-based objects (they are now most commonly assigned to journal articles), and are an integral component of data citations. They are designed to overcome the inherent unreliability of URLs by providing persistent locators for internet-based resources.

A NCAR/UCP Data Citation Group consisting of representatives across the institution was formed in the Summer/Autumn of 2010. EOL is well represented in this Group, and in FY 2012 began working towards a policy to handle EOL datasets. NCAR has also established membership with EZID, a California Digital Library service, in order to enable NCAR/UCP groups to assign DOIs to data sets. In FY 2012, EOL began testing EZID within the EOL Metadata Database and Cyberinfrastructure (EMDAC), including enhancing our metadata database, and we are developing plans for pilot implementations. This work will continue in FY 2013.

NCAR Membership in the Federation of Earth Science Information Partners (ESIP)

Under EOL leadership, NCAR became a member of the Federation of Earth Science Information Partners in FY 2012. From the ESIP **web site**:

> "*the Federation of Earth Science Information Partners (ESIP) is an open networked community that brings together science, data and information technology practitioners... In this forum, practitioners work together on interoperability efforts across Earth and environmental science allowing self-governed and directed groups to emerge around common issues, ebbing and flowing as the need for them arises. These efforts catalyze connections across organizations, people, systems and data allowing for improved interoperability in distributed systems. By virtue of working in the larger community, ESIP members experience the network effect, which enables more coordinated cyberinfrastructure across domain-specific communities. Using this open, community-based, discipline and agency neutral approach, the ESIP Federation has a 14-year track record of success and continued growth.*"

EOL sponsored three staff members at the summer 2012 ESIP meeting, where there were productive exchanges and discussions of future collaborations related to data services and cyberinfrastructure for observing systems.

EarthCube

The goal of the NSF-sponsored **EarthCube initiative** is to transform the conduct of research by supporting the development of community-guided cyberinfrastructure to integrate data and information for knowledge management across the Geosciences. EOL staff participated in EarthCube Charrettes One and Two in FY 2012 and helped define a community framework, which includes the domain of lower atmospheric observing systems, for the initiative. EOL also submitted two vignettes, or case studies, to the EarthCube Workflow Subgroup: "NCAR/Earth Observing Laboratory Field Project Data Services Lifecycle Workflow" and "A Real-Time Operations Paradigm: Real-Time Science Mission Situational Awareness Workflow." Workflow methodologies have grown in importance as a result of the greatly expanding complexity and scale of large computing activities, which touch on data analysis and modeling, often performed throughout cloud computing infrastructure. EOL provides extensive and sizeable observational datasets and so we are commonly at the front end of a workflow. It is therefore crucial for EOL to effectively integrate with these new computing paradigms.

Advances in Observing System Software

In FY 2012, EOL continued to innovate in observing system software on many fronts, a few of which are discussed below.

- The Mission Coordinator (MC) has evolved into a "must-have" application for all NSF/NCAR research aircraft programs. The MC, which began as a SUPER intern project (see **Imperative IV**), has evolved into a highly extensible and user-friendly tool for situational awareness and mission-planning. In FY 2012, the DC3 project benefited from the MC's new and greatly extended menu of customized real-time products delivered to flight crews and ground based scientists.

- EOL was proud to share the Software Defined Digital Down-Converter (SD3C) with the Center for Severe Weather Research (CSWR) in FY 2012. SD3C was developed at EOL as a radar processor for EOL radars and wind profilers, and we are now working with CSWR to employ it as a signal processor for the Doppler on Wheels.

- Remote instrument control, especially for airborne platforms, has long been a goal for EOL. This became a reality in FY 2012 with the development of remote operations for the AVAPS dropsonde system, deployed on the NASA Global Hawk. This work is being expanded and adaptated for use with the NSF/NCAR GV aircraft (see **Imperative III**). Development of a general-purpose communication architecture began in FY 2012; this will allow PIs to remotely monitor and control their own instruments on the GV. AVAPS will be the first measurement platform to utilize this system.

- The University of Wisconsin-developed High Spectral Resolution Lidar (HSRL) was integrated on the GV for airborne observations in FY 2012. However, the software delivered with the instrument was prototypical in nature, and so in FY 2012 EOL collaborated with the U. Wisconsin developers to successfully refactor and migrate the software into a more robust and modern form.

- The first deployment of the Compact Atmospheric Multi-species Spectrometer for HIAPER (CAMS) occurred during DC3 and used software built on an Object Oriented (OO) LabVIEW framework. EOL has become a leader in exploring and developing the OO LabVIEW methodology, which brings improved software architecture and practices to the LabVIEW ecosystem.

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  - Atmospheric Chemistry Observations & Modeling Lab
  - Climate and Global Dynamics Lab
  - Computational & Information Systems Lab
  - Earth Observing Lab
  - High Altitude Observatory
  - Mesoscale & Microscale Meteorology Lab
  - Research Applications Lab
  - Director's Office
  - Advanced Study Program
  - Integrated Science Program
  - Budget & Planning Office
  - NCAR Library
- Find People
  - Staff Directory
  - Scientific Visitors
- Locations/Directions
  - Maps, Directions, Help
  - Public & School Tours
- Closures/Emergencies

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Imperative V

Attract and Inspire New Generations of Scientists, Engineers and the General Public to Atmospheric Science

The promotion of atmospheric science is crucial to inspire the development of the next generation of observational scientists and engineers, and is an institutional charge that is important EOL. With the suite of NSF LAOF that EOL manages, we are in a unique position to provide exceptional education and training to new observational atmospheric

Imperative IV
Imperative V
Frontier I
Frontier II
Frontier III
Frontier IV

scientists and engineers, and to inform and excite the public with the impact of observational research.

Students pursuing education in science, technology, engineering and mathematics (STEM) can be motivated to seek careers in observational meteorology through exposure to NSF LAOF, and EOL outreach activities. EOL can also help the public understand better the value of observational atmospheric science by demonstrating direct measurements of the atmosphere and explaining what scientists learn from these observations. Contributing in this way is part of the EOL mission, and the mechanisms EOL provides to support and inspire undergraduates and graduates, high school students, teachers, and faculty will ensure the field of atmospheric science remains vibrant well into the future.

In FY 2012 EOL participated in seven educational field deployments, including one aimed primarily at minority-serving institutions. FY 2012 also saw the 12th year of EOL's Summer Undergraduate Program for Engineering Research (SUPER) internship, and the successful completion of the first year of the pilot Technical Internship Program (TIP) for science support students.

Educational Deployments

NSF makes a subset of NSF/LAOF available for educational purposes to colleges and universities across the continental U.S. every year. This effort is managed by EOL and is designed to expose undergraduate and graduate students in science and engineering to observational meteorology, without requiring faculty to design and propose a full-scale scientific field campaign.

NSF funded eight educational projects in FY 2012, all involving the Doppler On Wheels (DOWs) radars:

1. Careers in Science (CiS) at Western Wyoming Community College; ITT Technical College; Boulder TEC; and Arapahoe Community College in November 2011
2. Storm Chasing Utah Style (SCHUSS 2011) at the University of Utah, Salt Lake City from 21 October - 21 November 2011
3. DOW Observations of New England Storms (DOWNEWS 2012) at Lyndon State College in northern New England from 30 January - 17 February 2012
4. DOW Observations of Lake-Effects (DOLE 2012) at State University of New York (SUNY) Oswego from 21 March - 8 April 2012
5. Doppler in Wheels Research Radar at Purdue (DROPS 2012) at Purdue University from 5-17 March 2012
6. University of Illinois DOW Education, Research, and Outreach Project (UIDOW 2012) at the University of Illinois at Urbana-Champaign from 8-28 April 2012
7. Polarimetric Radar for Examining Streamflow and Soil Erosion Studies (PRESSES 2012) at the University of Missouri in Columbia, Missouri from 8-29 September 2012
8. Boundary Structure Experiments with Central Minnesota Profiling (BaSE CaMP) at Saint Cloud State University from 27 September – 4 October 2012.

Figure 30: The Doppler on Wheels (DOW) radar at the University of Utah for SCHUSS 2011.

Careers in Science (CIS)

The CiS team visited 4 schools in the greater Colorado/Wyoming Front Range area in November 2011 and reached close to 300 students and faculty. CiS's goal was to expose students of accredited post-secondary minority serving institutions to career opportunities within the areas of science and science support. This meshed well with the pilot Technical Internship Program (TIP) (see below), which was created to attract and inspire young adults to technical, science-support careers, and to provide opportunities at NCAR for such students. Therefore, as part of each visit, CiS alerted students to the TIP.

The student bodies of the schools visited by CiS were ethnically, racially and socio-economically diverse, as well as well-prepared to enter the work force in a vocational or technical career. The main message of the CiS visits was that science needs more than just scientists, and the talks emphasized the critical, non-science jobs that are needed to conduct atmospheric science field campaigns. In this way, EOL removed some of the mystique from science and the students understood that they do not have to be a scientist to be involved in science.

Each CiS event began with a presentation, which included the UCAR introductory video *Air. Planet. People.* This was followed by a talk that focused on EOL, the instruments used in field campaigns, and the types of people that are needed to design, develop, and maintain them. In the remaining time, the Center for Severe Weather Research (CSWR) staff spoke more specifically about the VORTEX field project giving the students an in-depth look at

atmospheric science field research. After the presentation portion of the visit, students were given a hands-on demonstration of a CSWR-maintained Doppler on Wheels (DOW) radar. The presentation prepared the students for the upcoming demonstration, and the demonstration reinforced what was presented.

CiS's broader impacts were to foster an interest and appreciation of geosciences and weather; to increase the participants' knowledge of climate and weather science; and to broaden their awareness of careers available in meteorology and atmospheric science.

Figure 31: Chris Golubieski, EOL electro-mechanical technician, displays a table of in-situ sensing instrumentation for Boulder TEC students during a CiS visit.

Education and Outreach Support in Field Deployments

Dynamics of the Madden-Julian Oscillation (DYNAMO)

EOL took the lead in developing, coordinating, and implementing a customized education and outreach plan for DYNAMO. A working group made up of representatives from EOL (NSF), DOE/ARM, ONR and NOAA worked to build a plan that matched expectations with agency requirements. This included outreach events, printed outreach materials (including project and facility brochures and media packets), and a suite of online communication materials.

The main focus of community outreach activities was in the Republic of Maldives, where several facilities were deployed over an extended period. There were 5 school presentations made on Addu Atoll and in Male City, reaching over 215 students and 15 adults. The simplest prop – a weather balloon – got the most attention at all of the student presentations. EOL held a workshop at Addu High School in Addu City for 20 high school science teachers and conducted meetings with school principals to describe the presentations. The October 2011 DYNAMO/AMIE Opening Ceremony, which included local dignitaries and some 80 other attendees, was another outreach oportunity as attendees were educated about the campaign and its instrumentation. The EOL S-PolKa scientists offered additional outreach by training 12 Maldives Meteorological Service meteorologists in basic radar theory and interpretation. This included on-site experience working with S-PolKa in real time to learn about the local conditions on Addu Atoll from the radar perspective.

Figure 32: Alison Rockwell, EOL's Education & Outreach Coordinator, talks with a group of students after an outreach presentation in Male during DYNAMO.

Deep Convective Clouds and Chemistry (DC3)

EOL, in collaboration with NASA, developed and implemented a comprehensive Public Information Program for DC3 to satisfy the outreach requests of the Principal Investigators (PIs) and agencies. This program consisted of online informational materials; tours of the aircraft and operations center; public speaking engagements; teacher workshops; undergraduate and graduate student involvement; and printed outreach materials. National and international media were also targeted by the outreach efforts, and DC3 was featured in over 30 accredited publications.

Online efforts consisted of a DC3-specific public outreach website, posts on the EOL Facebook page, a DC3 operations Twitter feed, and a DC3 blog that had almost 1,200 views. The nature of online outreach material enabled viewers to explore the information at their own pace and to the extent with which they are comfortable. This allows for higher retention and extends learning outside of the classroom.

The community outreach events were very well attended and supported by the PIs and the entire DC3 team. The Public Open House was widely publicized in the Salina, KS community, and about 300 visitors and 5 journalists and photographers attended. Two DC3 teacher workshops brought in eight science teachers from the Salina and Wichita areas, and one of these teachers was able to be an observer on a DC-8 research flight towards the end of the project. Seven presentations were given to local civic organizations such as the Rotary and Lions' Clubs, and the PIs spoke on two radio talk shows that focused on the outreach events of DC3, as a means to promote the events.

Figure 33: Alison Rockwell (far left), EOL's Education and Outreach Coordinator, shows local science teachers the NSF/NCAR Gulfstream V during one of the DC3 teacher workshops.

The Kansas State University-hosted National Intercollegiate Flying Association SAFECON event, a national collegiate pilot safety competition, was held during the first week of DC3 operations, and attendees had great interest in seeing the research aircraft. An EOL/DC3 booth was displayed at the SAFECON week-long expo, providing information on the

project, EOL, NCAR, NASA and DLR, and a sign-up sheet for research aircraft tours. 75 people toured the DC3 aircraft during the SAFECON week.

Summer Undergraduate Program for Engineering Research (SUPER)

EOL has pioneered a variety of Education and Outreach programs, and we consider our Summer Undergraduate Program for Engineering Research one of the most successful. SUPER focuses on undergraduate students in various fields of engineering in order to complement existing programs within NCAR that primarily target students in geosciences. FY 2012 was SUPER's 12th year, and as in years past EOL received numerous resumes from undergraduate engineering students vying for these summer internships. During the 12-week internship, each student works with EOL engineers on a well-defined and manageable project that is of direct significance to EOL's activities. EOL coordinates with UCAR's Significant Opportunities in Atmospheric Research (SOARS) program, the NCAR/CISL Summer Internships in Parallel Computational Science (SiPARCS) program, and other UCAR and NCAR intern programs to provide joint social events for SUPER students and mentors. In FY 2012 48 students applied for the five available positions. The internship ran from the end of May and lasted into August.

The five students who participated in the 2012 SUPER program were:

- Kaiser Ali, a student from the University of Maryland-College Park, worked with John Militzer and Steve Semmer in EOL's In Situ Sensing Facility on a serializer. Kaisar's project involved designing and building an interface between a sonic anemometer, an analog device, and the Integrated Surface Flux Systems (ISFS) data system. The sonic anemometer sends binary serial messages at a rate of 60 messages per second. At the beginning of each record, a sample must be taken from the analog device, scaled, and an ASCII representation attached to the end of the sonic message as it is forwarded to the data system. Output will be optional between two choices: serial RS232 or a Bluetooth radio module.
- Devin Brown, a student from Metropolitan State University of Denver, CO, worked with Erik Johnson in EOL's Computing, Data and Software facility to monitor field catalogs with Nagios. Devin's project focused on developing a robust Ruby back-end for use with the Nagios IT Infrastructure Monitoring Platform. This included the creation of an automated and configurable system that checks incoming data streams for potential ingestion issues, and ultimately allows for a timely response with detailed notifications.
- Stephanie Fawaz, a student from Harvey Mudd College in Claremont, CA, worked with Tom Baltzer at EOL's Research Aviation Facility to develop software that remotely controls aircraft instrumentation. Rather than having researchers board a cramped aircraft and fly through all kinds of weather to monitor and control instruments on the plane, they can use this software to send commands and receive status updates about their instrument from the ground instead. This is done using a secure, encrypted Transmission Control Protocol (TCP) connection between a proxy client, the ground server, and User Datagram Protocol (UDP) sent from the ground server to the aircraft.
- Taylor Hall, a student from the University of Colorado at Boulder, worked with Joe VanAndel in EOL's Computing, Data and Software Facility on building a user-interface for easier lidar data access. Creating a graphic interface allows for easier access to graphs of data collected by High Spectral Resolution Lidar (HSRL) for those unfamiliar with the command-line interface.
- Andrew Nelson, a student from the Colorado School of Mines in Golden, CO, was mentored by Gordon Maclean in EOL's In Situ Sensing Facility on a project that implemented bluetooth networking on embedded systems. Andrew's project focused on wirelessly connecting Linux based data systems using Bluetooth networking. This is done over long ranges (up to 1 km) with multiple data systems connecting to one central hub. This Bluetooth network is intended to replace either a wired network or a standard Wi-Fi wireless network.

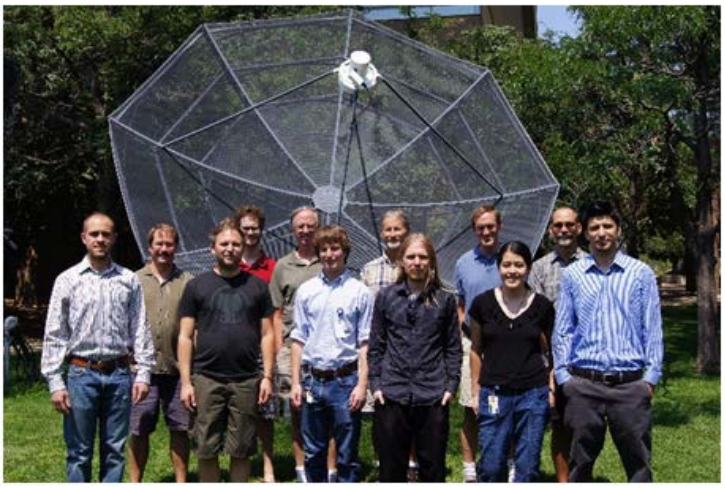

Figure 34: 2012 SUPER interns and their mentors: (L-R) Devin Brown, Tom Baltzer, Erik Johnson, Nick Potts, Gordon Maclean, Andrew Nelson, John Militzer, Taylor Hall, Joe VanAndel, Stephanie Fawaz, Chris Burghart, and Kaiser Ali.

Technical Internship Program (TIP)

EOL's pilot Technical Internship Program (TIP), funded by an NCAR diversity proposal, created internship opportunities to establish interactions with two-year college and technical school faculty and students to spark interest in technical careers in the geosciences. TIP's target audience dovetailed neatly with those underrepresented groups targeted by CiS and not covered by the existing internship programs. TIP therefore joined CiS' outreach events in the Front Range region to advertise the TIP opportunities to these two-year colleges and vocational schools. Under the motto "*science needs more than just scientists,"* these events emphasized the need for a wide range of skill sets, backgrounds and job categories in support of scientific research. The focus of the TIP during these outreach events was to attract non-science major students to explore possible career opportunities in atmospheric sciences. The primary job categories for TIP include Electronics Technician, Instrument Maker, and Computer Help Desk Staff.

In FY 2012, EOL sponsored two interns through TIP: Chris Chacon (CDS computer helpdesk intern) and Jesse Stillwell (ISF electronics technician intern). TIP created an NCAR-student mentoring relationship to ensure that these interns learned skills that will assist them in their career and academic advancement. In addition, we hope to realize downstream benefits for EOL by establishing connections with institutions that will help provide technical staffing conduits for EOL in the future.

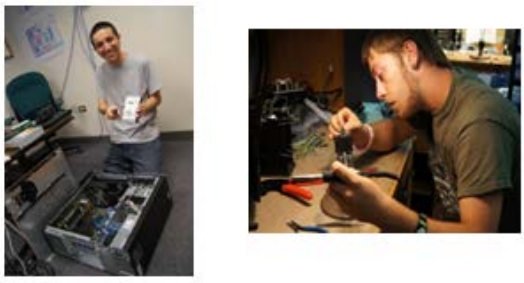

Figure 35: TIP Interns Chris Chacon (left) and Jesse Stillwell (right).

Other E&O Activities

NCAR Research Experience for Teachers Institute (RETI)

In October 2011, 12 pre-service and in-service secondary level science teachers in the Research Experience Teachers Institute (RETI) program began the program with staff from UCAR, NCAR and UNC, including several months of online climate change classes. The teachers then visited NCAR in July 2012 to learn about the many aspects of climate change and how it is researched, and they developed climate change curriculum based on their experiences and the knowledge they had gained. The RETI program is sponsored by NASA, coordinated by UCAR's science education office, Spark, and involves the efforts of UCAR, NCAR, and the University of Northern Colorado (UNC) Math and Science Teaching Institute (MAST).

While visiting NCAR in July 2012, the teachers had an opportunity to visit EOL's Design and Fabrications Services machine shop to learn about the technology and instrumentation that makes climate studies possible. They participated in a weather balloon launch by EOL's In Situ Sensing Facility as well and thus experienced one method of data collection. During the teachers' visit, EOL staff also highlighted how the teachers could use data from the HIPPO project in their curricula, and how to integrate educational resources from field projects in their classroom to help teach climate science. The resultant developed curriculum that integrated EOL field projects included topics such as learning about climate change in a chemistry class, evaluating climate change using case studies, and understanding how climate change affects humans.

Figure 36: 2012 RETI teachers watch as an MGAUS is prepared by EOL Technician Tim Lim.

Pre-College Internship

EOL staff mentored a pre-college intern from Puerto Rico this summer, Osvaldo Massanet, who created an EOL Field Project Map application for iOS devices. Mobile information is quickly becoming mainstream as more people use smartphones in their daily lives. EOL is committed to keeping up with technology and providing comprehensive outreach material, both of which can be accomplished by creating an EOL iOS app.

This new outreach tool will allow mobile users to gain a broader perspective of the global scale of EOL by interfacing with a dynamic and interactive mapping display. The EOL Field Project Map iPad app will open the EOL KML file displaying all the locations of EOL's field projects using the EOL icon, and each icon will be clickable with a pop-up balloon of more information about that particular project. The intern was able to complete a working prototype; however, further development is needed for a public application.

Figure 37: 2012 Pre-College Intern Osvaldo Massanet demonstrates the working prototype of the EOL Field Projects App that he created during his internship.

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Frontier I

Improve observing capabilities for weather and climate phenomena with high socio-economic impact.

EOL has provided prominent support for studies of hurricanes, tornadoes, and other severe storms. Airborne studies of convective systems require nowcasting and displays of the rapidly changing meteorological environment. EOL developed the Mission Coordinator and Google Maps displays to provide important information needed by decision

makers both on the aircraft and on the ground. These displays played a crucial role in DC3 and were considered an essential tool by the science and operations teams. The Mission Coordinator display for DC3 is discussed further in **Imperative II** and the Google Maps displays are discussed in **Imperative IV**.

Observational aspects of hurricane studies are centered on measurements from dropsondes. EOL developed the Airborne Vertical Atmospheric Profiling System (AVAPS), or dropsonde system (including the launch mechanisms, sondes, and software for launch operations, real time sonde data displays, and postprocessing) that are currently used for operational and research purposes on aircraft, balloon, and Unmanned Aerial System (UAS) platforms in the U.S. and internationally. A unique partnership among EOL, NOAA and NASA led to development of an autonomous, remotely operated dropsonde system for the NASA Global Hawk UAS. In FY 2012 EOL leveraged this technology in redesigning the dropsonde system on the NSF/NCAR GV. The new system will use the smaller sondes as used on the Global Hawk, will allow 8 sondes in the air simultaneously instead of the current 4 sondes, and will have remote operations capability. The system is further described in **Imperative III**.

Another unique potential EOL system for studies of severe weather is airborne phased array radar (APAR). Explorations continued in FY 2012 of phased-array technology for the NSF/NCAR C-130, where it could be combined with other remote sensors available in EOL and with the many other measuring capabilities that platform provides. Further discussion of the phased array effort can be found under **Imperative III**.

The CentNet system development could be used for both weather and climate process studies. CentNet builds on EOL's current Integrated Surface Flux System (ISFS), expanding it to include an array of semi-autonomous sensor stations that can be deployed in a variety of spatial patterns and for a wide range of time periods. CentNet is further described in **Imperative III**.

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Frontier II

Provide New or Significantly Strengthened Capabilities to Support Observational Research in Key Areas Where Support Needs are Growing in Importance.

EOL has much to offer in support of climate research, and a significant portion of EOL support throughout its history has been devoted to such investigations. However, the nature of the needs and opportunities are changing, so there is

an occasion to change the nature of our support. The NSF/NCAR GV opens new opportunities for global-scale observations, and the HIPPO missions served to highlight the potential of such observations. The C-130 can continue to play a role in climate process studies, as it did in campaigns such as VOCALS-Rex, which was an international field experiment designed to provide observational data to improve model simulations of physical and chemical processes central to the climate system of the Southeast Pacific region. FRONT and CentNet have the potential to provide longer-term observations covering an area similar to a grid box in a climate model. FRONT can also provide a setting for incorporating testbed measurements while longer-term observations provide context for the testing of new instruments. The history and experience of EOL in process studies will continue to serve the needs of the climate community for such observations.

EOL's collaboration with Montana State University on the water vapor DIAL is an example of a development that will support observational research in a number of key areas. The WV DIAL will provide measurements of water vapor from the surface to 6 km and of aerosols to 12 km. A unique aspect of this instrument, which in FY 2012 was tested and evaluated, is the low cost due to the use of commercial off-the-shelf components. For more information on the water vapor DIAL system see **Imperative III**.

In an effort to enhance measurements of water vapor, EOL has five Trimble NetR8 GPS receivers. Each of the receivers is equipped with a Vaisala WXT520 weather station and is available for use as part of FRONT or as part of remote field campaigns with EOL's ground-based or ship-borne instruments. The GPS receivers are Internet-ready and the data are incorporated into standard SuomiNet processing by the UCAR/COSMIC program. Continuous Integrated Precipitable Water (IPW) retrievals are computed in near real-time (~1-hour latency). When FRONT is operational, these systems will be distributed within the FRONT radar coverage domain. The IPW data will be used to monitor the moisture variability in the domain and research will be done to assess the potential for tomographic retrievals. External PIs may also request the receivers for remote field campaigns to enhance their moisture measurements. The GPS receivers have been used with both S-Pol (DYNAMO) and ISS (PCAPS and DYNAMO).

The development of the balloon-borne Driftsonde system that releases dropsondes via commands from the ground is another example of how EOL's expertise has expanded into developing observational capabilities needed by scientific areas that are growing in importance. Driftsonde operates up to 20 km depending on the size of the balloon and is ideal for remote areas including the tropics and high latitudes. In 2011 this capability was used in the French/U.S. sponsored campaign in Antarctica, Concordiasi, which demonstrated the maturity of the EOL Driftsonde system in one of the most challenging environments imaginable. Before Concordiasi, the Driftsonde supported two other international field programs, the African Monsoon Multidisciplinary Analysis (AMMA) project over the African continent in 2006 and T-PARC over the Pacific Ocean in 2008. Each consecutive deployment spurred additional improvements, advances, and refinements in hardware, software, and communications.

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Frontier III

Develop New Capabilities That Focus On Processes at Interfaces in the Atmosphere.

The air-sea interface, the air-land interface, and the tropopause have diverse observational needs: ships, buoys, and aircraft for the first; facilities such as ISFS for the second; and high-altitude aircraft and balloons for the third. There are many possible measurement tools and observational opportunities for these interfaces: controlled towed vehicles

Imperative IV
Imperative V
Frontier I
Frontier II
Frontier III
Frontier IV

to extend the reach of research aircraft closer to the surface; ocean sensors like Airborne eXpendable BathyThermographs (AXBTs) for studies of the upper layer of the ocean; measurements of fluxes of trace gases to or from the lower surface (land or sea); new sensors on dropsondes for characterizing the chemistry of the tropopause region; the development of remote sensors that measure profiles of trace gases and for measurement of fluxes (e.g., via combining a DIAL lidar with a Doppler lidar); and development of large arrays of sensors to increase coverage and resolution of measurements. Other areas with potential include using UASs for boundary-layer studies, the remote measurement of 3-D wind, tethersonde capability to increase the altitude range of boundary layer measurements, and higher-response measurements from research aircraft to measure fluxes and probe the fine-scale structure of turbulence. Understanding processes at interfaces continues to grow in importance and is prominent in many assessments of needs for the future.

To address some of these needs, EOL is developing CentNet and FRONT for greater boundary layer coverage through longer timeframes, broader areas, and complex terrain. Sensor simplification and miniaturization are leading to new opportunities in this area and FRONT will be an excellent testbed for these sensors (see **Imperative III** and **Frontier IV**). EOL is also developing an innovative, modular 449 MHz wind profiler network to expand and replace our 915 MHz boundary-layer wind profiling capability. As a basic boundary-layer wind profiler, the new system will probe higher and be simpler to deploy. The 449 MHz profiler's unique hexagonal-antenna and its modular design will provide for assembly in a variety of configurations to meet the diverse range of experiments that EOL supports. The envisioned system could be deployed as a network of six boundary-layer profilers, a single full-tropospheric profiler, or variations in between. Advanced hardware and innovative signal processing such as spaced antenna winds, range imaging, and adaptive clutter suppression are important features of the 449 MHz profiler development effort. More information on the 449 MHz wind profiler may be found in **Imperative III**.

Another development activity is the Laser Air Motion Sensor (LAMS), which provides high-resolution wind measurements from aircraft. Air motion relative to an aircraft is usually measured with a 5-hole gust probe, which employs pressure sensors. Although robust, the method is not highly accurate, in part because the aircraft shape and motion modify the air flow field. Ideally, air motions should be measured some distance from the aircraft, where the airflow has not been modified by deformation around the fuselage. To address this issue, EOL engineers developed the LAMS for deployment on the NSF/NCAR GV and C-130. By focusing a continuous-wave coherent laser beam about 20 m ahead of the aircraft, the instrument is able to make accurate wind velocity measurements in undisturbed air and measure the aircraft's true air speed. The current LAMS sensor measures the air speed towards the aircraft with an accuracy of about 10 cm/s; this is almost a factor of 10 more accurate than what can be obtained using in-flight aircraft calibration maneuvers. In FY 2012, EOL worked on development of a 3-beam version of LAMS that will be capable of providing 3 dimensional winds. 3-D LAMS will provide high quality wind measurements for use in a variety of scientific studies, including those involving dynamics and chemistry in the upper troposphere-lower stratosphere (UTLS) region in mid and high latitudes from the NSF/NCAR GV and lower tropospheric studies using the NSF/NCAR C-130.

One of the HAIS instruments, HSRL, will be especially useful in studies of the UTLS region in all areas of the globe when it's included in the NSF/NCAR GV payload because of its ability to measure particle backscatter and depolarization 10km above the aircraft flight level. For more information on HSRL measurements see **Imperative I** and **Imperative II.**

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Frontier IV

Develop new calibration and testing facilities, including testbed capabilities, for the community, either in collaboration with other agencies or specifically for NSF-supported research.

The most prominent test-bed development area in EOL is the Front Range Observational Network Testbed (FRONT), which will be in place in FY 2013 and has substantial potential to serve community needs. FRONT integrates Colorado

State University's (CSU) CHILL and EOL's S-PolKa radar systems to streamline engineering development and operations for expanded science, research and education opportunities. FRONT will provide the scientific community with opportunities to conduct target-of-opportunity scientific field experiments; maintain a long-term mesoscale test bed for assessing instruments, data quality procedures, sensor integration, numerical models, networking capabilities and derived products; provide a framework for local field campaigns; and provide hands-on education.

FRONT's technical goals are to establish common system software, data formats and data processing environment; share common receiver and system control hardware; and remote-control both radars for unattended operations. The near-term deliverable is S-PolKa's move to a new home-base east of Interstate 25 to create a world class dual-Doppler, dual dual-polarization network, with fully available S-Pol functionalities. For more information on FRONT see **Imperative III**.

Beyond the testbed capabilities of FRONT, there are also needs for calibration facilities for water vapor sensors; an environmental chamber with precise pressure and temperature control for testing instruments over a wide range of these parameters; and a wind tunnel test facility for aircraft inlets to which EOL would have access, perhaps operated by EOL. Associated with these needs, is the need for more attention to measurement science: calibration, uncertainty characterization, and documentation of instrument characteristics.

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Table of Contents

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  - Climate and Global Dynamics Lab
  - Computational & Information Systems Lab
  - Earth Observing Lab
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  - Advanced Study Program
  - Integrated Science Program
  - Budget & Planning Office
  - NCAR Library
- Find People
  - Staff Directory
  - Scientific Visitors
- Locations/Directions
  - Maps, Directions, Help
  - Public & School Tours
- Closures/Emergencies

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NCAR Earth System Laboratory | NESL
2012 Annual Report

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I. Scientific Discovery

I. Scientific Discovery

- I.A. **Formation and Spread of Aircraft-Induced Holes in Clouds**
- I.B. **Atmosphere/Ocean Interactions**
- I.C. **Research using Cloud Resolving Models (CRMs)**

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    - DLS
    - GLOBE
    - JOSS
    - MetEd
    - UCAR Center for Science Education
    - UCARConnect
    - Unidata
    - VSP
    - UCP Director's Office
    - UCP Budget & Administration
  - President's Office
    - Communications & Media Relations
    - Development & Partnerships
    - Government Relations
    - Membership
    - Office of General Counsel
    - University Relations
  - Human Resources
  - Finance & Administration
- NCAR
  - National Center for Atmospheric Research
  - Atmospheric Chemistry Observations & Modeling Lab
  - Climate and Global Dynamics Lab
  - Computational & Information Systems Lab
  - Earth Observing Lab
  - High Altitude Observatory
  - Mesoscale & Microscale Meteorology Lab
  - Research Applications Lab
  - Director's Office
  - Advanced Study Program
  - Integrated Science Program
  - Budget & Planning Office
  - NCAR Library
- Find People
  - Staff Directory
  - Scientific Visitors
- Locations/Directions
  - Maps, Directions, Help
  - Public & School Tours
- Closures/Emergencies

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II. Prediction Across Scales

II. Prediction Across Scales

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    - Membership
    - Office of General Counsel
    - University Relations
  - Human Resources
  - Finance & Administration
- NCAR
  - National Center for Atmospheric Research
  - Atmospheric Chemistry Observations & Modeling Lab
  - Climate and Global Dynamics Lab
  - Computational & Information Systems Lab
  - Earth Observing Lab
  - High Altitude Observatory
  - Mesoscale & Microscale Meteorology Lab
  - Research Applications Lab
  - Director's Office
  - Advanced Study Program
  - Integrated Science Program
  - Budget & Planning Office
  - NCAR Library
- Find People
  - Staff Directory
  - Scientific Visitors
- Locations/Directions
  - Maps, Directions, Help
  - Public & School Tours
- Closures/Emergencies

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III. NESL Observational Science

III. NESL Observational Science

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IV. Modeling in Support of Field Operations

IV. Modeling in Support of Field Operations

- IV.A. **The Hurricane Forecast Improvement Project (HFIP)**
- IV.B. **The Antarctic Mesoscale Prediction System (AMPS)**
- IV.C. **Wind Energy Research**

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Research Applications Laboratory | RAL

2012 ANNUAL REPORT

Table of Contents

- InFlight, Ground and Engine Icing
- Prediction of Storm Hazards for Aviation
- Turbulence
- Ceiling and Visibility Research and Development
- Integration of Weather Information into Air Traffic Management Decisions for Reduced Weather Impact
- Dissemination of Aviation Weather Information
- Oceanic Weather
- Avian Radar Performance

New and Emerging Applications

- Surface Transportation Weather
- Renewable Energy
- Weather Prediction Statistical Optimization
- Advanced Operational Aviation Weather System

National Security Applications

- Operational Numerical Weather Prediction and Improved Data Assimilation
  - Four-Dimensional Weather System
  - Real-time Microscale FDDA Forecasting System for Korea
  - MAGEN RTFDDA and 3DVAR Hybrid System
  - Xcel Energy NWP for Wind Power Forecasting
  - AirDat CONUS and North America RTFDDA Forecasting System
  - The RTFDDA-3DVAR Hybrid Radar Data Assimilation System
  - Fine-Scale Precision Forecasting with WRF-RTFDDA-LES
  - 4D-REKF Ensemble Data Assimilation and Forecasting
  - Real-time Ensemble-RTFDDA Wind Energy Forecast for China
  - Real-time FDDA and WRF3DVAR Hybrid Weather Prediction System for PME
  - Analog Ensemble Prediction and DART-based Data Assimilation for Wind Prediction
  - Mesoscale Ensemble Prediction
  - High Performance Computing for Operational Modeling
- Mesoscale Climate Downscaling
  - Computationally Efficient Climate Downscaling
    - Statistical
    - Dynamical
    - Hybrid Statistical/Dynamical
  - Applications
    - Wind Resource Assessment
    - The National Ground Intelligence Center (NGIC) Project
- Atmospheric Transport and Dispersion of Hazardous Materials Research and Development
  - Atmospheric Transport and Dispersion Meteorological Data Services
  - Hazardous Material Source Term Estimation
  - Virtual Atmospheric Dispersion Field Testing
  - Sensor Requirements Analysis
  - Urban Transport and Dispersion

Numerical Systems Testing and Evaluation

- Mesoscale Modeling Systems
- Advanced Verification Techniques and Tools
- Data Assimilation
- Tropical Cyclone

Hydrometeorological Applications

- Short-Term Explicit Prediction Program
- Coupled Surface Hydrometeorological Processes and Regional Climate
- Aerosols and Precipitation
- Winter Weather
- Western Water
- Water, Energy and Food Security

Climate, Weather and Society

- Use and Value of Weather Information
- Governance and Adaptation: Socio-ecological Systems in a Changing Climate
- Resilient and Sustainable Cities
- Weather, Climate and Health
- Geographic Information System (GIS) Program

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Next Generation Air Transportation

Play a leadership role within the atmospheric research community to provide the necessary scientific underpinning and technology to support the weather and climate–related needs of the Next Generation Air Transportation System (NextGen).

- **InFlight, Ground and Engine**

- **Prediction of Storm Hazards for Aviation**
- **Turbulence**
- **Ceiling and Visibility Research and Development**
- **Integration of Weather Information Into Air Traffic Management Decisions for Reduced Weather Impact**
- **Dissemination of Aviation Weather Information**
- **Oceanic Weather: Convection and Turbulence**
- **Avian Radar Performance**

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New and Emerging Applications

Identify, explore, develop and implement advanced weather decision support systems for new and emerging user sectors.

- **Surface Transportation Weather**
- **Renewable Energy**

- **Weather Prediction Statistical Optimization**
- **Advanced Operational Aviation Weather System (AOAWS)**

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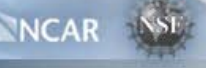

National Security Applications

Significantly advance our understanding of mesoscale and urban-scale weather and climate processes, especially in the boundary layer, and our ability to forecast these atmospheric conditions operationally for the purpose of providing forecasters, decision makers, and emergency managers with accurate information to save lives and property.

- **Operational Numerical Weather Prediction and Improved Data Assimilation**
- **Mesoscale Climate Downscaling**
- **Atmospheric Transport and Dispersion of Hazardous Materials Research and Development**

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    - GLOBE
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    - MetEd
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    - UCARConnect
    - Unidata
    - VSP
    - UCP Director's Office
    - UCP Budget & Administration
  - President's Office
    - Communications & Media Relations
    - Development & Partnerships
    - Government Relations
    - Membership
    - Office of General Counsel
    - University Relations
  - Human Resources
  - Finance & Administration
- NCAR
  - National Center for Atmospheric Research
  - Atmospheric Chemistry Observations & Modeling Lab
  - Climate and Global Dynamics Lab
  - Computational & Information Systems Lab
  - Earth Observing Lab
  - High Altitude Observatory
  - Mesoscale & Microscale Meteorology Lab
  - Research Applications Lab
  - Director's Office
  - Advanced Study Program
  - Integrated Science Program
  - Budget & Planning Office
  - NCAR Library
- Find People
  - Staff Directory
  - Scientific Visitors
- Locations/Directions
  - Maps, Directions, Help
  - Public & School Tours
- Closures/Emergencies

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Research Applications Laboratory | RAL
2012 ANNUAL REPORT

Numerical Systems Testing and Evaluation

Maintain and expand a central collaborative function within NCAR and a distributive network of collaborators for developing, testing, and validating numerical forecast systems important to operational decision makers and the international research community.

- **Mesoscale Modeling Systems**

- **Advanced Verification Techniques and Tools**
- **Data Assimilation**
- **Tropical Cyclone**

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Hydrometeorological Applications

Provide relevant information to water resource decision makers through directed and basic research and development in hydrometeorology, aerosol-precipitation interactions, precipitation nowcasting, microphysical modeling, and winter weather.

Short-Term Explicit Prediction Program

Coupled Surface Hydrometeorological Processes and Regional Climate
Aerosols and Precipitation
Winter Weather
Western Water
Water, Energy and Food Security

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2012 ANNUAL REPORT

Renewable Energy

Background:

For the past three years RAL has collaborated with university researchers, DOE labs, commercial partners, and other NCAR entities to develop methods to more accurately analyze and predict wind energy in support of the renewable energy industry. Projects have focused on resource assessment, real time forecasting to improve operations and

economics of incorporating wind energy into the power mix, and characterization and quantification of variability in wind energy.

Xcel Energy Wind Power Prediction Project

In FY2012, RAL completed a 2.5 year collaborative project with **Xcel Energy Services, Inc**.to increase the amount of wind energy in its energy generation portfolio. New wind prediction technologies help operators make critical decisions about powering down traditional coal- and natural gas–powered plants when sufficient winds are predicted, enabling increased reliance on alternative energy while still meeting the needs of customers.

The Wind Energy Forecasting System developed by RAL incorporates observations of current atmospheric conditions from satellites, aircraft, weather radars, ground-based weather stations, and even sensors on the wind turbines. The information is then utilized by a number of powerful tools: the Weather Research and Forecasting (WRF) model; the Real-Time Four-Dimensional Data Assimilation System (**RTFDDA**), which continuously updates the WRF model simulations with the most recent observations; the Dynamic Integrated Forecast System (**DICast®**), which statistically optimizes the forecasts based on current observations, climatological data, and real-time validation of the model predictions; an ensemble of numerical weather prediction forecasts based on both WRF and the MM5 (Penn State/NCAR) mesoscale models; NCAR calibration tools that improve the probabilistic forecast, specifically the Analogue Kalman Filter combined with Quantile Regression to remove bias, sharpen the forecast, and increase statistical reliability; the Four Dimensional Variational Doppler Radar Analysis System (VDRAS), which combines Doppler radar data with a cloud scale model to predict short term weather events; an NCAR-developed expert system that uses field observations to fine-tune predictions when wind ramps are most likely to impact the wind plant; and customized Graphical User Interfaces to provide grid operators with a best forecast that includes error estimates as well as meteorological GUIs to visualize the weather graphics (Figure A). The team who developed this system for Xcel won UCAR's Outstanding Performance Award for Scientific and Technical Advancement in December 2011.

Off-Shore Wind Energy Projects

A new DOE-funded project focus on enhanced understanding of the interactions between the ocean and the atmosphere in order to better predict winds for both locating wind plants and for forecasting power for plant operations. A second project, in collaboration with Penn State, is developing a "Cyber Wind Facility", a computational facility akin to a field wind turbine test facility that blends models across scales. These projects will lead to better modeling capability to reduce market barriers to developing offshore wind energy.

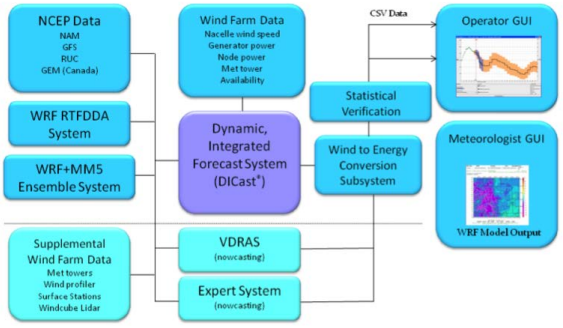

Figure A: Conceptual diagram of the wind energy prediction technology components incorporated into the system configuration.

Quantifying the Wind and Solar Resource and its Interannual Variability

In 2012, NCAR collaborated with the National Renewable Energy Laboratory (NREL) to produce a new database of annual means and interannual variability of wind and solar resources. The goal was to produce a reliable dataset that is useful for assessing the inter-annual variability of wind and solar power over the continental U.S. (CONUS) for NREL's Regional Energy Deployment System (ReEDS). The end result is a database of expected future climate wind and solar resource values and their interannual variability, quantified by season and by time of day. An example of projected changes for the summer season appears in Figure B.

Wind Turbine and Turbine Array Wake Characterization

The effects of operating wind turbine rotors on atmospheric flows can be represented using a generalized actuator disk model. To further study these effects, RAL scientists have implemented a generalized actuator disk model in the Weather Research and Forecasting (WRF) model to examine wind turbine wakes, their structure and interaction in wind turbine arrays, as well as their effect on transport processes in atmospheric boundary layers using the large-eddy simulation (LES) approach. In collaboration with the Lawrence Livermore National Laboratory (LLNL), RAL scientists are working to validate the generalized actuator disk model in WRF-LES using the data from the Turbine Wake and

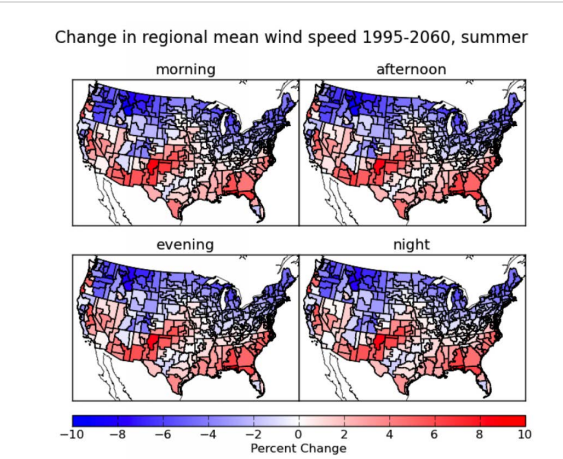

Figure B. Projected future changes in hub-height wind speed from current summer means for different time periods.

Inflow Characterization Study (TWICS) experiment that took place at the National Wind Technology Center (NWTC) test site of the National Renewable Energy Laboratory (NREL) in the spring of 2011. The validated generalized actuator disk model implemented in WRF will advance the capability to model details of flow through wind turbine arrays under a wide range of atmospheric conditions and thus will become an advanced tool for wind resource assessment and wind turbine array performance evaluation as well as turbine load calculations.

Using Analog Methods for Renewable Energy

A successful and economically feasible integration of a large portion of wind power into the electrical grid requires accurate wind power forecasting, as well as reliable quantification of the state-dependent uncertainty associated with the wind power forecast. To accomplish this, RAL scientists are combining real-time and historical data from state-of-the art numerical weather prediction models and extensive records of wind power observations to provide reliable quantification of the forecast uncertainty and accurate power forecast of day-ahead lead times. The approach, called the analog ensemble, is being tested on an off-shore wind park. Predictions are evaluated in terms of spread error consistency, normalized mean absolute errors, and in terms of value score in a simple cost/loss model for a range of users' cost/loss profiles, and compared to a conventional deterministic power forecasting approaches. The analog method has shown great value for improving both the best prediction and in quantifying its uncertainty.

Using Typhoon Modeling to Design Better Wind Turbines

In 2012, RAL collaborated with Taiwan's Industrial Technology Research Institute (ITRI) to enable wind energy development in Taiwan. Most of this energy is expected to be developed off-shore, and thus the impact of typhoons on wind turbine performance under extreme conditions is a major concern. A secondary concern is how to best deploy arrays of wind turbines to optimize their performance. A third issue emphasizes the operation of wind turbines in the marine environment, including forecasting wind power. NCAR and ITRI are planning an applied research program that will integrate observations, model output, and design criteria to advance wind energy capabilities in environments that experience extreme wind events.

Plans for FY2013:

DOE has recently selected RAL's proposal, "A Public-Private-Academic Partnership to Advance Solar Power Forecasting" for funding. This new three-year program will feature partnerships with the National Renewable Energy Laboratory, Brookhaven National Laboratory; a number of universities; independent system operators (ISOs); and commercial forecast providers, as well as with NOAA scientists. This program will develop a solar power forecasting system that advances the state-of-the-science through cutting edge research, test it in several high penetration solar utilities and ISOs, and disseminate the research results widely to raise the bar on solar forecasting technology.

Other plans include:

- Continued collaboration with Xcel Energy to enhance the Wind Power Prediction System, including predicting icing, high speed cutouts, load forecasting, enhancing power conversion algorithms, etc.
- Collaboration with NREL and the University of Colorado to deploy a vertically pointing lidar to study wind turbine wakes and to model those wakes using LES techniques.
- Expansion of wind forecasting capability into new areas, including mountainous and coastal sites.
- Assist NREL with resource assessment and developing measurement programs in developing countries.

- Work with partners at Colorado State University to quantify how wind power can be integrated with pumped storage to supply reliable power
- Work with colleagues at Penn State University to assess the feasibility of integrating wind turbines into buildings
- Work with partners at Colorado School of Mines to analyze how wind power forecasting can help smooth the demand/variable energy balance when applying smart grid concepts
- Work with partners at the University of Colorado to study the impact of atmospheric stability and shear on wind power production
- Work with partners at Penn State to include mesoscale model data in a coupled multi-scale cyber wind facility
- Expand calibration of the uncertainty in wind forecasting systems in conjunction with other laboratories and with commercial partners
- Downscale model solutions for resource assessment
- Apply new artificial intelligence techniques to wind prediction problems
- Work on improving offshore hub-height wind speed and wind shear prediction
- Improve marine boundary layer parameterization to better account for the interaction between sea surface and the atmosphere.

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RAL Annual Report

Water, Energy and Food Security

Background

Policy and management decisions regarding water and energy figure prominently in efforts to adapt to and mitigate anthropogenic climate change. To be effective, these decisions need to consider the interconnections between energy, water and food production and use–the *water–energy-food nexus*--and to assess the implications of a changing

climate for the reliability of energy and water supplies. A number of important, quite complex research efforts are currently underway addressing each side of the nexus. Assessments of water use in generating hydroelectric power, are for example, studying freshwater use and consumption as a function of the generation type (combustion turbine, combined cycle, etc), fuel used (coal, natural gas, nuclear, etc.) and the cooling system technology (once–through, recirculating, dry, etc.). Analyses focusing on the consumption of energy by the water sector are also underway, examining energy use extraction, transport, delivery, pre– and post–use treatment, and user applications. Both sides of the *energy–water-food nexus* are being examined, but typically as loosely connected puzzle pieces rather than as integrated components of a coupled resource management system.

While the *water-energy–-food nexus* information–base has been growing, there remains a dearth of modeling tools to evaluate long–term interactions and feedbacks between these sectors in the context of a changing climate. In particular, a spatially-explicit coupled modeling system is needed to facilitate a more complete and accurate evaluation of the workability and consequences of alternative climate mitigation and adaptation strategies.

To address these needs, RAL in collaboration with the Stockholm Environment Institute US-Center (SEI) and the Union of Concerned Scientists, has made exploration of the water-energy-food nexus in the Western United States a research frontier in its Strategic Plan. Initial efforts in FY2012 have been conducted with support from a NOAA SARP grant, the NSF, and a Norwegian firm, Der Norske Veritas.

FY2012 Accomplishments

The physical sciences in support of Integrated Water Resources Management (IWRM) is extremely useful, yet conventional approaches to natural resource management, based on physical sciences alone often fail to fully address the continual need to negotiate tradeoffs between conflicting resource use and changing interests. A coupling is needed between the natural, social, and the ecological systems with interactions across spatial and temporal scales. Along with the Stockholm Environment Institute-US Center, we have successfully linked two planning-purposed models with a long legacy of successful use in decision support in their respective disciplines; the Water Evaluation and Planning (WEAP) and the Long-range Energy Alternatives Planning (LEAP) modeling systems. WEAP and LEAP have been recently coupled to better explore the *water-energy-food nexus.*

As part of this work, Yates and Miller (2013) have explored the implications of energy alternatives on water in the southwestern U.S.; their paper, "Integrated Decision Support for Energy/Water Planning in California and the Southwest", has been accepted for publication in the *International Journal of Climate Change: Impacts and Responses.*

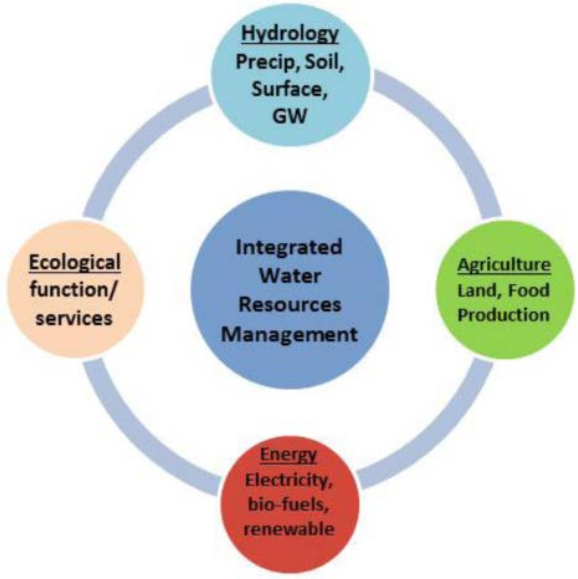

Figure 1. A simplified representation of the . Groundwater (GW)

FY2013 Plans

Research is needed to better understand the interactions, and possible collisions, between water-management and energy-management decision making. National-scale guidance is needed on energy policy and decision making that leads to reduced greenhouse gas emission, and avoids unintended consequences related to water management in the context of energy generation. Different energy management strategies will have different water management implications that extend from the local, to the regional, and ultimately to the national scale. Further, it is recognized that the local importance of these impacts will be defined by the characteristics of individual water systems within which energy management strategies are implemented.

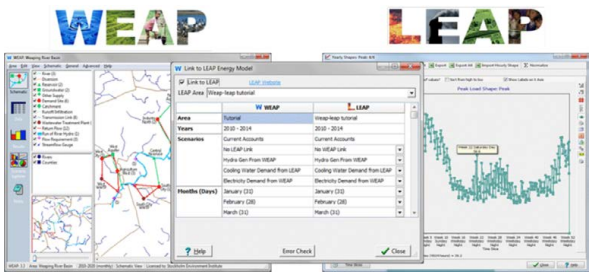

Figure 2. The Integrated WEAP and LEAP tools, showing the linking window (center), where common modeling areas, scenarios, periods of analysis, and timesteps are matched.

Proposed areas of focus include:

- In collaboration with the Headwaters Program, explore how improved scientific understanding of seasonal changes in precipitation, sublimation, snow water equivalent, snowmelt, soil moisture, and transpiration in the

western USA impact the water-energy-food systems of the region. Explore the particular emphasis to changes associated with a shift to earlier snowmelt and the potential shift from energy-limited to water-limited systems.
- Using improved scientific understanding of the magnitude of the expected drought through the use of high-resolution climate models (in association with the Colorado Headwaters Project), explore water-energy-food relationships in the region.
- Work closely with the social science community, both at RAL and externally, to explore the impacts of climate change on the *water-energy nexus* from a societal perspective.

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RAL Annual Report

Climate, Weather and Society

Promote societal welfare by conducting interdisciplinary research on the interactions between society and weather and climate in order to increase societal resilience to the associated risks and to support decision making.

- Use and Value of Weather Information

- Governance and Adaptation: Socio-ecological Systems in a Changing Climate
- Resilient and Sustainable Cities
- Weather, Climate and Health
- Geographic Information System (GIS) Program

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