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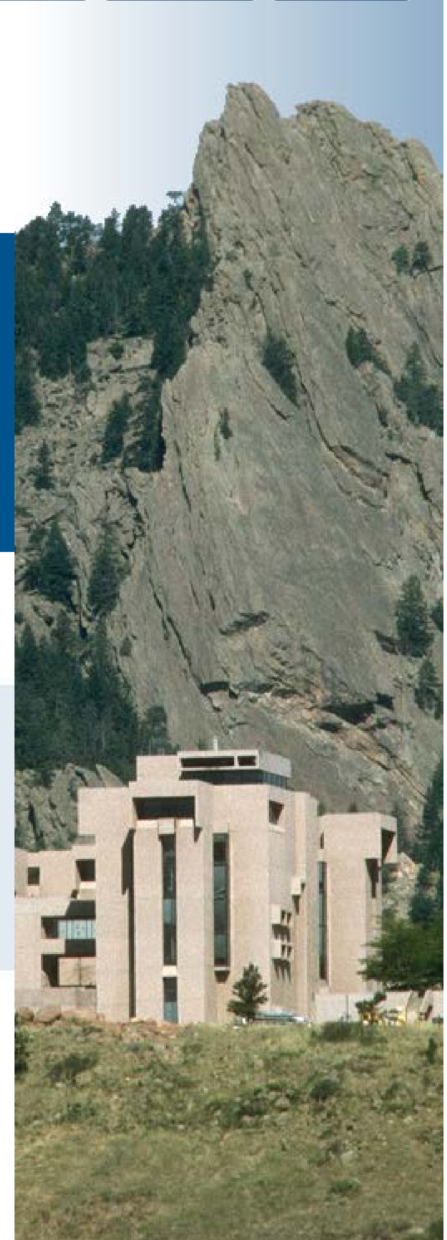

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A Message from the Director

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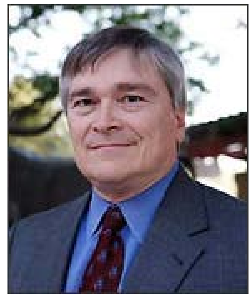
A Message from the Director



Fiscal Year 2009 (FY2009) was an exciting one, as NCAR continues to be a crossroads for scientific interaction and collaboration. The heightened interest in climate by decision makers, funding agencies and society as a whole is reflected in many of the stories included in this annual report. Our focus — and that of the National Science Foundation — on ways in which science can serve and improve societal welfare also features significantly, as does work being done by the universities, government laboratories, and international and national research institutions that we serve. By focusing on five themes—**Accelerated Scientific Discovery**, **U.S. Western Water and Environment**, **Science Serving Society**, **Taking Science to the Field**, and **Cutting-edge Research**—we provide a snapshot of NCAR competencies, facilities, and the community-wide accomplishments achieved in Fiscal Year 2009. Additional details on the support, tools, and research efforts being pursued within NCAR's four Laboratories can be found in the Laboratory Annual Reports.

I invite you to delve further into the NCAR Annual Report, as well as the Laboratory Annual Reports, to learn more about these and our many other FY2009 efforts.

Best wishes,
Eric Barron

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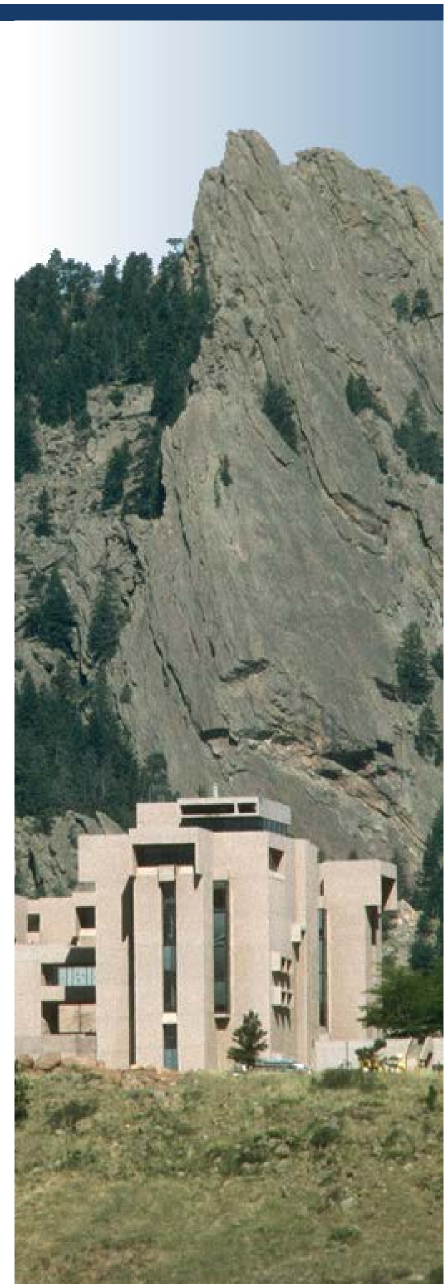

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Accelerated Scientific Discovery

During the first three months of FY2009, nearly 40% of bluefire, NCAR's latest supercomputer, was dedicated to the Accelerated Scientific Discovery (ASD) initiative, which provided a number of production-ready projects with the opportunity to make accelerated progress on important scientific problems. In the subsequent months of Fiscal Year 2009, NCAR's Computational and Information Systems Laboratory (CISL) dedicated smaller portions of bluefire to NCAR and university scientists to address select challenging problems. Highlights related to some of these projects are featured in the following pages. Also see **CISL's Laboratory Annual Report** for additional project details.

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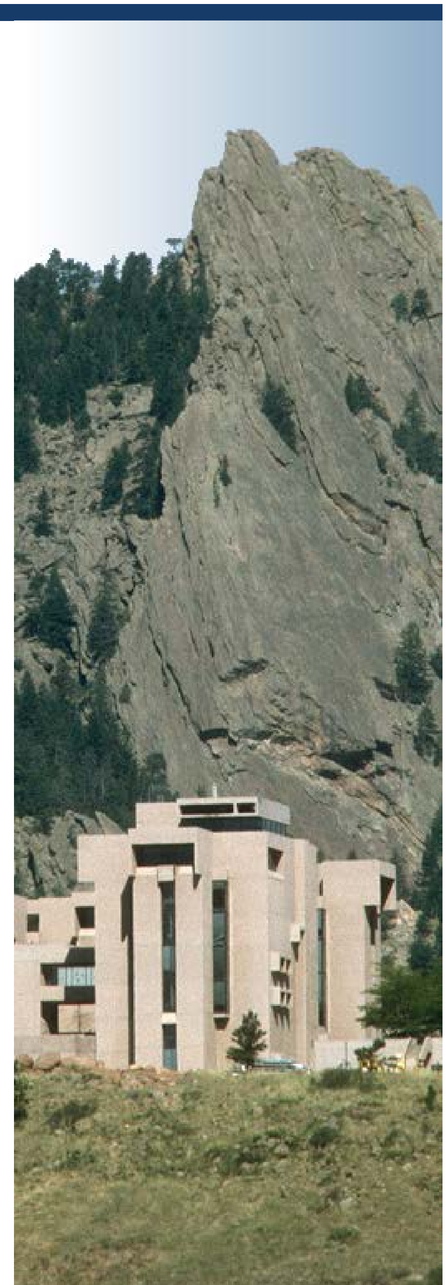

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Slicing into the future of hurricanes: Insurers get a sharper look at potential trends

Like individuals, industry faces safety and financial risk related to extreme weather events. Reinsurers — insurers of insurance companies — want to understand how changing climate might affect the strength and frequency of extreme events. Similarly, energy companies that have infrastructure (oil rigs, refineries) and personnel located on and near coasts clamor for ever-more accurate weather forecasts and climate change impact information to aid evacuation planning and infrastructure design efforts, as well as to address bottom-line concerns.

In the case of hurricanes in the Caribbean and U.S. Gulf Coast, forecasts of future storm activity — hurricane path, intensity, distribution — in the next 50 to 100 years have traditionally been made using statistical models based on historical data.

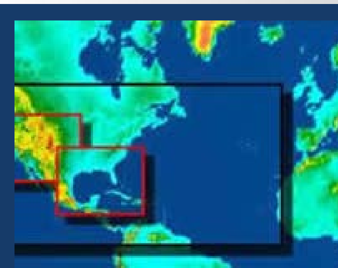
In the case of hurricanes in the Caribbean and U.S. Gulf Coast, forecasts of future storm activity — hurricane path, intensity, distribution — in the next 50 to 100 years have traditionally been made using statistical models based on historical data. But, because of the long life of many greenhouse gases (50 to 100 years in the case of carbon dioxide), ongoing climate warming is effectively built into the system. This means that historic hurricane data are not likely to be useful predictors for future hurricane trends during the next 50 years. As a result, industry leaders are turning to scientists for help in predicting how climate might affect their business in coming decades.

Wanting to capture both global climate dynamics and the behavior of a single hurricane, a group of researchers from NCAR, the university community, federal agencies and industry looked at combining the Weather Research and Forecasting (WRF) model and the Community Climate System Model (CCSM). The Nested Regional Climate Model (NRCM) was the result, offering the benefit of both global and regional perspective.

Funded by NSF's Accelerated Scientific Discovery, which allocates windows of computing time to study science questions, and by the Willis Research Network and the offshore oil industry, the researchers looked at the effects of warming climate and hurricane genesis for 1995 through 2055. Because of the intensive computing power and time required to generate high-resolution (36 km) model output, the team generated time slices for three decades — 1995-2005, 2020-2030, and 2045-2055 — and used statistical analyses to fill in the missing data points. While other research groups have used similar nesting techniques, these efforts haven't been done at such a high level of resolution or for this duration of time.

The study's focus honed in on tropical areas — especially over Africa and the North Atlantic — so as to capture the disturbances in pressure, temperature, wind and other variables, known as easterly waves, as they travel from Africa to the Caribbean. Approximately 60% of all North Atlantic basin tropical cyclones and 80% of strong hurricanes develop from these easterly waves. Of particular interest to the team and its funders were high resolution views of hurricane formation in the Caribbean and Gulf of Mexico.

The baseline climate was generated by CCSM using an Intergovernmental Panel on Climate Change CO2 emissions scenario: the A2 'business-as-



Zooming in on future climate. NCAR scientists are using a combination of weather and climate computer models to simulate the atmosphere in three dimensions at resolutions ranging from about 20 miles across a large part of the Northern Hemisphere to as fine as 2.5 miles in targeted areas of North America (red boxes). This strategy enables scientists to forecast future climate in detail for specific regions without overloading existing supercomputing resources.(Contrast between coarse and fine resolution has been increased for illustrative purposes; image by Steve Deyo, �UCAR.)

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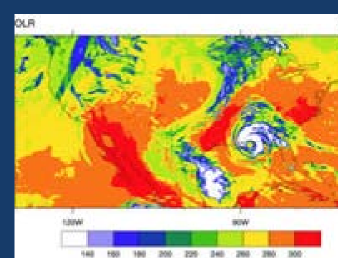

Nested Regional Climate Model Landfalling Cat 4 Simulation. October 10, 2046. Image is color enhanced Outgoing Long Wave Radiation in W/m2.

Click here to enlarge +

usual' scenario based on moderate economic growth. By nesting the higher resolution WRF inside the lower resolution CCSM, model output reflected both large-scale and smaller, hurricane-scale dynamics. The scientists noticed that the NRCM didn't represent tropical cyclones as well as it should, but by incorporating NCAR-NCEP (National Centers for Environmental Prediction) Reanalysis data, improved NRCM accuracy in depicting regional atmospheric phenomena.

Already, insurance companies are using this work to identify the level of risk faced by coastline development. These initial runs are being analyzed to address the reinsurance and energy organizations' immediate needs, even as NCRM work continues. Among the planned model improvements is an enhanced ability for 2-way telescoping of data. Currently, NRCM scales down to regional dimensions effectively, but with improved scaling from regional up to global, users would gain more nuanced understanding of the small-scale effects of wind, precipitation, humidity, etc. on global climate; this would enhance the realism with which global climate is replicated in general circulation models.

A fully coupled regional and global modeling system offers a practical approach to high-resolution climate modeling, yet the knowledge of how best to achieve this is still in its infancy. The NRCM provides a powerful tool from which we can learn from and satisfy an urgent need to provide useful forecasts of changes in high-impact weather.

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Modeling Ocean Transport Pathways

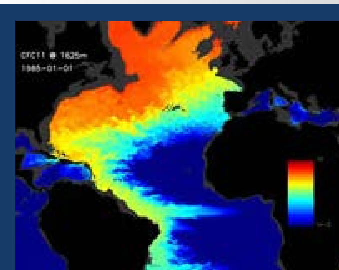
by Agatha A. Bardoel

Oceans play a critical role in the Earth's balance of heat and water, and in the uptake and redistribution of chemicals such as carbon dioxide (CO2) and chlorofluorocarbons (CFCs). After absorbing chemicals from the atmosphere at the surface, the ocean can store substances for hundreds to thousands of years, circulating them through the 319 million cubic miles of water around the globe. This ventilation process influences climate in multiple, still-to-be-determined ways. Difficult to measure directly, it can be inferred from observations of dissolved chemical compounds, or tracers. One particularly useful class of chemical tracers for seeing how chemicals are moved through the ocean are CFCs, which human activity has introduced to the atmosphere in known quantities since the 1930s.

Using Jaguar, the Cray XT computer system at Oak Ridge National Laboratory, and the National Center for Atmospheric Research's (NCAR) blue fire super computer, NCAR's Synte Peacock and Frank Bryan, and Mathew Maltrud at Los Alamos National Laboratory (LANL) , for the first time carried out a 100-year global eddying ocean simulation run. The model carried CFCs, as well as a host of other tracers that have yielded valuable information about ocean ventilation pathways and timescales. By comparing the measured CFC concentration at a point deep in the ocean to the surface concentration, scientists can estimate how long it has been since a water parcel was last at the surface. However, because CFCs have been in the atmosphere for only tens of years (not thousands), this age metric has an inherent bias. To better understand ventilation timescales, a number of highly idealized age tracers were also transported by the NCAR/LANL ocean model. Together with simulated CFCs, these have provided new insights into transport processes and timescales.

Due to the limits of computational power, most previous ocean model studies of tracer distributions have used fairly coarse resolutions (grid spacing greater than 100 kilometers), for which some important transport activities are poorly resolved. To begin to resolve features such as narrow currents and mesoscale eddies (circular loop-like features with diameters of less than 200 kilometers), researchers need a model with a finer grid resolution — kilometers to tens of kilometers. Thanks to powerful supercomputers such as Jaguar and blue fire, it has been possible to perform studies of the ocean uptake of CFCs and other trace gases using global fine-resolution (eddying) models. The NCAR/LANL model is among the most realistic global eddying models ever run, Maltrud says, and the only one to simulate such a large set of tracer distributions. A standard way to assess the accuracy of the model's eddy strength is to compare model sea-surface height changes with measurements from satellite altimeters (signals bounced off the sea surface to detect local changes in the height of the water). The close agreement between altimeter readings and the size and distribution of the model eddies is unprecedented in this type of ocean model.

While much has been learnt about transport processes by studies such as the one described above, there is still a great deal to do, says Peacock. While the observational data are as yet too sparse to characterize concentrations of these tracers on space and time scales associated with turbulent eddies, computational modeling is bringing researchers closer to a realistic assessment. Eddy-resolving ocean models are now providing sufficiently realistic proxies of ocean transient tracers, Peacock continues, which researchers can begin to use to provide a realistic picture of how, and on what timescales, the ocean is ventilated. "This will help researchers better understand the role of the ocean in uptake and redistribution of gases such as anthropogenic (man-made) CO2, which will increase understanding



Nested Regional Climate Model Landfalling Cat 4 Simulation. October 10, 2046. Image is color enhanced Outgoing Long Wave Radiation in W/m2.

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of the role that the ocean plays in climate change."

For more information read ***Tracking CFCs in a Global Eddying Ocean Model*** (published by Oak Ridge National Laboratory).

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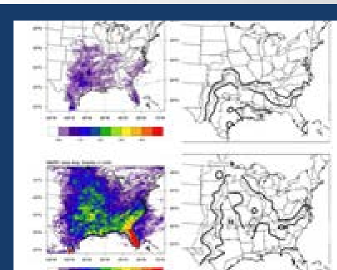
Scaling down to understand climate effects on severe storm formation



Monthly mean occurrences of hourly > 1 in hr. [left] from the NNRP-forced WRF runs, over the period 1991-1999; [right] from Brooks and Stensrud (2000), based on the period 1948-1993.

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Observations show global warming is resulting in both rising temperatures and increased moisture in the Earth's lower atmosphere. Both are basic components in thunderstorm generation. As climate warms, therefore, it seems likely that thunderstorms and other severe weather events could grow in number. As part of an effort to identify trends related to such events, and to better understand how climate change is affecting severe storm formation in the United States, a team of Purdue University scientists received computing time on NCAR's blue fire supercomputer as part of the National Science Foundation's Accelerated Scientific Discovery (ASD) program.

Led by Jeff Trapp, the team developed a 10-year climatology of high-resolution weather forecasts. The scientists dynamically downscaled coarse-resolution models (scales of 100s of kilometers) to create finer resolution (scales of a few kilometers) model output capable of reproducing local-scale atmospheric phenomena such as thunderstorms. The dynamical downscaling tool was the Advanced Research WRF (ARW) model, run initially using the temperature, humidity, winds, etc. from the NCAR-NCEP (National Centers for Environmental Prediction) Reanalysis Project (NNRP). These data, Trapp says, represent well the observed global atmosphere.

Using NNRP data from April through June for the years 1991 to 2000, the researchers generated a sequence of single-day high-resolution model forecasts rather than a continuous 90-day forecast; doing so eliminated potential error in the modeled output resulting from, for example, a storm mistakenly located in an area outside the observed location. In such a situation, inaccurate representation of a single characteristic, such as soil moisture content, in turn affects representation of heat transfer, humidity and temperatures in the lower atmosphere, cloud formation, etc.

Trapp and his colleagues used the ASD computing time to generate a decade of model runs, which they then compared to observed data to get an idea of how the simulations/climatologies compared to reality. With initial analysis showing the modeled data accurately replicating observed atmospheric dynamics, the team next moved on to running the ARW with the Community Atmospheric Model as input, thereby generating two different sets of climatologies.

"The ASD project gave us a jump start on model runs, data comparisons, and climatology development," says Trapp. "Next we'll focus our efforts on further analysis of the NNRP results to understand the spatial distribution of storms producing severe weather to see how well the modeled simulations work both over time and spatially."

Since creating its climatologies, the team has begun looking at severe storm trends. Identifying trends in thunderstorm generation is a trickier prospect, Trapp explains, because a variety of factors can be introduced into the observational record. For instance, thunderstorm reporting happens with good accuracy in populated areas, but in less-populated regions, storms can be under-reported, reported incorrectly or not reported at all. In addition, changes in reporting procedures also affect reporting accuracy. A trend needs to be both recognized and attributed, which can be difficult for reasons listed above, before definitive correlation of increasing thunderstorm activity can be correlated with growing greenhouse gas concentrations. To aid this effort, the team will develop a longer — 20 or 30 years — time series, which will provide longer, more reliable statistics from which to work on trends.

"By correlating observed and modeled data we can assess how well the models are doing and potentially use these to identify and better understand storm trends," says Trapp.

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CCSM Progress Report

The Community Climate System Model (CCSM) will be included as one of more than a dozen general circulation models providing data to the Intergovernmental Panel on Climate Change's (IPCC) Fifth Assessment Report. In preparation for this report, CCSM development has been frozen. The latest version, CCSM4, boasts a variety of updates to all its components — atmosphere, land, ocean, and sea ice — compared to the previous wide-release version, CCSM3; CCSM4 will be made widely available to the climate research community in spring 2010.

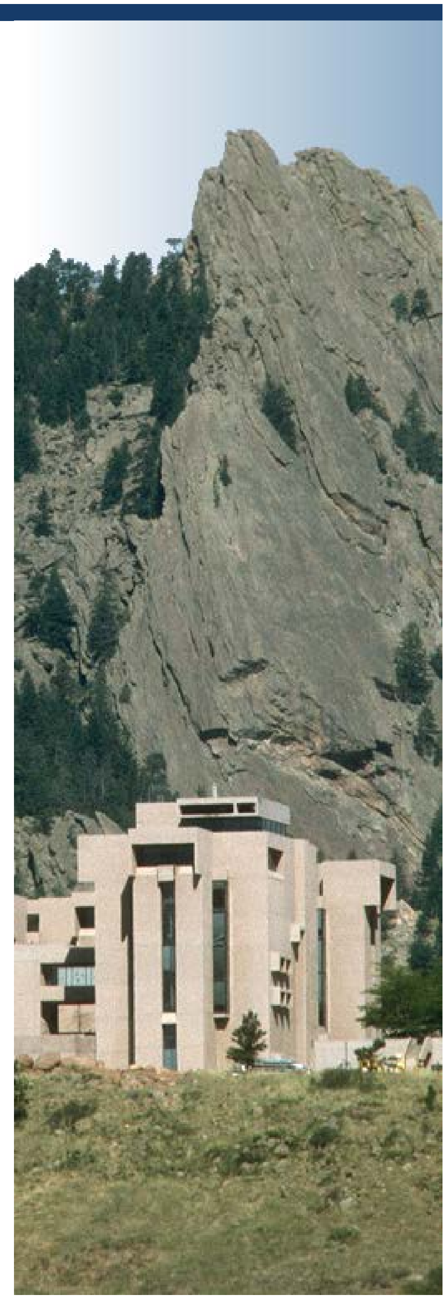
CCSM4 advances include a variety of new developments in the ocean model, such as increased vertical resolution. The new sea ice component contains improved radiative transfer and albedo schemes, a surface melt pond parameterization, and radiative effects and cycling of dust and black carbon aerosols. Another exciting enhancement is the coupling of a terrestrial carbon/nitrogen-cycle component to the Community Land Model (CLM4).

IPCC run preparations are moving ahead full steam, with a longer than 1000 year, 1850 control run complete for the chosen resolution of 1o in all the components. An ensemble of 20th century runs, which go from 1850 to 2005, are now underway. An ensemble of 21st Century runs from 2005 to 2100, using different projections for future levels of carbon dioxide in the atmosphere, will be made in 2010. In addition, the CCSM project is working with NCAR's Data Assimilation Research Testbed (DART), an open-source community facility that allows atmospheric scientists, oceanographers, hydrologists, chemists, and other geophysicists to build state-of-the-art **data assimilation systems**.

The CCSM4 ocean component is being used to assimilate a new set of ocean observations collected since 2003 by the Argo program, part of the Integrated Ocean Observing System. Argo data provide greater detail on ocean characteristics, including salinity and temperature, which will provide a more realistic ocean state using the DART assimilation system. These ocean states will be used as initial conditions for decadal forecasts using the CCSM, which are a new class of climate predictions that will be submitted to the IPCC Fifth Assessment Report.

In addition, two atmospheric chemistry components have been developed for the CCSM4. One version includes a very large number of chemical compounds, which will provide researchers with detailed information on, for example, pollution levels in urban areas. However, because of its comprehensive chemistry capabilities, the model requires significant computing resources. Consequently, a second, pared down version was created for users who need less exhaustive atmospheric chemistry, and simply want to understand how basic chemistry will affect future climate scenarios.

Other CCSM developments include significant progress on the **CCSM land-ice model**. Using the Community Ice Sheet Model, scientists will soon run future climate scenarios that include an interactive Greenland ice sheet; this will provide insights on the effects of glacial run off on sea level and the North Atlantic Ocean thermohaline circulation. In addition, an updated version of the Whole Atmosphere Community Climate Model (WACCM) based on the CCSM4 will soon be available. The updated model will allow a better representation of ozone, which is important as the "ozone hole" over Antarctica recovers during the first half of the 21st century.



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US Western Water and Environment

With population growth in the U.S. West among the fastest in the nation, a clear understanding of the effects of climate on health, natural resources, and societal welfare becomes increasingly important. Because of this, and because we are located in the U.S. West, these issues have particular interest to NCAR scientists. Below is a snapshot of some of the projects that our researchers and community focused on in FY2009.

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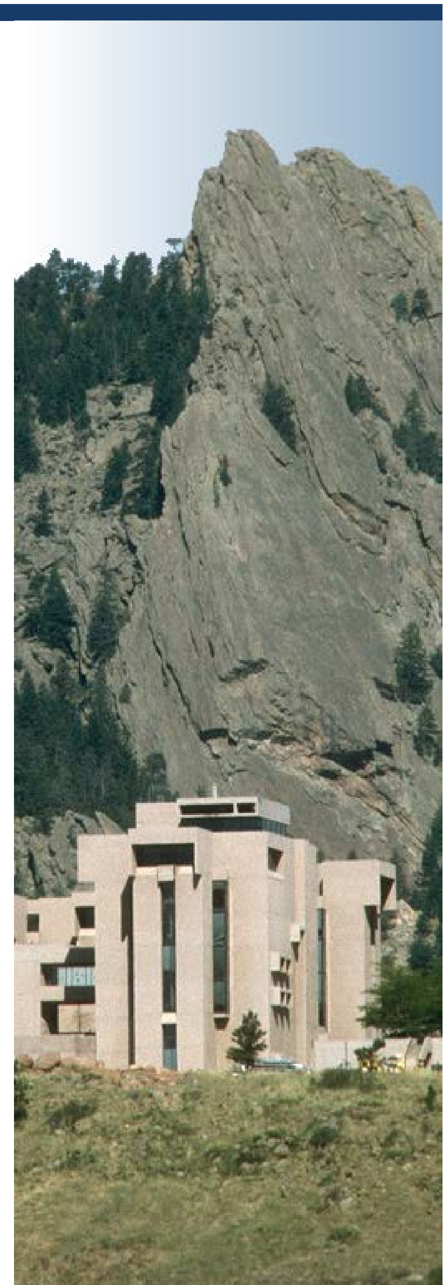


Climate change and moisture: Giving water managers a better sense of tomorrow's supply

Water managers have historically made resource projections assuming that past climate predicts future trends. With regional climate changing, these assumptions are less accurate and in worst case scenarios incorrect conjecture will leave resource managers — and water users — high and dry. NCAR's David Yates and Stockholm Environmental Institute (SEI) researchers retrofitted SEI's Water Evaluation and Planning System (WEAP) to address some of these planning needs

In 2001, responding to a call by the U.S. Environmental Protection Agency for new water resource forecasting tools that could factor in climate change, the team received funding to advance WEAP's algorithms. Originally created to in 1988 to evaluate sustainability of water demand and supply patterns, the team updated WEAP to include parameters such as humidity, wind, precipitation, temperature, etc. — key information for forecasting long-term future water scenarios. WEAP now transforms these parameters into practical hydrologic properties, like streamflow and runoff, which resource managers rely on to assess current and future climate conditions as they relate to flow forecasts.

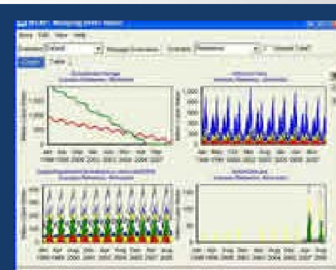
> ***With several thousand licensed users around the world, many have come to depend on the WEAP decision support system.***

With several thousand licensed users around the world, many have come to depend on the WEAP decision support system. This input has been essential to informing software revisions and improvements; working directly with users is important for ensuring ongoing innovation and utility. California water planners — who face some of the most demanding water issues in the United States — have been among those instrumental in putting WEAP development through its paces.

Among the organizations that rely on WEAP is the California Department of Water Resources, which uses the tool to generate data and scenarios used in its annual five-year water-plan update. WEAP lets planners evaluate water supplies, estimate agricultural, environmental, and urban water uses and demand — quantifying gaps between water supplies and uses — and assess options for meeting future water needs. Eldorado Irrigation District staff worked with University of California, Berkeley to devise a drought plan; they used WEAP to look at potential water delivery cut backs, including how and where these might be imposed under various drought stages, from Stage 1 (15% water use reduction from normal), to Stages 2 (30% reduction) and 3 (50%-plus reduction).

Many international water resource specialists have added WEAP to their water resource/climate change planning arsenal. In Peru, a tunnel is being drilled through the heart of the Andes' to transport up to 2 billion cubic meters of water from the lush Amazonian side of the continental divide to agricultural lands on the dry Pacific coast. As part of the process of considering how future climate change might affect water availability and climate patterns on both sides of the tunnel, Yates is working with project planners to use WEAP as part of their analysis process.

The next likely frontier for WEAP, says Yates, is the energy-water nexus; in California, 20% of energy use is tied to moving water from north to south. WEAP, with planned modifications, will soon help managers assess



WEAP allows users to design a bird's-eye view that highlight key indicators in a water-resource system.

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tradeoffs between energy use and costs, water costs, demands, needs, and availability in coming years. WEAP provides water agencies and decision makers with a means to make considered resource choices, which will be ever more essential as water becomes an ever more pressing concern to society.

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Neighborhood by neighborhood: Using GIS to assess how people deal with heat waves

In Phoenix, Arizona state and county public health personnel work diligently to ensure citizens are ready and able to deal with the city's frequent extreme heat events. Despite having a wide variety of programs and preventative information in place and publicly available, many preventable heat-related deaths and illnesses occur in Phoenix every summer. Scientists from NCAR, working with researchers from Arizona State University (ASU), and county and state public health service personnel, headed up a pilot project to better understand societal vulnerability and adaptive capacity to extreme heat in several Phoenix neighborhoods threatened by effects of summer-time heat events. Through their efforts, the team hopes to pinpoint characteristics of the most vulnerable populations for more targeted health interventions and extreme-heat preparedness programs. If successful, results will be extrapolated for use in other cities facing similar heat health issues.

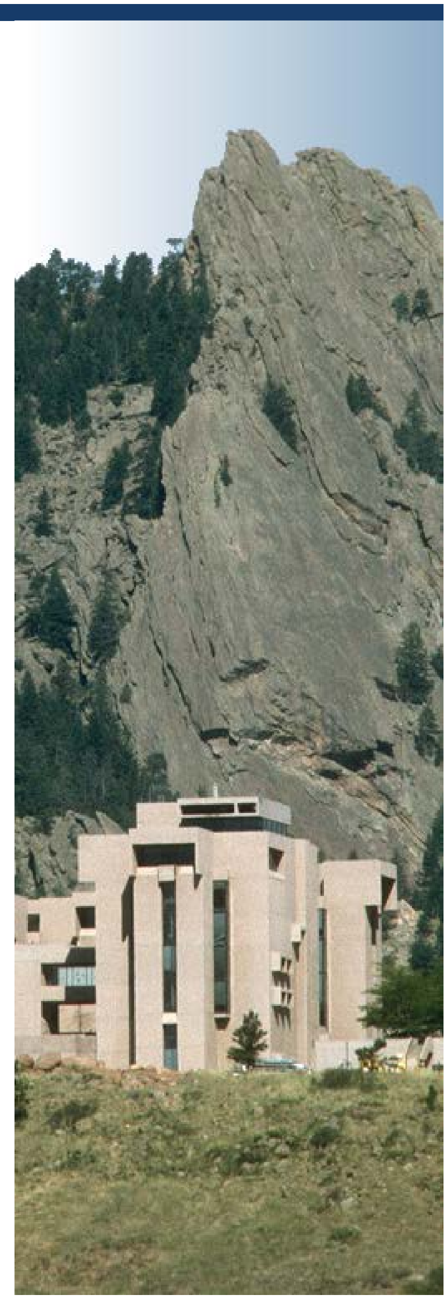
Typically, census data (income level, race, age, etc.) are used to assess a population's ability to cope with and adapt to extreme events. However, these data often gloss over adaptation capabilities at individual and neighborhood levels. In studying the demographics of heat wave mortality in Phoenix, for instance, the number of relatively youthful heat-related fatalities surprised the scientists — generally, heat affects older populations. Equally important is understanding why some neighborhoods fare better than others in extreme weather. For example, work done by Eric Klinenberg in Chicago shows that areas with strong community networks have reduced likelihood of injury and death related to heat exposure because neighbors check on each other's well being. In less interconnected neighborhoods, fatalities increase because individuals must cope with extreme weather largely on their own.

To identify study neighborhoods, the team mapped zones of higher vulnerability to heat waves across the city. Researchers used previous heat mortality cases and 911 heat distress calls, provided by ASU, and census-based socio-economic and demographic data, aggregated by neighborhood.

> ***Mapping spatial distribution of heat-related health outcomes and identifying links to neighborhood demographics was a first step.***

Mapping spatial distribution of heat-related health outcomes and identifying links to neighborhood demographics was a first step. Local public health experts and ASU researchers helped narrow the study to three neighborhoods that varied in terms of income level, and ethnic and cultural diversity. Researchers and a team of students from ASU and the University of Arizona conducted door-to-door surveys, gathering detailed information to assess household-level vulnerability to extreme heat, as well as adaptive capacity. Correlating geographic location with responses, the scientists will incorporate spatial components that relate neighborhood characteristics directly to coping capabilities and mechanisms as they vary by site. With this knowledge, the scientists hope to discover ties between the socio-economic, cultural and behavioral patterns that have — or might — influence neighborhood heat-wave coping strategies.

In addition to providing the foundation for future modeling of spatial adaptive capacity characteristics of a neighborhood and its residents to generate a



wider context of heat health vulnerability, the outreach provided neighborhood residents with practical information for effectively dealing with future heat wave issues. Because of this study, ties between residents and public health officials have strengthened, allowing health services personnel to more effectively meet their public mandate. And that's not a bad way to begin.

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