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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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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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. 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-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–
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.

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.

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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 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).
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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Scaling down to understand climate effects on severe storm formation

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. 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 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 even more essential as water becomes an ever more pressing concern to society.
WEAP allows users to design a bird's-eye view that highlight key indicators in a water-resource system.

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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. 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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Assessing winter precipitation in the Colorado Headwaters region

Snow provides a significant portion — up to 75 percent — of the U.S. West's water supply. The amount of water supply from snowpack varies dramatically from year to year, depending on a variety of factors ranging from total precipitation to soil moisture content, to effects of wind and wind patterns, etc. With millions of users depending on this water for hydropower generation, irrigation, recreation, and other uses, accurate prediction of snow melt and runoff is critical.

In generating annual water resource plans, decision makers rely on both direct observations, culled from a vast array of data collection sites located throughout the West, as well as climate models. In situ data provide information on snow water equivalent, precipitation and temperature for discreet areas, however, in mountainous areas individual sites do not always accurately reflect the collective snowpack characteristics for the region because of the highly heterogeneous terrain. Ideally, climate models can help interpolate snow characteristics between sites, but because many models have resolution on scales of 100s of kilometers, they too miss the nuance of the West's geography, and therefore poorly replicate snowfall patterns, and snow accumulation and melt processes. As a result, model results often don't match observations.

A recent Advanced Scientific Discovery (ASD) effort, funded by the National Science Foundation and supported by NCAR's Computational and Information Systems Laboratory, offered a way to improve model output that should provide water resource managers with better information from which to assess annual snowpack. The ASD award gave the Colorado Headwaters project team, which is looking at snow cover in the Colorado River headwater region, with computing power to run high-resolution regional climate simulations of cold-season snowfall, snowpack, and evapotranspiration across this area of complex terrain.

The Colorado Headwaters project received 500,000 computer GAUs — units charged for computing use — to run the high-resolution Advanced Research WRF-ARW model in assessing winter precipitation, snowpack, and runoff processes from Colorado's headwater basins. This region is particularly important because about 85 percent of the stream flow for the Colorado River comes from snowmelt in this area, and the Colorado is the primary source of water for much of the arid U.S. Southwest.

While diagnostic analysis of the simulations are still in progress, results so far show that the high-resolution regional model is able to reproduce observed SNOTEL (Snowpack Telemetry) precipitation amounts to within 10 percent of observations from 111 SNOTEL sites for all four simulated years; model simulation of spatial patterns of precipitation also shows excellent agreement with SNOTEL observations.

"The simulated strong dependence of snowfall and snowpack on grid resolutions illustrates the importance and usefulness of high-resolution models in improving the future climate projections by global climate models," says project lead, Roy Rasmussen, a senior scientist at NCAR. "Future work will focus on analysis of the future climate runs and conducting nested regional climate runs."

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Science Serving Society

Among NCAR’s missions is fostering transfer of knowledge and technology for the betterment of life on Earth. From improving prediction of severe weather both on Earth and in space, to providing health care workers with insights on disease outbreaks, those within the NCAR science community are breaking new research ground to better serve society.

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Bright models, big cities: Simulating urban weather in new detail

More than half of the world’s humans already live in cities, and urban growth seems likely to continue apace. United Nations (note to Rachel: verify this source) experts suggest that by 2015, the globe will have as many as 60 cities with populations of 5-million-plus. For these and many other reasons, scientists are looking at how cities affect local and global climate.

Combined factors such as high heat emissions from building climate-control, pollution resulting from industry and transportation, and a preponderance of paved surfaces, create urban heat islands (UHI) where day-time temperatures are 2º to 5ºF warmer than rural areas; during summer nights this difference climbs even higher — up to 12ºF. UHIs considerably influence local and regional weather, affecting wind regimes, precipitation, and humidity, for example. In turn, urban weather characteristics affect efficient dispersion of heat and pollution, human health, water quality, and energy consumption and greenhouse gas emissions.

Weather models provide one way of better understanding UHI effects on local and regional climate. With increasingly fine grids — resolutions of 0.5 km in some cases — these models offer a way of estimating and understanding urban weather in detail.

Fei Chen, an NCAR scientist in the Research Applications Laboratory, has studied UHI effects all over the world, looking at air quality in particular. Chen and other NCAR researchers and university and agency colleagues are developing an integrated urban modeling framework for the Weather and Research Forecasting (WRF) model. By coupling WRF — or other fine-scale weather models like the Pennsylvania State University/NCAR MM5 — to land surface (LSM) and urban canopy models, they can more accurately replicate urban weather dynamics. The Noah LSM, for example, hones the UHI perspective by providing details on city characteristics such as building type, height and density, land use, surface type, anthropogenic heating, heat and moisture exchange between indoor and outdoor atmosphere — details critical for accurately capturing and understanding the influence a city has on weather.

"We are applying WRF to look at various urban problems, such as the effects of urbanization on air pollution, public health, and how land–use changes affect climate change," says Chen.

HongKong, one of several cities Chen is studying, suffers from temperature inversions. As a result, during summer nights heat relief generated through mixing of cooler land air and warmer ocean air occurs less frequently because urban air temperatures often do not cool enough to instigate mixing. And, lacking the land breeze, pollution can languish in the city, resulting in human health problems related to respiratory issues, heat–related mortality and general discomfort.

Like HongKong, many urban areas contend with the effects of higher night–time temperatures in summer, which make looking at seasonal UHI effects a significant focus. Chen will soon take a more in–depth look at the impact of winter–time UHI on weather and climate. Less noticeable in its impact on human health and mortality, Chen expects this research will provide valuable new insights on urban weather regimes.
Coupling the Weather Research Forecasting Model with a large-eddy simulation model (Eulerian/semi-Lagrangian fluid solver), scientists can simulate urban canyon thermodynamical fields (for example, temperature and pressure) and transport fields to simulate transport of a contaminant from its source through an urban area.

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It's all related: Linking people, policy, and land use with a changing climate

Individuals, governments and industry clamor for a view on the effects of changing climate tens to scores of years down the road. To answer their questions and investigate options for responding to climate change, more and more scientists and policy makers are turning to integrated assessment models (IAMs). These models merge climate science, economics, demographics, land use, and policy analysis under a single umbrella.

IAMs are used to address applied policy questions such as, what might it take to cap greenhouse gas emissions at a given level? What role might land use play in driving future emissions or mitigation efforts? How might different rates and levels of climate change impact societies in the future? Is it better to act now or postpone some of our efforts until later? Answers to these and similar queries require decision makers to know how climate scenarios relate to non-climate factors such as economic growth projections, energy and land use changes, and global and regional demographics, among other parameters.

NCAR is among those U.S. research organizations that have a strong — and growing — IAM team addressing such questions. Starting at the global and national level their model, the Integrated–Population–Economy–Technology–Science (iPETS) model, currently focuses on answering emissions–related questions. Led by Brian O’Neill, the team is using iPETS to look at how future demographic change may affect emissions, and how viable achieving particular emissions reduction goals might be. Over time the group expects to focus on the role of land use and to do more impacts–related work, which would include assessing adaptation strategies in collaboration with the community of researchers studying climate impacts, adaptation and vulnerability (IAV). NCAR’s IAM group is also part of a consortium of research teams involved in developing a new round of integrated scenarios to be used as part of the Intergovernmental Panel on Climate Change’s Fifth Assessment Report.

The team is exploring ways to make iPETS the latest addition to NCAR’s suite of community models. The team plans to make the iPETS model accessible through a web interface and to make model code publicly available. Users will be welcome to contribute modifications and suggestions related to iPETS development. In addition, NCAR hopes to link its IAM to general circulation models like CCSM. Until recently, this cross–model integration was hampered by slow computing speeds and limited demand for integrated assessment output. However, in both areas, this reality has changed.

Despite IAMs being in vogue as a means of answering pressing climate questions, the need for continued work and refinement of GCMs remains critical. Climate science/model uncertainties like cloud and precipitation issues need to be resolved so as to further bolster IAM efficacy. NCAR’s climate science and IAM groups will work together to participate in achieving this end.
National Center for Atmospheric Research

2009 ANNUAL REPORT

The storms between Sun and Earth: Looking for more lead time on damaging space weather

Beyond providing Earth with its predominant source of heat and light, the Sun affects the planet and human society in a variety of other ways. For instance, effects from storms propagating from the solar corona outward through space, can seriously impact aviation, electrical grids, and satellite performance on Earth, often impinging on daily societal function directly. Due to distance from the Earth and few observing instruments, solar storms cannot currently be predicted. But, once observed, researchers can monitor a storm’s progress, tracking it through space, into the magnetosphere, Earth’s outermost protective boundary. To isolate and identify storm characteristics and better forecast future events, scientists are turning to the Coupled Magnetosphere Ionosphere Thermosphere (CMIT) model developed by HAO scientists in collaboration with the NSF–funded Center for Integrated Space Weather Modeling.

Extreme space weather events include coronal mass ejections (CMEs). Not unlike hurricanes in space, CMEs expel a plasma of charged particles and elements like helium, iron, and oxygen, and cause the coronal magnetic field to propagate outward from the Sun, toward Earth. Despite the magnetosphere, which acts as a gatekeeper, protecting the lower atmosphere from solar winds by harnessing the energy and momentum of incoming ions and magnetic forces, CMEs can have serious repercussions on Earth.

In particular, aviation faces significant challenges during strong space storms. Pilots flying above 85 degrees latitude are outside the range of satellite communications and therefore must rely on radio communications for navigation. However, severe space weather disrupts radio transmissions; ionized particles and heightened magnetism affect radio wave propagation. A highly ionized atmosphere can also disrupt Global Positioning System (GPS) signals, throwing off the required triangulation of points that allows correct location of an object — such as an airplane — by GPS receivers. The more ions present in the atmosphere, the longer a signal takes to triangulate between points, so precise information on ionization level (the total electron content of the upper atmosphere) helps assess GPS accuracy. Also, the global wide area augmentation system (WAAS) provides the aviation industry with direct connection to GPS units. Capable of providing GPS calculation corrections in most circumstances, under extreme atmospheric ionization events, WAAS capabilities can be severely curtailed if not completely debilitated.

CMIT couples a magnetospheric model (Lyons–Fedder–Mobarry) with NCAR’s Thermosphere–Ionosphere Electrodynamics General Circulation Model (TIE–GCM). CMIT can simulate ionosphere activity by driving magnetospheric dynamics; these dynamics, in turn, are driven by the solar winds. The CMIT framework connects these linked systems and allows scientists to compare modeled outcomes with observed space weather events and characteristics. In doing this, new insights are being gained on the cascading effects of solar activity on Earth, which is particularly important for regions acutely affected by space weather.

Observational data obtained from satellites like NASA’s Advanced Composition Explore (ACE), provide researchers with information about solar wind — temperature, composition characteristics, speed, etc. — and geomagnetic storm observations back to Earth within an hour of storm onset. Feeding these observations into the CMIT drives magnetospheric dynamics, which are used to drive — and better understand — ionospheric activity. In doing so, CMIT isolates what causes for many of the Earth–bound anomalies. Causes can range from variation in atmospheric chemistry to motion of ionospheric plasma.

CMIT is not currently used in real time — and therefore cannot be used operationally to forecast space weather events — but over the long term, scientists hope to use the model in a predictive capacity. Right now CMIT is an
effective research model, providing an improved view on Sun–Earth interactions as well as in assessing how the two models do individually and as a coupled unit.

This scientific visualization shows results from the CMIT model depicting the impact of a shock at the head of a coronal mass ejection on the magnetosphere. The visualization clearly shows the inward motion of the magnetopause and compression of the magnetosphere at the arrival of the shock which is modeled from solar wind observations and throughout of the coupled magnetosphere – ionosphere – thermosphere system. Accurate modeling of these types of events is essential for creating reliable space weather predictions.

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How strong a hurricane? New modeling brings fresh angles to a perennial problem

The stronger the near-ground winds in a hurricane, the greater the damage to infrastructure and the higher the risk to human lives. A hurricane's inner core drives storm intensity, however little is known about inner core dynamics because few direct observations have been made; lacking observational data, scientists have only slightly improved hurricane-intensity forecasts in 30 years. Hoping to advance and enhance such predictions, the National Oceanic and Atmospheric Administration (NOAA) recently launched the Hurricane Forecast Improvement Project (HFIP), providing funding for both in-the-field research and hurricane modeling efforts. The field observations will not only help scientists refine understanding of processes occurring in the hurricane's eye wall, where the strongest wind and rainfall occur, they will provide a means of testing and improving weather-model output.

Model output evaluation is critical. The inner core of a hurricane spans a limited geographic area (at its widest, the eye wall is perhaps 10 miles wide), and evolves quickly in time and space. The time it takes a hurricane to spin up from a tropical storm can be as little as 24 hours. These characteristics complicate the modeling effort, requiring high-resolution models that can predict hurricane intensity changes and that are agile enough to resolve the attendant weather on timescales of hours.

NOAA initiated its HFIP effort asking researchers at participating modeling centers to look at hurricane development at varying spatial and temporal resolutions to assess a given model's forecast capabilities. NOAA chose to focus on 2005 and 2007 hurricanes, were both difficult to predict at the time and had a significant societal impact.

Led by Chris Davis, NCAR's Mesoscale and Microscale Meteorology (MMM) Division participated in HFIP using the Advanced Hurricane-research WRF (AHW) model. Davis and colleagues wanted to see how changing the AHW's horizontal resolution — that is, the individual cell blocks within the model — affected model output, comparing forecast data generated at a grid size of 12 km to data generated with the addition of a smaller, moving 1.33-km grid that followed the storm. Not least, NCAR's scientists wanted to determine if costs incurred from increasing computing time and power as a result of running higher resolution models could be balanced against potential forecast improvements. NCAR's HFIP results indicated a measurable improvement due to increasing resolution, and were the only modeling results among the many HFIP participants to find such a benefit.

Davis believes that among the reasons for this result, MMM and AHW have the advantage of a long history and modeling experience at high resolution, and AHW development benefits from significant scientific community input. As result, AHW is more nimble than other models, particularly in terms of nesting higher resolution grids within lower resolution grids to generate hurricane intensification predictions. Furthermore, collaboration with Ryan Torn at the University at Albany (State University of New York) allowed the use of a more sophisticated method of initializing the forecasts. This method, generally termed ensemble data assimilation, reduced the imbalance that is sometimes introduced into the initial state of models and provided more realistic storm structures than can be obtained with more traditional initialization methods. At a minimum, NCAR's HFIP results suggest a place for fruitful cross-center collaboration to begin. In future, MMM and other centers hope to run similar experiments in real time. With a quiet 2009 hurricane season, HFIP participants look forward to 2010 as the season to advance this goal.
Tracks of Katrina generated from high-resolution forecasts performed for the Hurricane Forecast Improvement Project (HFIP). The dates in the upper right corner are initialization times of each of the six numbered forecasts. Intensity is also indicated along the track by color code at bottom left.

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Forecasting for Disease Prevention in Africa's Meningitis Belt

Periodically, epidemics of bacterial meningitis break out across a stretch of sub-Saharan Africa. This region, dubbed the meningitis belt, reaches across the continent from Senegal to Ethiopia. During the world's largest recorded outbreak of epidemic meningitis in 1996 and 1997, more than 250,000 Africans fell ill and 25,000 died. Dry, dusty conditions seem to be correlated with the disease, while onset of the summer rainy season sees epidemics end. With limited vaccine available to combat the disease and difficulties related to getting vaccines to those in remote areas, health officials and scientists combating the disease hope to use weather forecasts to concentrate efforts on regions most at risk, while pulling back from areas about to get rain.

In November 2008, an international team of health and weather organizations and experts launched a project to provide long-term weather forecasts to medical officials in Africa to help reduce outbreaks of meningitis. The forecasts will allow local health providers to target vaccination programs.

Meninges, the thin linings that surround the brain and spinal cord, are affected by the often-fatal disease. Researchers do not completely understand the relation between dry and dusty conditions and meningitis. Some theorize that mucous linings in people's respiratory systems are irritated by dusty conditions, while others suspect changes in social behavior might be to blame as residents tend to stay indoors during the dusty season, which facilitates spread of the disease.

"We're applying our expertise in weather forecasting to assist health care officials on the front lines of this disease," says Rajul Pandya, director of the University Corporation for Atmospheric Research's Community Building Program (UCAR is NCAR's managing body).

By targeting forecasts in regions where meningitis is a threat, we may be able to help vulnerable populations, continues Pandya. Ultimately, we hope to build on this project and provide information to public health programs battling weather-related diseases in other parts of the world.

Over the next year, project leaders will focus on Ghana, a country hard-hit by past meningitis outbreaks. Issuing 14-day forecasts of atmospheric conditions in Ghana in 2009, NCAR meteorologists analyzed computer models run by agencies such as the European Centre for Medium-Range Weather Forecasts and the U.S. National Centers for Environmental Prediction. To make reliable predictions, the meteorologists are using statistical techniques to zero in on the meningitis belt, giving greater weight to models generating the most accurate forecasts under specific conditions. The forecasters also look at upper-atmospheric patterns that could indicate the impending start to the rainy season.

In the next two years, the team will work closely with health experts from several African countries to design and test a decision support system that will provide health officials with useful meteorological information. One of the biggest challenges will be disseminating the forecasts to health officials on the ground.

"Working closely with both the meteorologists and local public health officials will allow us to more effectively target vaccines to at-risk populations in areas with limited resources," says Mary Hayden, a medical anthropologist at NCAR.

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Taking Science to the Field

As part of our mission to serve the science community, NCAR supports NSF–funded field campaigns, providing equipment, services and staff. Field campaigns are an essential part of basic scientific research; the resulting in situ observations improve our understanding and ability to predict — and hindcast — Earth system processes and dynamics.

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Sunrise at the OASIS: Springtime's light triggers sharp changes in Arctic air chemistry

More than simply ushering in a promise of spring, increasing late-winter Arctic sunlight corresponds with depletions in the region's atmospheric ozone and mercury. During the winter's cold and dark, newly formed sea ice provides a reactive surface on which chemical species involved in ozone- and mercury-depletion events such as bromine oxide (BrO) form. In a recent, Barrow-based research campaign, scientists gathered to hone in on finding answers to questions of how and why these events occur, how BrO fits into the Arctic's ozone and mercury depletion picture, and at what scale and for how long these reactions are occurring.

Depletion of both ozone and mercury has significant environmental impacts. Such low levels of ozone are not common in unpolluted regions, and serve to alter the chemistry as well as influence biota. In the case of mercury, deposition from the atmosphere onto the sea ice, snow and ocean surfaces introduces this toxic substance to the biosphere. With the chemical and physical exchange processes poorly understood, a number of universities led a field campaign — the Ocean–Atmosphere–Sea Ice–Snowpack (OASIS) — as part of the International Polar Year to boost scientific comprehension of the drivers behind these processes.

Run between February and April 2009, OASIS scientists designed and carried out a thorough set of experiments measuring atmospheric chemical composition and chemical fluxes to and from snow and ice surfaces using a variety of sensors. Results will shed light on the influence, life-span and interactions between naturally occurring chemical species in the Arctic. Findings will also help to fine-tune chemistry and climate models that try to replicate these interactions.

Typically atmospheric ozone depletion events occur over distinct regions for periods of up to several days. With experiment results currently under analysis, the scientists also hope the OASIS program results shed light on the variety of possible effects of anthropogenic pollutants on the ecosystem, and provide insight on possible interactions between the region's quickly changing climate and regional chemical dynamics.

Among its unique characteristics, multiple universities initiated and led OASIS, including Purdue University and University of California, Davis. With a nucleus of scientists and research foci in place, additional researchers, including individual university investigators, science organizations and government agencies asked — and were asked — to participate. This broad community collaboration helped the 2009 OASIS campaign generate a wide-ranging set of measurements at a level unprecedented by anything done before in a similar research setting.

Sought out by OASIS principal investigators because of skills and expertise in field studies of this nature, NCAR scientists and staff coordinated many project logistics, and ran 10 different experiments that provided the backbone for the gas–phase component of the study. With a high number of ozone–depletion events observed during the campaign, the weather cooperating, all instruments operating as expected, and observations of anticipated chemical compounds secured, OASIS scientists have high expectations of exciting results from their two months of field work.
OASIS researchers inside one of the modules in Barrow, Alaska. The OASIS (Ocean–Atmosphere–Sea Ice–Snowpack) field project made some of the most extensive measurements ever on the chemical exchanges between polar air, snow, frost, brine, and sea ice. Part of International Polar Year, OASIS tackled a number of standing questions in polar chemistry, with the emphasis on the life cycle of pollutants that drift into the Arctic.

Little known outside the world of polar research, frost flowers haven’t been studied much till recently. They’re highly salty, which makes them potentially important in the chemistry of depletion events. This image shows an OASIS researcher working with equipment involved in the study of a freshly formed batch of frost flowers atop a patch of ice cleared the day before. The OASIS (Ocean–Atmosphere–Sea Ice–Snowpack) field project made some of the most extensive measurements ever on the chemical exchanges between polar air, snow, frost, brine, and sea ice. Part of International Polar Year, OASIS tackled a number of standing questions in polar chemistry, with the emphasis on the life cycle of pollutants that drift into the Arctic.
To the tropopause: Capturing fast-changing air at high-flying altitudes

Our planet's climate is influenced by the atmosphere's chemistry. How chemicals interact, how chemicals are distributed, and how many and the types of chemicals present in the atmosphere all play a role in influencing the Earth's climate. Much of the chemistry influencing climate occurs in the atmospheric layers closest to the surface — the troposphere and the stratosphere. But it is the boundary between these layers — the UT/LS (upper troposphere/lower stratosphere) region — that has a particularly large influence in terms of generating climatic effects.

Scientists have learned much about the chemistry of the atmosphere from remote sensing instruments placed on Earth-orbiting satellites. These instruments continually probe the atmosphere, providing global-scale observations of a limited number of gases and particles. Measurements of gases such as water vapor (H2O), ozone (O3), and carbon monoxide (CO) provide critical information on global atmospheric chemistry and air transport. However, measurements from satellites tend to miss the fine detail that is often important in unraveling the actual processes that control chemical distributions. And the chemical composition that can be determined is limited. This lack of detail becomes especially important in the UT/LS region, where changes in chemistry can occur over very short time and space scales.

Understanding the UT/LS role in the climate system requires extensive and detailed knowledge of chemical processes and distributions — processes and distributions that can occur over a range of scales, from minutes up to decades. To better understand these phenomena, it is essential to take in-situ measurements within the UT/LS. One obvious solution is to collect air from this region and bring it back to the lab to determine which chemical components are present. Until recently, no airplanes — the most obvious measuring platform — could fly high enough to achieve this. With NSF's Gulfstream V (GV), the platform became available.

Elliot Atlas (University of Miami), and Donald Blake and Eric Saltzman (University of California, Irvine) proposed creating a new instrument designed to fly on the GV and collect in-situ samples. The resulting instrument — the Advanced Whole Air Sampler (AWAS) — incorporates the investigators' years of research experience and provides a tool that they and the wider science community can use to sample the UT/LS region for the first time.

Once on the ground, AWAS air samples can be taken to a controlled laboratory environment, and run through multiple instruments to generate high-precision chemical analyses. Typically more than 50 individual trace gases can be measured from the AWAS, providing chemical fingerprints of industrial emission sources, biomass burning, and/or natural emissions from land plants or the ocean surface.

In its first scientific mission, Atlas used the AWAS on the GV during the START08 (Stratosphere-Troposphere Analyses of Regional Transport 2008) experiment. Of special interest, he and his colleagues wanted to determine how chemicals with different atmospheric lifetimes were distributed in the UT/LS region. Because of the wide range of chemicals that the AWAS can measure, it is possible to obtain fine-scale information on
original sources of air in the UT/LS, and on how air mixes across the troposphere/stratosphere boundary.

Among the exciting discoveries of START08, AWAS and the suite of instruments included in the GV payload provided the first in-situ observations of the chemistry of a deep intrusion of tropospheric air into the lowermost stratosphere. Combined with meteorological analyses, the source of the intrusion could be pinpointed to the upper troposphere in the tropics over India.
A tale of two continents: Why does Eurasia outpace North America in spring warming and melting?

Observations show Eurasian spring-time snow melt and warming proceeding at a faster rate during the past 30 years than has occurred in North America. Mark Flanner, a recent NCAR Advanced Study Program graduate, led a study that estimates that warming rates and snow cover decline in Eurasia are two times as great as those in North America. In the same study, Flanner and his colleagues also point out that climate scenarios generated by all but one of the Intergovernmental Panel on Climate Change’s (IPCC) Fourth Assessment Report general circulation models (GCMs) fail to reflect this trend; most IPCC model runs show the regions having similar spring–time temperatures and snow-melt rates. The scientists suspect aerosols — particularly black carbon and organic matter such as dust — might be responsible for the difference in modeled versus observed climate.

Generated by human activity, dust storms, and forest fires, Asia produces high levels of both types of aerosols. Blown across the Eurasian land mass, black carbon and organic matter affect the surface and nearby atmosphere in a variety of ways. Black carbon tends to warm the atmosphere by absorbing incoming solar radiation. In addition, aerosols reflect incoming solar energy, potentially cooling the underlying surface. However, particulates that fall to the surface reduce snow’s reflective qualities, causing more radiation to be absorbed. Overall, the amount of heating is greater than the amount of cooling over snow surfaces. Northern Hemisphere spring–time snow cover is unique both because of its widespread distribution and because the relatively intense incoming solar radiation makes the snow more vulnerable to atmospheric aerosols’ effects. Flanner and colleagues hypothesize that higher concentrations of organic matter and black carbon typically found in the atmosphere and on the snow–covered surfaces in Eurasia might account for regional snow-cover differences. By including black carbon and organic matter aerosols as GCM parameters, they thought the models might more effectively match spring–time observations.

To test their hypothesis and better understand why most IPCC GCMs don’t reflect the observed spring–time response, the team ran a number of modeling scenarios to see if the issue might relate to ocean–based effects. They began their study here because if oceans proved to be playing a leading role, their hypothesis would likely be incorrect, which would lead to identifying alternate explanations. But, after constraining the oceans’ effects, the GCMs continued under–predicting land–surface temperature trends. This indicated that a land effect had to account for the discrepancy between observed and modeled warming and melt trends.

Having eliminated ocean effects, they experimented with enhancing the GCMs with snow–darkening characteristics (i.e., deposition of materials darker than the pristine snow surface). In doing so, the models generated increased spring–time Eurasian warming.

Next, the researchers compared the models’ springtime climate responses to CO2 and black/organic carbon aerosols. The scientists found as much reduction in Eurasian spring snow cover caused by black carbon and organic materials currently emitted from fossil fuels and biofuels as from human–produced CO2. But over North America, CO2–induced snow cover loss was greater.

"While this research does not fully explain why springtime land temperatures and snow cover are changing so much faster over Eurasia than North America, it does suggest that snow darkening from black carbon,a process lacking in most climate models, is playing a role," says Flanner. Ultimately, Flanner continues, the magnitude of Earth’s climate response to CO2 and other human–generated products depends on feedbacks. Changes in snow
cover amplify initial climate changes and constitute one of the most powerful feedbacks. Because snow covers much of the Northern Hemisphere during spring, Flanner and his colleagues expect to see some of the strongest climate change signals in northerly regions during local spring.

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Storm Chasing: Tracking Tornadoes in the U.S. Midwest

Approximately 60 deaths occur each year in the United States as a result of the roughly 1,000 tornadoes generated each year. Tornadoes have long been studied, but questions remain as to why, how and under what circumstances tornadoes form. To better answer these questions, more than 100 scientists and staff gathered in the U.S. Midwest in late spring 2009 to study supercell — isolated thunderstorms characterized by strong, rotating updrafts that are the precursors to tornadoes — and tornado generation.

This work, funded largely by the National Science Foundation and the National Oceanic and Atmospheric Administration, expands on an initial Verification of the Origins of Rotation in Tornadoes Experiment (VORTEX) run in the mid-1990s. The 21st century effort involves researchers — including a significant contingent of graduate students — from around the world who spent a month as nomads, tracking tornadoes using a fleet of mobile radar and other ground-based instrumentation. Identifying likely supercells, they gathered in-depth information on tornado formation processes.

"We still do not completely understand the processes that lead to tornado formation and shape its development," says Roger Wakimoto, director of NCAR's Earth Observing Laboratory and a principal investigator for VORTEX2. "We hope VORTEX2 will provide the data we need to learn more about tornado development, which in time will help forecasters provide the public more advance warning before a tornado strikes."

Despite an unusually quiet tornado season in 2009, the team captured critical information from several severe storms that will bolster knowledge related to supercell and tornado genesis, life span, and death. Equally important, scientists also had an opportunity to observe supercell development that didn't result in tornado generation, despite seemingly ideal conditions. With a second month-and-a-half-long study to look forward to beginning in May 2010, scientists are currently assessing the 2009 data to refine study approaches and questions for the final stage of VORTEX 2.

VORTEX2 vehicles stop by the side of the highway as they track the Goshen Country storm in Wyoming on June 5, 2009. Two vehicles are equipped with roof-mounted weather stations. VORTEX2 is designed to improve our understanding of tornado formation, which ultimately will better allow us to assess the likelihood of tornadoes in supercell thunderstorms and possibly tornado intensity, longevity, and cyclic behavior.

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Cutting-edge Research

By its nature, scientific discovery is exciting. Taking existing understanding to the next level is the goal of every researcher. Below are some areas where the NCAR scientific community is leading the charge to take existing knowledge and apply it in new ways to address both age-old questions and existing and burgeoning issues.

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Plasma that packs punch: Spaceborne telescope finds a possible cause of the solar corona's heat

The 2006 launch of Hinode changed the picture of the Sun for astrophysicists. A satellite that includes a high-resolution telescope, Hinode captures images of the Sun in unparalleled detail without interference from the Earth's atmosphere. Among the regions observed by Hinode is the solar chromosphere, the area separating the Sun's surface — the photosphere — from its extended atmosphere — the corona. This advance in imaging allows scientists to measure smaller features missed by older, ground-based telescopes. With these new, better images in hand, several scientists found tantalizing clues that led them to a new way of addressing the age-old question of why the solar corona is millions of degrees hotter than the photosphere.

Intuitively, the Sun's atmosphere should get cooler with distance from the Sun's surface, but reality doesn't match supposition. Using Hinode imagery, Bart De Pontieu of Lockheed Martin's Solar & Astrophysics Laboratory and Scott McIntosh of NCAR's High Altitude Observatory were able to see differences between "classic" Type-I spicules — jets of dense plasma that shoot up from the chromosphere — and a new type of spicule. These Type-II spicules — that McIntosh and De Pontieu have recently dubbed "radices" — are hotter, shorter lived and faster moving than their Type-I brethren.

In the imagery, radices appeared to shoot upward, disappearing into the corona. The researchers observed radices (or a single radix) moving at speeds often in excess of 100 kilometers per second. The jets likely contain plasma that ranges in temperature from 10,000 to several million degrees Celsius, and have a life span of no more than 10 to 100 seconds. While astrophysicists — including NCAR founder, Walter Orr Roberts — have long studied Type I spicules, it is known that the material in those does not reach coronal temperatures of 1 million degrees Kelvin, which eliminates a connection to coronal heating.

At a 2008 Hinode meeting, when a colleague discussed seeing the presence of a very subtle 100-km-per-second upward velocity component in a coronal region of very strong magnetic field, McIntosh and De Pontieu looked at each other, and wondered if they were possibly seeing the coronal signature of radices. After an intense search for the "ideal" Hinode data set, they traced the columns of plasma ejected from the chromosphere into the corona. Each approached the task from a different perspective. McIntosh, with spectroscopic expertise, studied the coronal observations while De Pontieu, who has studied a host of chromospheric events in high-resolution ground-based observations, dealt with the chromospheric dynamics. Comparing their investigations, the two realized that the locations of the radices and the upward velocity signature were the same. They also found that the velocities of the chromospheric jets and those of the coronal events matched extremely well.

Based on this evidence, De Pontieu and McIntosh estimate that radices play an important role in supplying and replenishing the hot mass of the solar corona and wind. Based on their calculations, radices can fill the corona with hot plasma even if only one to five percent of the chromospheric radices' mass reaches coronal temperatures.

Interestingly, the location of radices in regions of strong magnetic field, combined with their role in heating the middle solar atmosphere means that they may play an important role in dictating the ultraviolet (UV) output of the solar atmosphere. For Earth, this is important because it implies that their presence and distribution over the solar surface plays an important role in governing the UV radiation that impinges on the Earth's atmosphere, in turn affecting the production and destruction of stratospheric ozone impacting climate dynamics and evolution.

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The Joint Numerical Testbed: A collaborative proving ground for cutting-edge models

Numerical models are the workhorses of U.S. weather prediction systems. Working behind the scenes, weather forecasters interpret model output; many real-time weather forecasts that the public has come to rely on are generated based on this output. Making these workhorses better, stronger, faster and — most importantly — more useful and reliable is the focus of NCAR's Joint Numerical Testbed (JNT). Working closely with the research and operational communities, the JNT takes research models' leading-edge capabilities and, through testing and evaluation, helps ensure that they meet operational needs.

Research and operational requirements vary significantly when it comes to weather model output. Operational forecasters (the National Weather Service, for example) have direct links to society, generating as-accurate-as-possible forecasts in real time. Not only do operational forecasters have to-the-minute time constraints, they must also contend with limited computing power and space; if anything goes awry with model runs, forecast delivery schedules can be left in tatters and operational forecasters caught flat-footed during potentially serious weather events. As a result, this community tends to be leery of using model code that hasn't passed a rigorous litmus test. Researchers work with fewer of these pressures and have greater flexibility when it comes to testing out new model functionality — and generally demand cutting-edge model capabilities. While both communities may use a single same model, output and public requirement differences mean that all jointly used tools must address disparate user needs.

The Weather Research Forecasting (WRF) model provides a good example of where the two worlds meet. While tackling each community's set of requirements may seem straightforward, achieving the required capabilities demands a high degree of model sophistication. And, having an agent — a neutral group without a horse in either race — assists model enhancement, validation and development, which was how the JNT came into being at NCAR. While born into the Mesoscale and Microscale Meteorology (MMM) division, home of WRF, NCAR's Research Applications Laboratory took on this effort so as to avoid perception of a conflict of interest within the wider WRF community.

In developing operational models from research versions, the JNT queries users from both communities to identify a model that would benefit from JNT code evaluation and testing skills. For instance, a particular aspect of a model — such as 1-day hurricane intensity forecasts — or intercomparison of models with similar forecast objectives might be assessed. Testing begins after choosing a representative period of model operations, including a variety of times, seasons, forecast lengths, times of day to ensure the desired level of thoroughness is met. Evaluation outcomes lead to new insights on model performance; these insights can be rolled into future model improvements that serve the public, government, private, as well as research interests.
The JNT’s four components — the Developmental Testbed Center (DTC), the Data Assimilation Testbed Center (DATC), the Tropical Cyclone Modeling Testbed (TCMT), and the Applied Statistics and Verification Research project (ASVR) — provide users with a breadth of services. The DTC, funded with support from NSF, NOAA, and the Department of Defense, is part of a national program supporting access for the research community to operational models and testing of next-generation numerical forecasting systems in the United States. The TCMT efforts center on testing and evaluating numerical weather prediction (NWP) systems used to predict tropical cyclones. And the ASVR project concentrates on developing statistically meaningful advanced verification tools for the assessment and comparison of the performance of NWP and other forecasts. Through its efforts, the JNT is helping bridge the gap between operational and research forecasting.

The figure above shows the 0.1-degree-latitude Parallel Ocean Program (POP) model simulated Chlorofluorocarbon-11 concentration (on a logarithmic scale) at 1625m depth in the North Atlantic Ocean on January 1st 1985.

Among the Joint Numerical Testbed capabilities are model evaluation tools, state-of-the-art software provided to the meteorological community for forecast verification. This example demonstrates the use of MODE – an object based diagnostic tool that evaluates the performance of forecasts by measuring meaningful attributes such as the displacement between forecast and observed storms, rather than focusing only on agreements between gridpoint values, as is done with traditional verification methods.
Gaining Stellar Insights

Scientists are gathering unprecedented quantities of solar and stellar data from sophisticated ground-based networks and space-based missions. Designed to take a closer look at global oscillations of the Sun and other stars to deduce their internal structure, the sheer volume of data creates a scientific challenge of its own: finding an efficient way to process and analyze vast amounts of information. Supercomputers provide an answer to this problem, and scientists are using the National Science Foundation's TeraGrid resources at NCAR's Computational and Information Systems Laboratory (CISL) and the Texas Advanced Computing Center (TACC) to delve deeper into stars' properties.

TeraGrid is a national cyberinfrastructure for open scientific research that includes 11 academic supercomputing centers, including TACC and NCAR. Hayden Planetarium counts itself among TeraGrid's beneficiaries, using celestial data, as well as visualization resources and tools to create a new planetarium show that takes viewers on a journey through the universe's early formation. Journey to the Stars explains how dark matter's gravity gathered the primordial gas in the universe to form the first stars, and how these massive stars exploded, seeding the galaxy with new stars and the chemical elements that made life possible.

The show's centerpiece, and the most difficult sequence to depict scientifically, is a flight into the center of the Sun. These visual sequences, created based on the research of Juri Toomre, a professor of astrophysics at the University of Colorado at Boulder, were run on TACC's Ranger supercomputer.

"It's not enough to know what comes out of the surface [of the Sun]," Toomre says. "We would like to understand how the magnetic engine of a star works, how it churns away and how it builds orderly fields. This is one of the top 10 questions in physics."

Toomre's doctoral student Benjamin Brown used VAPOR (Visualization and Analysis Platform for Ocean, Atmosphere, and Solar Researchers), a tool developed by NCAR in collaboration with the University of California, Davis, and Ohio State University, to generate visualizations of the Sun and the image sequences for the movie. In addition, NCAR's Matthias Rempel, a scientist in the High Altitude Observatory, contributed to the movie using his numerical sunspot model to visualize the connection between the magnetic field in the solar interior and sunspots on the visible surface of the Sun. He customized a simulation for Journey to the Stars, processing approximately a terabyte of solar data on TACC's Ranger supercomputer.

"The results are beautiful," says Ro Kinzler, the show's producer. "No one has seen the Sun in this way, and the software from NCAR and computational resources from TACC made it possible."

The centerpiece of Journey to the Stars is a flight into the center of the Sun, complete with narration and music composed for the show. This silent clip features a visualization created with VAPOR, the NCAR–based Visualization and Analysis Platform for Ocean, Atmosphere, and Solar Researchers. In 30 seconds it provides a small window into what visitors to the Rose Center for Earth and Space experience on the Hayden Sphere's 87–foot, seven–million–pixel dome. (© 2009, American Museum of Natural History)
NCAR Launches Green Energy Initiatives

Researchers from NCAR’s Research Applications Laboratory (RAL) are collaborating with university researchers, US Department of Energy labs, and other NCAR entities to develop methods to more accurately analyze and predict wind energy to support the renewable energy industry. Among the early efforts that RAL has focused on is a joint project with Xcel Energy to advance research and develop technologies that allow Xcel to increase the amount of wind-generated energy in its energy portfolio.

"One of the major obstacles that has prevented more widespread use of wind energy is the difficulty in predicting when and how strongly wind will blow at the wind farms," says William Mahoney, the NCAR program director overseeing the project. "These forecasts are a critical step in getting more energy from wind."

NCAR scientists are providing Xcel Energy with highly detailed, localized weather forecasts to enable the utility to better integrate electricity generated from wind into the power grid. The forecasts will help operators make critical decisions about powering down traditional coal- and natural gas–fired plants when sufficient winds are predicted, allowing the utility to increase reliance on alternative energy while still meeting its customers' needs. In turn, Xcel Energy and NCAR are analyzing the forecasts to identify areas of forecast success as well as areas requiring improvement, which will be used by NCAR to identify areas that need additional research and development.

DOE’s National Renewable Energy Laboratory (NREL) is also supporting the project, developing mathematical formulas to calculate the amount of energy that turbines generate when winds blow at various speeds. The wind generation "sweet spot" occurs when winds blow between 10 and 20 miles an hour — at speeds below about six miles per hour, the turbine blades don't turn, above about 25 miles per hour, blades reach the maximum speed that their design can handle without compromising the turbine infrastructure.

"The entire issue of our forecasting is to get the wind speed right when it's between about 10 miles an hour and 20 miles an hour," says David Johnson, a RAL scientist. "Getting an accurate wind forecast within a couple miles an hour of that range makes a dramatic difference in our power forecast."

Using its suite of tools and models, NCAR is issuing high–resolution wind energy forecasts for wind farm sites every three hours. The prediction system has already proven successful for Xcel Energy, and is saving the company significant costs. With this success, says Mahoney, it seems likely that other wind forecasting companies may adopt the technology as a means of helping utilities in the United States and overseas transition away from fossil fuels.

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2009 ANNUAL REPORT

Metrics

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NCAR Student Appointments
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Informal science education and presentations

Awards

Fellowships

Visitor Appointments

Publications

Partners

These metrics are qualitative and quantitative measurements and assessments of the productivity, quality, and impacts of NCAR programs and activities.
Collecting field data has always been 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 campaigns (field-based observing missions or experiments) ensure successful data collection.

NCAR led or participated in 56 field campaigns in 14 countries and the United States. Locations ranged from the Amazon to the Arctic, and included more than 1,100 participants.

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

Sixty-one NCAR staff served in 82 different editorial roles in 56 journals. Publications included top tier journals such as Journal of Geophysical Research – Atmospheres and Atmospheric Environment to targeted journals such as Radio Science.

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.

More than 145 NCAR staff served in a multitude of roles on 435 external committees for national and international scientific, education, and governmental organizations, including organizations such as the Intergovernmental Panel on Climate Change, the American Geophysical Union (AGU), and the American Meteorological Society (AMS). Positions ranged from Chair of the Board of Directors to Committee Advisor.

NCAR Staff give formal scientific and technical presentations about data, models, theories, hypotheses, reviews, and results around the world.

Over 80,000 people were in the audience when 239 NCAR staff made over 1,400 scientific and technical presentations across the country and around the world, from Kona, Hawaii to Ilulissat, Greenland. Examples range from Bill Mahoney's (RAL) presentation on optimizing wind power using wind power forecasts in Houston, Texas to a presentation on regional climate models, spatial data and extremes by Doug Nychka (CISL/IMAGe) in Eindhoven, Netherlands.

NCAR sponsored 75 colloquia in Boulder and abroad. Participants per session averaged out to 33, for a total audience of more than 2,400 peers and students. Some of the co-hosts include Rutgers University, DOE, NOAA, NASA, and the Max Planck Institute.

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 99 workshops and conferences in seven countries and nine U.S. states. We partnered with sponsors from the university community, such as the California Institute of Technology and Boston University, government agencies including NOAA, DOE and NASA, as well as with non-profit partners like the World Meteorological Organization and the American Statistical Association. In total, these workshops and conferences reached just under 6,000 participants, a 20% increase over last year.

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 47. Seventeen percent of these appointments occur in seven countries around the world; 83% took place in 13 U.S. states including NCAR's Super Computing partner, the University of Wyoming. The longest term is 24 years and counting and the current cumulative commitment adds up to over 190 years of service.

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

Of the 100 graduate students that have NCAR staff serving as graduate advisors, 25% hail from Colorado institutions; 31% attend schools in 16 other states. The remaining 44% study at schools in 19 countries around the world, including six students from the University of Eastern Finland who are advised by James Smith.
Thesis committee[link]NCAR staff serve as dissertation or thesis committee members for internal and external graduate students.

Twelve Master students and 96 PhD candidates work with 56 NCAR staff as they pursue their degrees from universities in 19 U.S. states; this includes 43 students from Colorado institutions. Twenty-four students come from 17 countries, with Korean students leading the international count at four.

NCAR Student Appointments[link]Students also enjoy NCAR–based appointments.

In FY09, there were 63 student appointments: five Graduate Students, five Graduate Research Assistants and 35 undergraduate Student Assistants appointments. There were also 18 student internships coordinated through the Summer Internships in Parallel Computational Science (SIParCS) program, [link]http://www.cisl.ucar.edu/siparcs/index.jsp and the EOL Undergraduate Engineering Internship program at [link]http://www.eol.ucar.edu/about/work/eng-internship. These students hail from home institutions ranging from Denver's Metro State College to Louisiana State University. NCAR also awarded 38 postdoctoral fellowships to talented staff through the Advanced Study Program at [link]http://www.asp.ucar.edu/ and other laboratory visitor programs [link]http://www.ucar.edu/opportunities/postdocs/.

Special Appointments[link]

**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 3 year terms. This appointment is particularly suitable for parties who desire an extended, close–working relationship on scientific problems of mutual interest. Currently 36 hold appointments including Dr. Lance Bosart of State University of New York/Albany whose current research projects focus on observational and modeling studies of synoptic and mesoscale phenomena from a multiscale perspective. Dr. Bosart collaborates with MMM.

**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 11 with the recent appointment of eminent HAO scientists Ray Roble and Peter Gilman.

K–12 Outreach[link]staff across NCAR 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.

Twenty–one NCAR Staff worked with K–12 students from 32 schools. Activities included mentoring, lectures, tours and field trips reaching 14 different communities.

Informal science education and presentations[link]NCAR scientists participate in educational activities by contributing to the development and provision of informal science education resources. Examples range from serving on an exhibit advisory committee, to providing and vetting science content in Web sites and modules, to supporting community outreach at local community events, including judging at a science fair and supporting Super Science Saturday.

This year's count totaled more than 61 events. Among the highlights: Kate Young (EOL) led a balloon launch at Meadow View Elementary School in Castle Rock, CO; Matthias Rempel (HAO) developed a special display on sunspot simulation at the Rose Center for Earth and Space in New York City and Sarah Gibson (HAO) led Solar Week for Girls in the Boulder schools.

Awards[link]Each year a number of NCAR Staff are honored for their work and contributions to the Atmospheric and related sciences.

Thirty–six staff received special recognition for their work in FY09. Marcia Politovich (RAL) was selected as a Fellow of the American Meteorological Society (AMS) for her outstanding contributions to the atmospheric or related oceanic or hydrologic sciences or their applications during a substantial period of years. Simona Bordoni (ASP/NESL/MMM)was selected for the AGU James R. Holton Junior Scientist Award. This award was established by the AGU Atmospheric Sciences section in 2004 and is given to an outstanding junior atmospheric scientist within 3 years of their Ph.D. The award is to honor James Holton, who was a pioneer in atmospheric dynamics and an inspiration to young scientists. Art Richmond (HAO) was selected as the 2009 AGU Joint Assembly AGU Bowie Lecture Series—Nicolet Lecturer. The AGU Bowie Lecture Series was inaugurated in 1989 to
commemorate the 50th presentation of the William Bowie Medal, which is AGU's highest honor and is named for AGU's first president. His presentation on the upper atmosphere's response to the magnetosphere is available at http://www.agu.org/meetings/ja09/lectures/.

Fellowships (top) a fellowship is typically a special appointment granting support for a term in order to support advanced research or study.

Natasha Flyer was granted a fellowship at the Oxford Center for Collaborative Applied Mathematics (OCCAM), situated in the Mathematical Institute at the University of Oxford. The objectives of OCCAM are to develop innovative mathematical and computational methods for application to biology, engineering, geoscience, and industry. During her stay, Natasha's research focused on the development of radial basis functions, a novel mesh–less computational method, for three dimensional modeling of geophysical phenomena.

Aaron Andersen continued his fellowship at the Uptime Institute. Using benchmarking, abnormal incident data, and industry Best Practices collected from members of its knowledge communities, The Uptime Institute, Inc. (the Institute) has distilled uptime management into scientific disciplines and practices which can be confidently applied. The synergy of a knowledge community encourages more to be shared so that more is known, and then there is even more to be shared. This exponential increase in knowledge is facilitated by the Institute and its faculty of Distinguished Fellows. http://www.upsite.com/TUIpages/tuihome.html

Carl Drews graduated in August 2009 from the University of Colorado at Boulder (CU) with a Master's Degree in Atmospheric and Oceanic Sciences. The CU Department of Atmospheric and Oceanic Sciences (ATOC) awarded him a travel fellowship in the amount of $1,000 to travel to the Symposium of the Office of Naval Research (ONR) in Chicago, Illinois and present the results of his thesis research into wind–driven storm surge. Mr. Drews used the Regional Ocean Modeling System (ROMS) to model storm surge in Manila Bay, forced by WRF wind fields over a range of possible typhoon tracks. The conference provided the opportunity to meet and discuss his research results with other oceanographers funded by the ONR.

Scientific and Technical Visitor Appointments (top) 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.

<table>
<thead>
<tr>
<th>Visit Length</th>
<th>Number of Scientific and Technical Visitors in FY09</th>
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<tbody>
<tr>
<td>1–7 Days</td>
<td>213</td>
</tr>
<tr>
<td>8–14 Days</td>
<td>88</td>
</tr>
<tr>
<td>15–30 Days</td>
<td>109</td>
</tr>
<tr>
<td>1–2 Months</td>
<td>87</td>
</tr>
<tr>
<td>3–6 Months</td>
<td>228</td>
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<tr>
<td>6 Months – 1 Year</td>
<td>36</td>
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<tr>
<td>Total</td>
<td>761</td>
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</table>

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<thead>
<tr>
<th>Scientific and Technical Visitor Types</th>
<th>Headcount in FY09</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visitors on Payroll</td>
<td>50</td>
</tr>
<tr>
<td>NCAR funded Visitors</td>
<td>335</td>
</tr>
<tr>
<td>Externally funded Visitors</td>
<td>376</td>
</tr>
<tr>
<td>Total</td>
<td>761</td>
</tr>
</tbody>
</table>

NCAR Visitors hailed from 317 institutions, located in 46 different U.S. states and 42 different countries.

Publications (top) 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 referred and non–referred publications lists for the period October 1, 2008 to

For excellent library resources please go the NCAR Library Web site at: http://www.ucar.edu/library/

**NCAR Refereed Publications**: 550 (download PDF Bibliography)

550 Publication(s) for the time period 2008-10-01 to 2009-09-30
Group(s): ASP, ISP, NCARLIB, CISL, EOL, HAO, NESL, RAL
Class: Refereed; Status: All; (most recent first, AMS format)

Author Collaborations Summary:

- UCAR Only: 86
- UCAR & University: 176
- UCAR & Other: 67
- UCAR, University, & Other: 188

**FY09 UCAR Outstanding Publication Award awarded to Bill Skamarock of NESL/MMM**
This award is given for the published results in the past five years of original research, review papers, or pedagogically oriented books that contribute to the atmospheric sciences. Publications are judged on four criteria: (a) importance of the subject to atmospheric science broadly defined, including work connecting atmospheric science with other disciplines or matters of public policy; (b) importance of the paper’s contribution to its specific subject area; (c) evidence of creativity and originality; and (d) clarity of exposition.


This publication tackles the very difficult problem of assessing the ability of numerical weather forecast models to accurately represent important weather features that occur at smaller scales. The author proposes a new approach, utilizing the characteristic behavior of observed kinetic energy spectra to evaluate the ability of numerical weather prediction (NWP) models to properly represent the behavior of weather disturbances and to quantify the effective resolution of the numerics of these models.

Partners (top) NCAR defines collaborators using the National Science Foundation’s definition of partner organizations as being “academic institutions, other nonprofits, industrial or commercial firms, state or local governments, and schools or school systems that have been involved with NSF base-funded projects.” Partner Organizations may provide financial or in–kind support, supply facilities or equipment, collaborate in research exchange personnel or otherwise contribute project support.

NCAR Collaborators come from 868 institutions, which are located in all 50 states, and 60 countries. Institutions range from the American Wind Energy Association (AWEA) to Yale University.

For a full list of each metrics topic, download NCAR 2009 Metrics Details.xls

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About NCAR

The National Center for Atmospheric Research (NCAR) is a federally funded research and development center devoted to service, research and education in the atmospheric and related sciences. Our primary sponsor is the National Science Foundation, with significant additional support provided by other U.S. government agencies, other national governments and the private sector. NCAR's mission is to understand the behavior of the atmosphere and related physical, biological and social systems; to support, enhance and extend the capabilities of the university community and the broader scientific community — nationally and internationally; and to foster the transfer of knowledge and technology for the betterment of life on Earth.

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