NCAR is sponsored by the National Science Foundation.

## NCAR DIRECTOR'S MESSAGE

NCAR Director, Tim Killeen

I am writing to you at the end of another busy and successful year of scientific work. I hope you will share my pride in the recent noteworthy accomplishments of the National Center for Atmospheric Research (NCAR) staff and collaborators in the areas of science, facilities, and service as you read through this latest edition of NCAR's Annual Report.

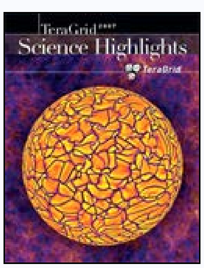
This year's science achievements result in no small part because of ongoing support from the **National Science Foundation**, which sponsors us in our work to advance basic research in the United States in atmospheric and related sciences on behalf of the university community. In addition, our successes are attributable to our science community's pervasive influence. Community interactions range from the many (and growing) number of individual collaborations, to active community participation on our advisory panels, and direct engagement in ongoing strategic planning–all of these relationships enhance and inform the work we do.


View Lab Reports on IPCC Participation:
ESSL report
SERE report

Fiscal Year 2007 (FY2007) saw the release of the **Intergovernmental Panel on Climate Change** (IPCC) Fourth Assessment Report (AR4). In addition to garnering the Nobel Peace Prize, which was shared with Albert Gore for "…efforts to build up and disseminate greater knowledge about man-made climate change," each AR4 Working Group report achieved extensive, worldwide media coverage worldwide, resulting in vastly increased public attention to changing climate.

The IPCC AR4 included intense scrutiny of current climate change science as documented in the peer-reviewed literature, and comparison of observational data with climate model simulations of past, present, and future climate states. The **NSF and DOE-funded Community Climate System Model** (CCSM) project was one of more than 15 different modeling centers around the globe that worked on a coordinated set of climate simulations which were provided to the AR4 scientists and authors. NCAR worked with DOE modeling centers and Japan's Central Research Institute of the Electric Power Industry (CRIEPI) to produce more than 10,000 model years of simulated climate. This was the largest contribution of modeling data to the IPCC project made by any research center.

Perhaps the IPCC climate news occurred at the right place and time, or perhaps the evidence gained from daily life–warmer days, changing seasons, more extreme storms–simply became incontrovertible to the public. Either way, to a large degree the strength of the AR4 message is certainly attributable to the IPCC authors' comprehensive examination of the evidence and clear expression of confidence in their findings. I would like to commend our many **UCAR university partners, as well as NCAR scientists** who contributed to this important assessment activity.



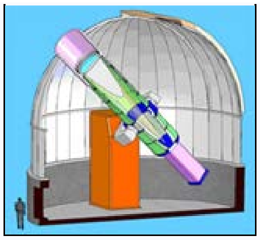

Click for more on CISL's Teragrid participation.

While FY2007 certainly had a significant climate focus, beyond this area, NCAR's research, facility, and community service activities also continued to make notable strides. For instance, our Computational and Information Systems Laboratory (CISL) increased NCAR's total computing capacity by more than a factor of two beyond last year's levels, and is a contributing partner in **NSF's TeraGrid**, an open scientific discovery computing infrastructure.

Click for more on EOL's instrumentation of the Gulfstream V research aircraft.

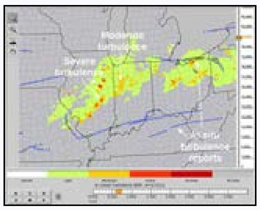
NCAR's Earth Observing Laboratory (EOL), which develops and deploys observing facilities and provides data services for the university community, put the **NSF/NCAR Gulfstream V** (formerly known as HIAPER) research plane through its paces, using its long-range capabilities during the Pacific Dust Experiment (PACDEX). Other EOL efforts ranged from taking direct ice nucleation measurements to better understand cloud ice-particle formation to developing a partnership with Colorado State University for creation of a national radar facility.

Our Earth and Sun System Laboratory (ESSL) plays a critical role in developing community models, and pursues fundamental research to address the environmental challenges facing society. Collaborations both within NCAR and with university colleagues have resulted in an exciting variety of work, including creation of new instruments and models, and research findings that are providing insights on Earth and Sun system interactions.



Click for more on ESSL's Coronal Solar Magnetism Observatory (COSMO).

Among the exciting findings in ESSL's divisions, the High Altitude Observatory's **Coronal Multi-channel Polarimeter** instrument enabled a scientific breakthrough by imaging, for the first time, Alfvén waves in the solar corona, which will provide researchers with greater understanding of the solar magnetic fields. The Mesoscale & Microscale Meteorology Division Advanced Research Weather and Research Forecast (ARW) model now includes new data assimilation capabilities, a variety of physics packages, and specialized packages such as **WRF-Chem, WRF-Fire, and the Advanced Hurricane WRF (AHW)**. Atmospheric Chemistry Division scientists also made considerable progress this year in incorporating an interactive chemistry capability into the **Community Atmospheric Model** (CAM).




Click for more on RAL's Turbulence Detection System for Aviation.

The Research Applications Laboratory (RAL) bridges the gap between scientific discoveries and societal requirements, serving a range of audiences, from government agencies to private companies, looking to benefit from the latest science and technology advances in weather and other areas. Among this year's highlights, RAL scientists created a **turbulence detection system** to alert commercial pilots to patches of rough air, thereby improving passenger safety.

In FY2007, the Societal-Environmental Research and Education (SERE) Laboratory gained a new director, Denise Stephenson-Hawk, who, with her team, developed a "**societal resilience system of systems**" (SRSS) framework that will help society better cope with, and mitigate against, climate, water, and weather uncertainties. Among the SERE highlights is the development of new analytical tools capable of functioning in both geographic information systems and weather and climate models.

Click for more on SERE's Societal Resilience System of Systems (SRSS).

For more information on these and our many other FY2007 efforts, I invite you to delve further into the 2007/2008 NCAR Annual Report.

*Best wishes,*

**Tim Killeen**

## TABLE OF CONTENTS

---

***Other Relevant Links***

- NCAR's Strategic Plan (pdf)
- NCAR's FY 2008 Program Operating Plan (pdf)
- Previous Annual Reports




*Postal Address: P.O. Box 3000, Boulder, CO 80307-3000 • Shipping Address: 1850 Table Mesa Drive, Boulder, CO 80305 • Contact*

# ABOUT NCAR AND THE 2007 ANNUAL REPORT

The National Science Foundation funds the National Center for Atmospheric Research (NCAR) to advance basic research in the United States in atmospheric and related sciences in support of the university community. As a federally funded research and development center, NCAR is able to sustain a long-term commitment to this scientific enterprise. This basic research also feeds into NCAR’s other strategic goals, allowing us to leverage our own and the community’s scientific findings to improve the modeling, computing, and observational facilities we provide, and also transfer the results of this work to the public and private sector.

## Introduction

As can be seen in the pages that follow, NCAR’s research and support capabilities include a wide swathe of research areas–from atmospheric chemistry, meteorology, solar physics, and solar-terrestrial interactions, to climate change and the related societal impacts of climate and severe weather events. And, because Earth and atmospheric science are inextricably linked, our scientists also focus on areas such as biogeochemistry, the hydrologic cycle, and geophysical turbulence, and use applied mathematics and statistical analysis to provide enhanced understanding of the phenomena under study. We conduct our research in close collaboration with university partners, local, state and federal agencies, with international partners, and private sector sponsors. Our goal is to make our research accessible and widely available.

To best meet the needs of atmospheric and Earth science researchers, NCAR created five laboratories, each of which has a focus designed specifically to serve the wider community. Our labs are also intended to address NSF’s strategic goals of Discovery, Learning, Infrastructure, and Stewardship. With frequent input from NSF, NCAR is advancing discovery, innovation and education beyond the frontiers of current knowledge, and empowering future generations in science and engineering.

### NCAR’s labs include:

- The **Computational and Information Systems Laboratory** (CISL), which provides the community with high-performance computers, high-speed networks, a world-class data archiving and storage facility, research data sets, state-of-the-art knowledge environments and visualization technologies, advanced mathematical tools, and a staff of professionals dedicated to advancing Earth system science across broad fronts.
- The **Earth Observing Laboratory** (EOL), which develops and deploys observing facilities, and provides data services that our research community needs to make the observations that are essential to broadening our understanding of the world we live in.
- The **Earth and Sun Systems Laboratory** (ESSL) research program addresses some of the complex scientific questions directly related to major environmental challenges the world is facing. ESSL’s research efforts–for example, building climate, weather, and other atmospheric and Earth system models–are pursued both in partnership with and on behalf of the wider scientific community.
- NCAR’s **Research Applications Laboratory** (RAL) conducts directed research that contributes to the depth of fundamental scientific understanding, fosters the transfer of knowledge and technology for the betterment of life on Earth, and supports technology transfer that expands the reach of atmospheric science.
- The **Societal-Environmental Research and Education** (SERE) Laboratory promotes inter- and multi-disciplinary research activities, engages in human and institutional capacity building, and research related to climate-environment-societal interactions. SERE also develops and sustains partnerships between NCAR scientists and our colleagues in universities and other institutions.

Both our work and this report are built around addressing our Strategic Plan, NCAR as an Integrator, Innovator and Community Builder, which outlines our five Strategic Goals and the priorities addressed to achieve each goal. NCAR's Strategic Goals are to:

1. Improve understanding of the atmosphere, the Earth system, and the Sun
2. Increase societal resilience to weather, climate, and other atmospheric hazards
3. Cultivate a scientifically literate and engaged citizenry, and a diverse and creative workforce
4. Provide robust, accessible, and innovative information services and tools, and
5. Provide world-class ground, airborne, and space-borne observational facilities and services.

In the following sections we report on the progress our laboratories have made in fiscal year 2007 (FY2007) toward attaining our scientific goal and priorities, and provide an overview of our plans for the coming year.

*Postal Address: P.O. Box 3000, Boulder, CO 80307-3000 • Shipping Address: 1850 Table Mesa Drive, Boulder, CO 80305 • Contact*

NCAR is sponsored by the National Science Foundation.

## NCAR'S STRATEGIC GOAL'S

NCAR's Strategic Plan, ***NCAR as an Integrator, Innovator and Community Builder***, outlines five Strategic Goals, and the priorities for achieving each. In the following sections we report on progress made in FY 2007 toward each scientific goal and priority.

**NCAR's five Strategic Goals are to:**

1. Improve understanding of the atmosphere, the Earth system, and the Sun,
2. Increase societal resilience to weather, climate, and other atmospheric hazards,
3. Cultivate a scientifically literate and engaged citizenry and a diverse and creative workforce,
4. Provide robust, accessible, and innovative information services and tools, and
5. Provide world-class ground, airborne, and space-borne observational facilities and services.




*Postal Address: P.O. Box 3000, Boulder, CO 80307-3000 • Shipping Address: 1850 Table Mesa Drive, Boulder, CO 80305 • Contact*

NCAR is sponsored by the National Science Foundation.

## NCAR METRICS

The following sections provide another method for viewing NCAR's contributions to the research community, over the past fiscal year. By providing concise “metrics” on a number of our outreach activities, it is easy to see just how much NCAR supports the greater research and education community.

We report on metrics in the following categories:

1. Education & Outreach
2. Honors & Awards
3. Community Service
4. Publications
5. People & Organization

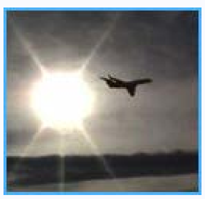
NCAR Metrics previous next

## THE END

You've reached the end of the FY2007 NCAR Annual Report, but there is much more to explore. The NCAR Laboratories have prepared annual reports featuring greater detail on a wide range of topics. You may view each of those reports at the links below.

**Annual Reports of the NCAR Laboratories**

- CISL report
- EOL report
- ESSL report
- RAL report
- SERE report






*Postal Address: P.O. Box 3000, Boulder, CO 80307-3000 • Shipping Address: 1850 Table Mesa Drive, Boulder, CO 80305 • Contact*

# Strategic Goal 1 Improve Understanding of the Atmosphere, the Earth System, and the Sun

The National Science Foundation supports the National Center for Atmospheric Research (NCAR) to advance basic research in the United States in the atmospheric and related sciences in support of the university community. As a federally-funded research and development center, NCAR is able to sustain a long-term commitment to this scientific enterprise. Our research and understanding of the atmosphere, the Earth System, and the Sun and their environments is essential to fulfilling our other strategic goals. We pursue this basic research to advance our knowledge. Concurrently, we also are able to improve the modeling, computing, and observational facilities we provide; and, to transfer the results of our work to the public and private sector.

Our research includes atmospheric chemistry; meteorology, solar physics, solar-terrestrial interactions, and the Earth's upper atmosphere; climate research; societal impacts of climate change and severe weather; biogeochemistry; water cycle; geophysical turbulence; and applied mathematics and statistical analysis. We conduct our research in close collaboration with university partners; local, state and federal agencies; and with strategic international partners and private sector sponsors. Our goal is also to make our research accessible and widely available.

**NCAR addresses four broad priorities within this goal:**

## Priority 1: Exploring Atmospheric, Earth System, and Solar Processes, Variability and Change

Exploring atmospheric, Earth system, and solar processes, and the variability and change of these processes, are critical components to reaching NCAR's Strategic Goal #1. Exploration into these areas includes: simulation of natural Earth system variability, research on magnetic-flux eruptions from the sun, and understanding the effects of gravity waves, including the coupling between the upper troposphere and lower stratosphere. *Read more about this priority*

## Priority 2: Investigating the Interactions of the Atmosphere, the Broader Earth System and Human Society

In the past, meteorology and climatology were considered separate fields, largely because of disparate time and length scales. Today, the two fields are strongly coupled, not only because climate provides boundaries for investigating the weather, but also because localized events can influence larger climatological scales. NCAR's activities in this area range from collecting in situ data to better understand climate, weather and related phenomena, to developing and analyzing ways to better model natural processes and working with university partners to devise ways of tackling scientific questions. *Read more about this priority*

## Priority 3: Improving Prediction of Weather , Climate, and Other Atmospheric Phenomena

Understanding of the Earth system is a prerequisite to predicting its behavior, the latter being, however, of a more direct use to many components of society. In that context, for this priority, the key activities within NCAR's laboratories range from improving climate models, to exploring new approaches to prediction across scales, and global and local weather prediction. *Read more about this priority*

## Priority 4: Developing Community Models

Developing numerical models and making them available to the scientific community is at the heart of NCAR's research and service to the community. Key activities in this priority are creating and adding to community models, research models, as well as progressing toward creation of an Earth system model.
*Read more about this priority*

Director's Message
Table of Contents
About NCAR
**Strategic Goals**: Science, Facilities & Technology
Metrics
Conclusion/Lab Links
Archives and Supplemental Info

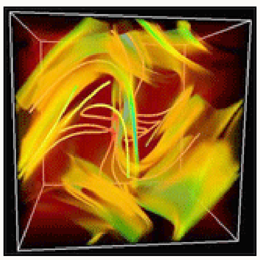


# *GOAL 1*, PRIORITY 1: EXPLORING ATMOSPHERIC, EARTH SYSTEM, AND SOLAR PROCESSES, VARIABILITY AND CHANGE

## Exploring Atmospheric, Earth System, and Solar Processes, Variability and Change

Developing a better understanding of atmospheric, Earth system, and solar processes, as well as the variability and change associated with these processes, is critical to achieving NCAR's first strategic goal. Exploration of these "Priority 1" areas focuses on three key activities: simulating the Earth system's natural variability, investigating the Sun's magnetic-flux eruptions, and understanding effects of gravity waves, including related interactions between the upper troposphere and lower stratosphere.

## FY2007 Accomplishments

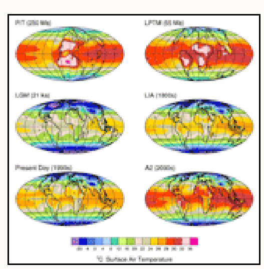


**Click to enlarge.** MHD Turbulence structures

The scientific leadership of NCAR recognized early on that to understand the dynamics of the atmosphere and oceans, the Sun, and solar-terrestrial interactions, it is essential to investigate relevant turbulent processes at a fundamental level. The Institute for Mathematics Applied to Geosciences (IMAGe), part of CISL, shoulders this task, bringing mathematical models and tools to bear on understanding fundamental problems in the geosciences.

IMAGe's Turbulence Numerics Team, in collaboration with faculty from universities around the world, has pursued a broad range of research topics. An FY2007 highlight was the creation of a large magnetohydrodynamic (MHD) simulation at a resolution of $1536^3$. This is the largest numerical experiment completed of this type, and it illustrates for the first time the self-similar growth of current and vorticity maxima by the formation, rolling, and stretching of current and vorticity sheets. This study has important applications to solar physics, astrophysics, and fusion studies. Other results stemming from this research include:

- Mathematical modeling of small scales in turbulent flows
- Adaptive Mesh Refinement for two-dimensional incompressible turbulent flows with pressure
- Scaling laws in turbulent flows, and a possible origin of self-similar behavior
- The origin of magnetic fields: extension to spherical geometry
- Generalization of an inviscid model of dissipative flows



**Click to enlarge.** Annual air temperature simulated by the NCAR Community Climate System Model (CCSM3) for four different past time periods: a warm

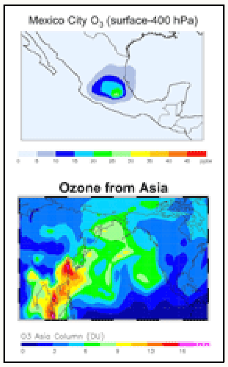
Modeling efforts are also fundamental for achieving NCAR's mission to support the wider community and to enhance understanding of atmospheric, Earth system, and solar processes. NCAR climate, weather, and solar process models are used to study past, present and future natural variability of the Earth system. Among these modeling efforts, ESSL scientists are exploring changes over many time periods–including the distant geologic past, when continental configurations, surface temperature, latitudinal gradients, and levels of atmospheric carbon dioxide, methane, and other greenhouse gases were significantly different. Simulations have covered a range of applications,

Related Lab Annual Report Sections: Goal 1, Priority 1
- EOL Activities
- ESSL Activities

including the last millennium, the Holocene El Niño-Southern Oscillation (ENSO), and the Last Glacial Maximum, among other periods.

These simulations highlight the importance of considering atmosphere, ocean, land surface, and sea ice feedbacks to compare the magnitude of past climate change to changes in past forcings. These runs also provide a benchmark for the Community Climate System Model (CCSM), and allow testing of various hypotheses of mechanisms to explain proxy records of past climate change. The ESSL Laboratory Annual Report (LAR) provides exciting details on the paleoclimate modeling efforts.

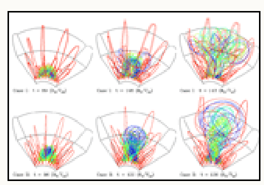
period approximately 250 Mya – the Permian-Triassic, a period of abrupt warming approximately 55 Mya – the Paleocene-Eocene Thermal Maximum, a glacial period approximately 21 kya - the Last Glacial Maximum, and a cold period approximately 500 years ago - the Little Ice Age. This image illustrates the large range of climates under natural forcings. A comparison of the CCSM3 simulations with geologic data confirms that this model captures the magnitudes of change about right justifying its use of future climate projections.




**Click to enlarge.** MOZART-4 has been used to calculate the impact of emissions from a specific region on the regional O3 concentrations.

When it comes to developing chemical weather forecasting, ESSL's Atmospheric Chemistry Division (ACD) has expertise in all of the required research areas–satellite remote sensing, field campaign measurements, global and regional modeling, and data assimilation. In FY2007, ACD's work in this area centered on refining assimilation of carbon monoxide measurements from MOPITT–a remote sensing instrument flying on NASA's Terra spacecraft–into MOZART-3 (Model for Ozone and Related chemical Tracers) and the Community Atmosphere Model (CAM-Chem), two global chemistry transport models. Recent modeling experiments under the direction of the U.N. Task Force on Hemispheric Transport of Air Pollution also allowed CAM-Chem to be evaluated against other chemistry transport models, and contributed to an international assessment of the importance of intercontinental transport to air quality.

Modeling the Earth's upper atmosphere and beyond falls into the domain of scientists in ESSL's High Altitude Observatory (HAO). In FY2007, these scientists continued advancing human understanding of the 11-year solar cycle and related phenomena by investigating the hemispherical asymmetry of solar active regions. This work is important for determining which solar disturbances are most "geoeffective" –that is, disturbances that impact the Earth's system and human activities. In addition, HAO researchers developed 3D MHD simulations of twisted flux tubes emerging into the corona, which have led to significant advances in understanding precursor structures and initiation mechanisms for coronal mass ejections (CMEs). ESSL's LAR contains details on these and related modeling efforts.



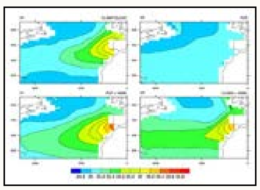
**Click to enlarge.** The top two rows of images show two MHD simulations of the eruption of a twisted flux rope in the coronal triggered by the onset of the torus instability where the erupting flux rope mainly shows an outward expansion (1st row of images), and the onset of the kink instability where the flux rope shows significant rotation as it erupts (2nd row of images).

HAO is also collaborating with Dartmouth College, Boston University, University of Maryland, and Rice University scientists to form a core component of the physics-based numerical modeling chain being developed at NSF's Center for Integrated Spaceweather Modeling (CISM). Version 2.0 of the Coupled Magnetosphere Ionosphere Thermosphere (CMIT) model was released to Boston University for validation in FY2007, and is being used in coupling studies to describe geomagnetic effects on the ionosphere. CMIT produces a more detailed rendition of the response to geomagnetic variations caused by space weather events, and also includes NCAR's Thermosphere-Ionosphere-Electrodynamics General Circulation Model (TIE-GCM) v.1.8.

Modeling efforts, both within the community and at NCAR require robust computing capabilities, and significant levels of computation parallelism are imperative to address the most challenging scientific problems. However, computing at such levels reduces the computing time available to other users. CISL responded to this challenge in FY2007 by continuing to provide traditional capacity computing to significant numbers of smaller scientific projects, which are also important to understanding the Earth system, while developing methods to provide capability computing resources, access, and support for large projects. A limited number of breakthrough science projects were selected from the geoscience community and awarded between 170,000 and 585,000 CPU hours on blueice, the new IBM POWER5+ cluster.

In addition to creating models and ensuring adequate capacity to run the models, observational data are critical to verifying model output. But, when it comes to modeling solar events, these data are limited, to say the least. However, the September 2006 launch of a joint Japan/US/UK Hinode solar physics mission from southern Japan will improve availability of such data. Already, spectacular views of the Sun, with unprecedented angular resolution and quantitative detail, are available. HAO and Lockheed Martin Solar and Astrophysics Laboratory collaborated to build Hinode’s enormously successful Spectro-Polarimeter–an instrument that is providing new understanding of the solar atmosphere’s magnetic fields.

Similarly, observational data from the extratropical upper troposphere/lower stratosphere (UTLS) region is limited. Led by NCAR scientists, analysis of data collected during the Stratosphere-Troposphere Analyses of Regional Transport (START) experiment began in FY2007. This experiment looked at transport processes impacting the chemical-microphysical distribution of this region. Results of this analysis suggest that, if the extratropical tropopause is treated as a transition layer, the thickness of the layer appears to have strong spatial variation.



**Click to enlarge & see full caption.** Time-mean salinity distributions (in psu) at a depth of 1100 m in the North Atlantic.

ESSL scientists are involved in the Climate Variability and Predictability (CLIVAR) initiative, which investigates climate variability and predictability on time-scales of months to decades, and looks at effects of anthropogenic forcing on the climate system. Within ESSL’s Climate and Global Dynamics (CGD) division, major ocean model developments are proceeding under the auspices of CLIVAR’s Climate Process Teams (CPT) on both gravity current entrainment and eddy mixed layer interaction.

Lastly, among NCAR’s FY2007 publication highlights is a landmark paper by Britt Stephens et al. published in Science that puts a new perspective on the “missing” carbon sink, greatly diminishing the apparent discrepancy between overall emissions and the rate of increase of atmospheric CO2. Another important paper, co-authored by NCAR’s Peter Thornton and included in Global Biogeochemical Cycles, shows that the response of net land carbon fluxes to changes in atmospheric CO2 concentration, temperature, and precipitation depends strongly on coupling of terrestrial carbon and nitrogen cycles.

## FY2008 Plans for Strategic Priority 1

Many of NCAR’s FY2008 plans focus on modeling. To reach new levels of understanding about the Earth system, CISL will continue providing access for leading-edge scientific investigations that require large portions of supercomputing power. Support will be provided as needed and requested for:

1. field projects that involve NCAR and/or university scientists,
2. real-time, high-resolution weather forecasting of convective systems during periods of intense activity, and
3. selected NCAR Capability Computing (NCC) and University Capability Computing (UCC) Earth science projects.

A few of NCAR’s model-centric efforts in FY2008 include:

- Continued analysis of the large MHD experiments by IMAGe, with emphasis on flows occurring under more complex settings, including interactions of eddies and waves arising from the incorporation of rotation and stratification.
- To generate observed data for solar and geospace modeling efforts, solar physicists at NCAR, the University of Hawaii, and the University of Michigan are working with HAO’s instrumentation group to design a

new, large coronagraph, the Coronal Solar Magnetism Observatory (COSMO).

- The Coupled Magnetosphere-Ionosphere-Thermosphere (CMIT) will be upgraded, and work will commence on developing the option of using a high-resolution version of the NCAR Thermosphere-Ionosphere-Mesosphere-Electrodynamics General Circulation Model (TIME-GCM) in place of the current TIE-GCM as the thermosphere-ionosphere portion of CMIT. The Global Ionosphere-Plasmasphere (GIP) model, developed for use with the TIE-GCM, will be tested to see how well it improves representation of the ionosphere. And, studies of global change in the thermosphere will be advanced by carrying out simulations with the three-dimensional TIME-GCM under different scenarios of trace-gas concentrations in the stratosphere.
- Using a CCSM-like management structure, NCAR and our scientific partners will collaborate on developing a community Earth System Model (ESM) that will account for interactions between the physical climate system, the biogeochemical system, and the social system. Achieving this goal requires two parallel approaches–creating a roadmap for developing a next-generation "Weather Climate Model," and crafting a model of intermediate complexity and low spatial resolution to capture increased numbers of processes, couplings and feedbacks, and accounts for relations between natural and social processes.
- Work will begin in FY2008 on a detailed chemical weather case study using data from the MIRAGE (Megacities Impacts on Regional and Global Environments) and INTEX-B (Intercontinental Chemical Transport Experiment) spring 2006 period. A nested regional model simulation concentrating on Mexico and parts of the INTEX-B Pacific region also will be performed using the Weather Research & Forecasting (WRF)-Chem model. This will be followed by an assimilation of available satellite data sets to impose constraints on the modeled chemical fields, which can be evaluated in comparison with actual field measurements.
- In the next year, emphasis will be placed on use of available High Resolution Dynamics Limb Sounder (HIRDLS) data for scientific studies, especially of gravity waves, and UTLS processes, notably stratosphere-troposphere exchange.
- CGD researchers will work on adapting the Mediterranean overflow scheme to the Denmark Strait and Faroe Bank Channel Overflows–proper representations are believed to have significant climate impacts–and implement a new submesoscale parameterization on behalf of two CLIVAR CPTs.

***Science: Strategic Goal 1***    previous    next


*Postal Address: P.O. Box 3000, Boulder, CO 80307-3000 • Shipping Address: 1850 Table Mesa Drive, Boulder, CO 80305 • Contact*

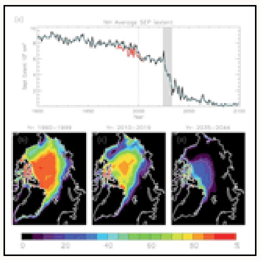
Director's Message
Table of Contents
About NCAR
**Strategic Goals**: Science, Facilities & Technology
Metrics
Conclusion/Lab Links
Archives and Supplemental Info



## *GOAL 1*, PRIORITY 2: INVESTIGATING THE INTERACTIONS OF THE ATMOSPHERE, THE BROADER EARTH SYSTEM AND HUMAN SOCIETY

In the past, meteorology and climatology were considered separate fields, largely because of disparate time and length scales. Today, the two fields are strongly coupled, not only because climate provides boundaries for investigating the weather, but also because localized events can influence larger climatological scales. The activities that NCAR scientists focused on this year ranged from collecting in situ data to better understand climate, weather and related phenomena, to developing and analyzing ways to better model natural processes and working with university partners to devise ways of tackling scientific questions.

### FY2007 Accomplishments



**Click to enlarge.** The time series of September Arctic ice extent from CCSM-3 (black), the CCSM-3 5-year running mean (blue) and the satellite observations (red), with the identified abrupt event shown by the grey shading. The sea ice conditions for the (b) 1990-1999 average, the (c) 2010-2019 average and the (d) 2035-2044 average are also shown and indicate the realistic present day ice cover simulated by CCSM-3 and the rapid decline that occurs by mid-century.

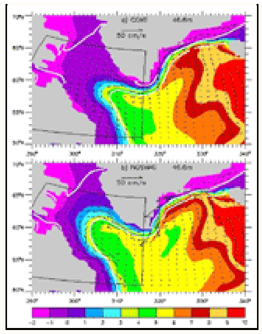
Most, if not all of the FY2007 research efforts under this priority rely on cross-community collaboration. Among the many examples of enhancing scientific and societal understanding of the effects of global climate change is the climate modeling being done around Arctic sea ice retreat. Considerable effort has occurred–and work continues–to examine observed and projected changes in the sea ice system, and the consequences of a seasonally ice-free Arctic ocean for the climate system. CCSM integrations exhibit abrupt reductions in the future summer sea ice cover, with the most extreme event going from 80% September ice coverage to 20% coverage in approximately 10 years.

The Earth's oceans have a significant impact on the Earth's system, making it important to understand ocean processes, and using this understanding to improve ocean models. CGD's FY2007 efforts in this area include prediction of the Earth's energy, water and biogeochemical cycles, and understanding natural and human influenced climate variability, including high impact variations such as sea level rise. In turn, the ESSL objective of understanding two-way scale interactions within the Earth system is central to improving our understanding of how ocean circulation features such as coastal upwelling zones, western boundary currents, and meso-scale eddies are affected by and affect the basin- to global-scale ocean circulation. In a complementary way, global atmospheric modeling efforts within CGD are examining the sensitivity of physical processes in the atmospheric component model to small errors in Sea Surface Temperature (SST). This work has illustrated large simulation sensitivity, particularly at low latitudes, pointing to the strong coupling existing between the ocean and atmosphere.

---

***Related Lab Annual Report Sections: Goal 1, Priority 2***

- EOL Activities
- ESSL Activities
- RAL Activities
- SERE Activities



**Click to enlarge.** Ocean velocity vectors and temperature in the north-west Atlantic and Labrador Sea near 50 m depth, averaged over years 101 through 120 of CCSM coupled model integrations: a) with higher viscosity (CONT, top panel) and b) with lower viscosity (NOSMAG, bottom panel). In both cases, the white contours are the 5% (offshore) and 50% (onshore) average sea-ice concentrations. As expected, the currents in (a) are stronger than (b), and advect more warm water into the Labrador Sea, especially along the west coast of Greenland. This warm water tends to melt the sea ice and initiate the positive ice-albedo feedback, where the reduced ice lowers effective albedo, which allows more absorption of solar radiation, which warms the ocean and leads to more melting. As a result, the sea-ice distribution in (b) is much more like the observed.

In addition to our atmosphere and ocean modeling work, FY2007 saw the CCSM Biogeochemistry and Land Working Groups place a strong emphasis on development and testing of new CCSM component models that improve the representation of known interactions between ecosystems, biogeochemistry, and climate in our fully coupled model. Accomplishments over the past year include adoption of a new land model component (CLM-CN) for the interim model version CCSM 3.5. CLM-CN includes a fully prognostic treatment of both carbon and nitrogen cycles within terrestrial ecosystems, and retains all of the mechanistic detail from CLM related to physical and biophysical mechanisms of land surface-climate interaction.

In collaboration with a broad group of university investigators, ESSL scientists also recently completed a series of fully coupled simulations linking new land and ocean ecosystem components to the physical components of CCSM. This system has been used to investigate the influence of climate-biogeochemistry coupling on climate-carbon cycle feedback finding very significant impacts due to the new coupling. See the ESSL LAR for further details.

Mentioned under the previous priority, the MIRAGE initiative aims to understand the fate of urban emissions in the downwind atmosphere. Important new results include:

- Air downwind from Mexico City continues to be chemically active, with production of ozone (O3) and organic particles continuing for several days.
- Organic reactivity is dominated by hydrocarbons near the surface in Mexico City, but by oxygenated organics (particularly aldehydes) in the outflow.
- Reactive nitrogen appears to be lost more rapidly than expected, and a significant fraction is unidentified.
- For more MIRAGE results, see the ESSL LAR.

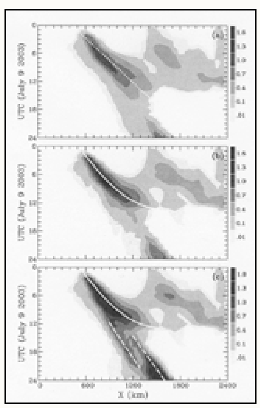
The collection and analysis of data on aerosols, clouds and storms have been important element of the rainfall enhancement programs RAL conducts throughout the world. Field programs in West Africa and in Saudi Arabia in 2007 have yielded important new insights into the effects of aerosols as agents of significant climatic perturbations, particularly with respect to cloud microphysical processes and precipitation. For more results, see the RAL Annual Report.

Scientists and support teams from EOL and other NCAR labs collaborated with university investigators to plan and conduct the second Airborne Carbon in the Mountains Experiment (ACME07) campaign using the University of Wyoming's King Air aircraft. ACME endeavors to shed insight on carbon dynamics in mountain forest regions by developing new methods for estimating carbon exchange at local to regional scales. This second campaign began in early spring and ran through the fall, focusing on Colorado and Wyoming.

EOL also collaborated with investigators from Harvard, NOAA, and Scripps Institution of Oceanography, and ESSL's The Institute for Integrative and Multidisciplinary Earth Studies (TIIMES), to begin planning the HIPPO (HIAPER Pole-to-Pole Observations) campaign, which will investigate the global carbon cycle. Data collection will be done on the NSF-NCAR Gulfstream V (GV)–formerly known as HIAPER (further project details are available in Goal 5, Priority 1). EOL and TIIMES staff also continued operating the Regional Atmospheric Continuous CO2 Network in the Rocky Mountains (Rocky RACCOON) network of CO2 analyzers, collaborating with University of Utah and University of Wisconsin to investigate regional carbon cycling in the Rocky Mountains, this work will continue in FY2008.

In April and May of 2007, EOL and ESSL/ACD scientists and support staff became involved in studying the role of aerosols in climate and weather. EOL deployed the GV in support of the PACific Dust EXperiment (PACDEX), which is designed to provide insights on the dynamics of the Eurasian-Pacific-North American dust plume. The dust plumes' full effect has not been widely explored because there has not been, until recently, an airborne platform capable of sampling the plume throughout its evolution, in situ, as it moves across the Pacific Ocean. The GV solves this problem.

The Bio-hydro-atmosphere interactions of Energy, Aerosols, Carbon, Water, Organics and Nitrogen (BEACHON) program is providing a detailed, quantitative characterization of biosphere-hydrosphere-atmosphere interactions. These quantitative characterizations are being used to improve regional and global models of the Earth system. Part of the BEACHON program, the Canopy Horizontal Array Turbulence Study (CHATS) is a prototype "super site." Located in a relatively simple ecosystem–a walnut orchard–unmanned instrumentation was used to observe effects of everyday turbulent flow over the orchard. Microscale measurements of phenomena such as boundary layer depth and local mesoscale circulations, atmospheric CO2 and water vapor, among other characteristics, are being studied and will be put into context of the larger atmospheric environment.



**Click to enlarge.** Effects of the hybrid parameterization applied in MM5 at 60 km grid spacing illustrated by the diurnal variability of precipitation over the continental U.S. a) Betts-Miller convective parameterization. Precipitation is under-predicted and the organized system travels too slowly, about 10 m/s compared to the observed 17m/s. b) hybrid parameterization (i.e., Betts-Miller coupled to a representation of mesoscale stratiform heating and the mesoscale downdraft). c) As in b) except the explicit ('grid-scale') precipitation is added. The mesoscale components augment the precipitation and increase the propagation speed while it operates (curved line in top figure.) [From Moncrieff and Liu ( 2006)].

In the realm of hydrology studies, scientists contributing to TIIMES' Water Cycle Program are striving to improve representation of the hydrologic cycle in climate models. In FY2007, program focus was on improving representation of convective precipitation downwind of major continental mountain ranges. Toward this end, Mitch Moncrieff and Changhai Liu developed a new parameterization of convection and looked at some of the key characteristics of these systems, for example, organized, mesoscale transport of heat and momentum to larger scales over the continental United States. Work done by Wojciech Grabowski on the super-parameterization concept, provides an alternative approach to the convection question. Grabowski uses a full 2D, high-resolution cloud model at each grid point to more accurately account for the shear impacts on clouds and momentum transport. His efforts focused on improving the model's microphysical scheme, including the impact of aerosol particles. This approach to modeling precipitation will become more attractive to climate models as computer power increases.

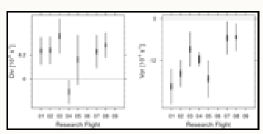
During FY2007, RAL continued to provide hydrological modeling support for a World Bank-funded project for the country of Romania. Working in collaboration with scientists from Baron Advanced Meteorological Services we have completed a suite of enhancements to the Noah-distributed hydrological model and implemented and tested the new modeling system in several new river basins in both the United States and in Romania. All components of the Noah-distributed hydrological modeling system arebeing fully parallelized for use on NCAR supercomputers.

A new project aimed at improving predictions of short term (hours to one day) flash flooding events in the Colorado Front Range was initiated during FY2007. This project deploys, in an unprecedented manner, the newly developed Noah-distributed hydrological modeling system over a large region in north-central Colorado. During FY2007, the model domain was defined and attributed and case study simulations were executed that focused on simulating the 1997 Ft. Collins flash flood. Additionally, this model was coupled to the Advanced Weather Research and Forecasting model for fully-coupled simulations of high-impact hydrometeorological events. Results from an initial round of sensitivity studies have been completed and were presented at the annual WRF User's workshop in late June.

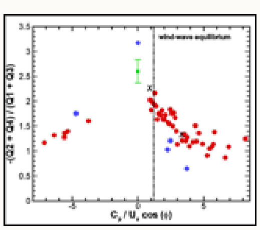
RAL scientist, David Gochis, remained heavily involved in the NOAA-NSF-NASA sponsored North American Monsoon Experiment (NAME), co-operating a regional rain gauge network in western Mexico with collaborators at the University of Sonora. The network is now entering its seventh year of operation and continues to provide research quality data for warm season precipitation research in western Mexico and to evaluate satellite-based estimates of precipitation. Studies are now underway using parcel trajectory analysis tools to analyze the transport of moisture, which drives monsoon rainfall.

While precipitation is a key component of the water system, surface and ground water dynamics play similarly important roles. A TIIMES and University of Arizona-run hydrometeorology workshop in November 2006 explored various aspects of hydrology relevant to the proper simulation of the water cycle in climate models, including the education of students in this important area.

During the past year, data from the NCAR C-130 aircraft from the Dynamics and Chemistry of Marine Stratocumulus (DYCOMS-II) Experiment were used to estimate the accuracy of divergence and vorticity measurements from the horizontal wind field in the atmospheric boundary layer and to refine techniques used to obtain these measurements. Results indicate that wind-field measurements with minimal systematic errors should provide estimates of mesoscale divergence and vorticity with much greater accuracy than is now possible with other existing methods.



**Click to enlarge.** Divergence (left panel) and vorticity (right panel) for 7 DYCOMS-II cases. The thick vertical bar is one standard deviation of the estimated random error and the thin vertical bar is one standard deviation of the mean calculated from the measurements.



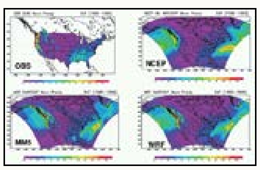
**Click to enlarge.** Analysis of the vertical momentum flux in the marine surface layer for varying wave age with winds following and opposing surface water waves. The vertical axis

Other accomplishments in FY2007 focused on winds and waves in marine boundary layers, which are often in an unsettled state as fast-running swells generated by distant storms propagate into local regions and modify the overlying turbulent fields. A large-eddy simulation (LES) model with the capability to resolve a moving sinusoidal wave at its lower boundary was used to investigate this low-wind/fast-wave regime. An analysis of the momentum flux from recent field campaigns Coupled Boundary Layers Air-Sea Transfer (CBLAST) (see Figure 6 below) and the Ocean Horizontal Array Turbulence Study (OHATS) validate the LES compares the momentum flux generated by atmospheric turbulence and the surface wave field. As the winds decrease or the speed of the waves increase, the momentum transfer from the ocean to the atmosphere becomes larger. Observational results are indicated by red dots and by **X**. Results for flow over a stationary land surface (note wave age = 0) are indicated by an open green square with an error bar. LES results are indicated by blue dots. The vertical dotted line indicates the speed (or wave age) where the winds and waves are in equilibrium with each other.

predictions and illustrate that the wave field modifies the drag of the ocean in fundamentally different ways than a rough land surface. Read more about this work and MMM's efforts to nest a finer-grid LES inside a coarser-grid LES, using the WRF modeling system's dynamic core in the ESSL LAR.

SERE scientists also conduct research that seeks to provide better understanding of the interactions among long-term climate change, climate variability, and weather extremes, while reducing societal vulnerability to their impacts. Among SERE's FY2007 efforts, planning for and conceptual development of the Society-Water and Natural Systems (SWANS) program began. The SWANS pilot project launched in FY2007, focusing on the Colorado River Basin and the effects of climate change on snow processes in Colorado's mountains, and the resulting implications for water management and policy. This project also involves RAL and ESSL scientists, and collaborators from the University of Colorado and NOAA.

SERE's efforts to understand changes in society-relevant extremes include looking at how climate change can influence climate extremes–such as heat waves, heavy rainfall, drought, etc.–not only in quantity, but also in intensity and variability. During FY2007, researchers from SERE's Institute for the Study of Society and Environment (ISSE) continued comparing model simulations of extremes to observed trends in order to validate climate model projections.




**Click to enlarge.**
Comparison of observational data, NCEP reanalysis data, NCEP-driven WRF data, and NCEP-driven WRF data for long-term average winter (DJF)

ISSE scientists also spearheaded the North American Climate Change Assessment Program (NARCCAP) at NCAR. This international program includes principal investigators from Canada and the UK and aims to produce multiple high-resolution climate change scenarios for most of North America. The initial program phase of the program, which entailed creating high-resolution, regional climate model simulations using National Centers for Environmental Prediction (NCEP) re-analyses boundary conditions from 1979 to 2004, was completed in FY2007.

### FY2008 Plans for Strategic Priority 2

The role of natural versus external forcing in driving transitions and potential predictability of climate- and weather-related events will continue. Among NCAR's plans to address these scientific questions in FY2008 are the following:

- Analysis of sea ice projections from other (non-CCSM) models included in the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC AR4). CGD scientist are analyzing these models' sea ice mass budget changes, the relationship to changing surface heat budgets, and the impact on the timing and transition to seasonally ice-free conditions. Implications for future polar bear habitat loss are also being assessed.
- A high-latitude terrestrial climate change feedback project has been initiated to investigate how permafrost thaw will affect the Arctic's carbon balance. This interdisciplinary project aims to improve our ability to simulate, understand, and predict high-latitude terrestrial climate feedbacks in CCSM, with a particular goal to develop a version of CCSM that can address the critical carbon issues in the Arctic tundra.
- In FY2008, MMM and CGD will generate a large-domain (about 500 km x 500 km x 20 km), high-resolution (a grid mesh about 100 m x 100 m x 20 m) LES of a tropical deep convection system in which deep and shallow convection, as well as large turbulent eddies (inside the PBL and inside the convection) are all resolved. MMM scientists plan to use a new Vector Vorticity Model developed by CMMAP scientists to perform such a LES. This will be the first attempt to

simulate tropical deep convection with its associated shallow convection and turbulence motions explicitly calculated as well.

- Scientists in CGD's Terrestrial Sciences Section have initiated a project to merge the carbon and nitrogen cycling capability of the CLM-CN model with a previously developed global dynamic vegetation model (CLM-DGVM). ESSL scientists will also be exploring the introduction of coupling between the carbon, nitrogen, and phosphorus cycles.
- MIRAGE data analysis and interpretation is still in its earliest stages, and is expected to continue over the next several years. The FY2008 phase is expected to involve model simulation and evaluation (both process-level, and 3D chemistry-transport models).
- For the first time in a rainfall enhancement experiment, dual-polarization, dual-wavelength and advanced weather radars will all be implemented in the field for a new RAL program in Queensland, Australia. In combination with airborne measurements, these radar systems will make it possible to trace the physical chain of events from the natural or seeded small particles to droplet and ice crystal growth, subsequent precipitation development in clouds, and ultimately rain on the ground in both natural and seeding clouds.
- Analysis of PACDEX data will be a priority for EOL and ACD scientists in FY2008/2009.
- In the upcoming year, ESSL/MMM scientists will continue analysis of the CBLAST and OHATS databases, and extend these analyses to the OBL. In the latter, focus will be on wave and current interactions under high winds.
- In late September 2007, a team of staff from EOL completed the site survey for TiMREX, a joint U.S.-Taiwan multi-agency field program. The field program will be conducted from 15 May to 30 June 2008 in the northern South China Sea, western coastal plain and mountain slope regions of southern Taiwan.
- BEACHON will continue developing its observational infrastructure. In FY2008, this work will include instrument acquisition and development of a BEACHON super-site, which will be placed in a water-limited region of Colorado. A BEACHON super-site workshop will be convened to refine these plans with university partners, as well as scientists from across NCAR.
- During FY2008/2009, the Water Cycle Program will focus on evaluating the Moncrieff/Liu convective scheme, as well as other candidate schemes. Water Cycle Program researchers will also use diagnostic studies to better understand linkages between soil moisture and precipitation in climate models.
- A new collaboration between RAL scientists and Dr. Enrique Vivoni of New Mexico Tech will focus on observing and modeling hydrometeorological processes in the North American monsoon regions of northwest Mexico.
- With baseline development and implementation of the Noah-distributed hydrological model for the Colorado Front Range nearing completion, several additional efforts are being initiated. RAL scientists will begin to develop new quantitative precipitation forecasts, using RAL's nowcasting systems and the Advanced Weather Research and Forecasting (AWRF) model, for operational deployment during the spring and summer of 2008.
- New hydrometeorological model development is planned within RAL. New forecast products along with the hydrological forecasts will be shared with the Denver/Boulder National Weather Service office through a new collaboration initiated in September 2007.
- During FY2008, NCAR scientists will work toward establishing SWANS as a multi-institutional collaborative effort. Diagnostic studies will be used to explore implications for water management and policy, and compare findings to IPCC AR4 diagnoses, and other regional assessment models.

- Currently, the NARCCAP team is analyzing output from the NCEP runs, and is archiving the data. In FY2008, SERE/ISSE will make these data available to the broader climate community.
- FY2008 work related to changes in society-relevant extremes will include applying new methodology to extreme, high sea surface temperatures in the tropics to ascertain whether increasing trends are consistent with the thermostat hypothesis. This research will have important implications for assessing potential impacts of global warming on coral reefs.
- In FY2008, SERE scientists will also initiate the RESUCCCITIES (Initiative to Attain Resilient and Sustainable

Relationships among Carbon, Climate, and Cities) program to address three major constraints affecting urban areas. These include:

1. the imminent peak in fossil-fuel production, particularly petroleum;
2. environmental injustice between developed and developing nations resulting from unequal access to energy resources, and from the negative effects of greenhouse gases–the preponderance of which developed nations generated–that developing nations are less able to deal with effectively; and
3. climate forcing related to greenhouse gas emissions, which have increasingly negative, and unequal impacts on cities. Further RESUCCCITIES details are available in the SERE LAR.





*Postal Address: P.O. Box 3000, Boulder, CO 80307-3000 • Shipping Address: 1850 Table Mesa Drive, Boulder, CO 80305 • Contact*

## *GOAL 1*, PRIORITY 3: IMPROVING PREDICTION OF WEATHER, CLIMATE, AND OTHER ATMOSPHERIC PHENOMENA

Understanding of the Earth system is a prerequisite to predicting its behavior, the latter being, however, of a more direct use to many components of society. In that context, for this priority, the key activities within NCAR's laboratories range from improving climate models, to exploring new approaches to prediction across scales, and global and local weather prediction.

### FY2007 Accomplishments

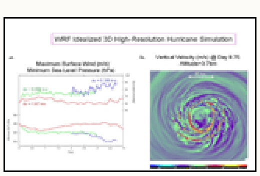
**Click to enlarge.** Data is being analyzed from the T-AMMA project to investigate and improve the performance of the driftsonde, shown above, as a research tool. (Photo by Terry Hock)

To a large degree, improving prediction of atmospheric and related phenomena requires improved understanding of the underlying process drivers. Among the FY2007 highlights that address these capabilities are analyses of data gathered during the FY2006 THORPEX-African Monsoon Multidisciplinary Analyses (T-AMMA) field campaign, which investigated and improved the performance of driftsondes as a research tool, and investigated hurricane genesis and the genesis environment.

RAL continued to work with scientists from EOL in analyzing data from the 2005/06 Refractivity Experiment For H2O Research And Collaborative operational Technology Transfer (REFRACTT). Considerable effort has been spent on data quality control and re-calibration of the refractivity fields in preparation for case study analysis of convection initiation and assimilation of the refractivity data into a numerical model. Approximately six cases from REFRFACTT-2006 have been identified for detailed analysis on the variability of water vapor in the near-surface boundary layer in the pre-storm environment and its role in the initiation of new convection. One of the cases is highlighted in a paper on REFRACTT-2006 that we are preparing for submission to the Bulletin of the American Meteorological Society.

RAL, ESSL/MMM, and EOL conducted significant research within the NSF-sponsored Short-Term Explicit Prediction (STEP) program. This work, aimed at improving zero-to-six hour forecasts of high-impact weather provides funding to a number of scientists working to improve forecasting of convective weather, gain better understanding of the interaction of the land surface and the atmosphere, improve microphysical parameterizations, and develop better tools for evaluating weather forecasts.

A new bulk microphysical scheme for WRF has been developed at RAL, incorporating a new snow particle size distribution scheme based on aircraft observations that represents snow particles as a sum of exponential and gamma distributions. RAL scientists also conducted a detailed microphysical study of two winter storms occurring during the IMPROVE (Improvement of Microphysical PaRameterization through Observational Verification Experiment) II field program. An unexpected finding was that freezing drizzle formed outside convective updrafts and ice crystals formed in convective cores. These observations suggest that ice nuclei depletion and ice formation via supersaturation need to be included in microphysical parameterizations in order to properly simulate these types of storms.




NCAR's dynamics and predictability work in FY2007 also focused on hurricanes with a special grant of computer time on NCAR's blueice, enabling testing of very high-resolution simulations of hurricanes under idealized conditions. Initial results indicate increasing simulated intensity with higher resolution.

Related Lab Annual Report Sections: Goal 1, Priority 3

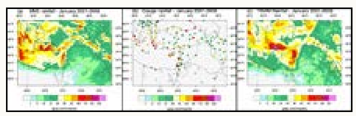
- EOL Activities
- ESSL Activities
- RAL Activities

**Click to enlarge.** Very high-resolution (150 meter) simulations of hurricanes under idealized conditions were run on NCAR's "blueice" computer. Initial results indicate increasing simulated intensity with higher resolution. A second important finding is that for fixed external conditions (under ambient environment sea-surface temperature, for example), the simulated internal variability of storm intensity is relatively small. The latter result gives rise to the hope that hurricane-intensity changes may result as a response to changes in external conditions, which are more easily predictable.

**View Animation**

A second important finding is that for fixed external conditions (under ambient environment sea-surface temperature, for example), the simulated internal variability of storm intensity is relatively small (Figure left below, blue curve), even though the three-dimensionality of the flow is apparent (Figure right, below). The latter result gives rise to the hope that hurricane-intensity changes may result as a response to changes in external conditions, which are more easily predictable.

RAL scientist, Thomas Hopson, worked with Peter Webster and colleagues at the Georgia Institute of Technology, as well as with members of the Asian Disaster Preparedness Center, in developing Climate Forecasting Applications for Bangladesh. Using European Centre for Medium Range Weather Forecasts (ECMWF) forecast products and NASA and NOAA precipitation estimates, the group produced short-range (1- to 10-day) and long-range (1- to 6-month) forecasts of upper catchment discharges from the Brahmaputra and Ganges Rivers. Medium-range forecasts (20- to 25-day) were produced using a statistical model to bridge the short and long-range time scales. The operational flood forecasts they issued in July and August 2007, and disseminated through a network of local and regional organizations, has been credited with saving tens of thousands of lives.



**Click to enlarge.** Figure a shows the average January precipitation amount based on MM5 simulations, for the inner computational domain at 15 km horizontal grid spacing. The rain gauge data in Fig. b are consistent with the MM5 estimates, and the coastal amounts of precipitation from the satellite/gauge merged data set show a similar pattern (Fig. c). Visual comparison of the amount and geographic distribution of monthly rainfall between model and the observations reveals considerable skill in the model simulation.

A new Climatological Four Dimensional Data Assimilation (C-FDDA) System has been developed at RAL to facilitate climate downscaling using the MM5 or WRF models. In 2007, CFDDA was used to generate a climatography for a region of interest to the U.S. Department of Defense (DoD); typical boundary layer conditions were used to define likely directions and speeds of hazardous-material transport for different seasons and times of day. C-FDDA is also being used to create a global mosaic of moderate resolution (~40 km) climatographies for the 1979-2005 period. This database will be used by state, and local emergency managers for predicting the effects of accidental or intentional releases of hazardous material. And finally, C-FDDA is being used to study the hydro-climatology of the eastern Mediterranean and the adjacent countries of the Middle East, where the balance between water supply and demand could be significantly altered by climate change.

Investigations on the impact of future climate and land cover on regional air quality in the Pacific Northwest and north central U.S., performed by ESSL/ACD scientists, as well as several university partners, and the U.S. Forest Service also falls under this priority. Results indicate that U.S. regional air quality (e.g., ozone and particles) will degrade even if U.S. anthropogenic emissions remain the same. See the ESSL LAR for more details on this research.

The Pentagon, and its 25,000+ occupants, represents a potential target for a terrorist attack using chemical, biological, or radiological material released into the atmosphere. In response to this concern, DoD has engaged RAL to develop a building-protection system called Pentagon Shield (PS). The PS system assimilates meteorological and contaminant observations from remote and in-situ sensors into a complex linked system of models that operate together to represent processes–from mesoscale to building scale. In the event of a hazardous-material release, the system calculates the properties of the contaminant source (e.g., location), the current characteristics of the contaminant plume, and the future path of the plume. In 2007, the modeling domain of the system was expanded to cover all of Arlington County, Virginia. This new "Urban Shield" domain will support emergency response efforts in the area.

### FY2008 Plans for Strategic Priority 3

NCAR's labs have a variety of plans for improving prediction capabilities in FY2008, including:

- Scientists involved in the Short Term Explicit Prediction (STEP) program will conduct an International H2O Project (IHOP) retrospective study to evaluate and further develop NCAR's data assimilation, nowcasting, and short-term forecasting systems for high impact weather prediction. Some of these systems will be used and evaluated in a real-time forecasting demonstration during the 2008 Beijing Summer Olympics.
- ESSL/ACD scientists will continue field and laboratory studies of the impact of climate change on regional air quality.

Lastly, improving short-term climate simulations at regional scales requires finer (in both the horizontal and vertical) resolution models, and perhaps ultra-high resolution modeling through two-way regional nesting. Opportunities in this area in FY2008 and beyond include:

- Simulations with and without data assimilation between about 1980 and 2005, which can be used to address predictability of the climate system on decadal timescales.
- Examining the implications for hydrology and water supplies that are controlled by local mountainous topography (e.g., snowpack and runoff in the West)
- Developing better understanding of the likelihood of changes in extremes, such as extended heat waves, floods, droughts, and Atlantic hurricane frequency and intensity.

Initial results from RAL's C-FDDA are a first step toward downscaling global model simulations of future climates for that region. The preliminary simulation will be repeated later without the use of observations but using "grid nudging" toward the driving analysis to keep the model analysis from drifting. This process of model verification and adaptation for the area will then be repeated with WRF for the entire winter season, when most precipitation occurs. The model that better represents the regional and local climate will be selected and run for the same period using lateral-boundary conditions from a simulation of the present global climate by the NCAR Community Atmospheric Model, driven by observed sea-surface temperatures and land use. Lastly, the regional model will be run with lateral-boundary conditions provided by future climate simulations conducted for the Fourth IPCC assessment report with the coupled ocean-land-atmosphere CCSM. This regional-model output will be compared with regional-model simulations of present climate in order to assess the impact of future climate forcing scenarios on the components of the water cycle in this geographic area.

The Urban Shield system will be enhanced during FY2008 by upgrading the transport and dispersion model to account for dense-gas effects and adding a variety of release source models–including Terminal Doppler Weather Radar data in the Variational Doppler Radar Assimilation Systems within Shield, and porting the transport model to run on high-speed Graphics Processing Unit hardware.



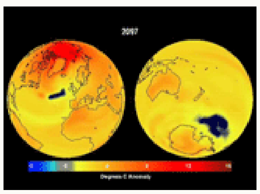

*Postal Address: P.O. Box 3000, Boulder, CO 80307-3000 • Shipping Address: 1850 Table Mesa Drive, Boulder, CO 80305 • Contact*

## *GOAL 1*, PRIORITY 4: DEVELOPING COMMUNITY MODELS

Developing numerical models and making them available to the scientific community is at the heart of NCAR's research and service to the community. Key activities in this priority are creating and adding to community models, research models, as well as progressing toward creation of an Earth system model.

### FY2007 Accomplishments

Discussion of some of the CCSM-related research has already been touched upon, however, details on CCSM development–including development of component models, and associated models of intermediate complexity–will be covered here.



**Click to enlarge.** One image from an animation depicting global surface warming as simulated by the Community Climate System Model (CCSM), version three. It shows the surface temperature anomalies relative to an 1870-1899 average for each month. Notice the greater difference from average at the poles. This is known as "polar amplification".

**View Animation**

FY2007, CCSM successes and development include the extensive number of modeling experiments designed to study the effects on various aspects of the climate system, such as the impacts of releasing varying amounts of chemicals into the atmosphere. These experiments were included as part of the IPCC AR4. Another significant accomplishment was creation of a preliminary version of the next-generation CCSM, referred to as CCSM3.5, which includes improved physics in all component models, including:

- Ocean: Moved to the POP 2 code-base, incorporated a new advection scheme, a revised horizontal viscosity that allows for the correct amplitude of Tropical Instability Waves, an improved mesoscale eddy parameterization, and movement toward higher vertical resolution
- Sea Ice: Moved to the CICE 4 code base, incorporated a revised ridging scheme, improved snow treatment, improved the shortwave radiation scheme, improved boundary layer exchange, and developed a new melt pond parameterization
- Land: Created new surface datasets, incorporated an improved canopy integration scheme and scaling of canopy interception, implemented new surface and sub-surface runoff models, developed a simple groundwater model, and new frozen soil scheme, improved the description of soil water availability, introduced a resistance term to reduce excessive soil evaporation, introduced nitrogen limitation on plant productivity, and improved snow age calculations
- Atmosphere: Adopted the finite volume core, incorporated modifications to deep convective processes, started assessments of new aerosol formulations, new microphysics, a new planetary boundary layer, and shallow convection scheme and new deep convection schemes, revised gravity wave and orographic wave-breaking formulations, hybrid isentropic coordinates, new radiation packages, and horizontal and vertical resolution sensitivities
- Biogeochemistry: Completed the land model intercomparison, which resulted in adoption of CLM-CN (Community Land Model with Carbon and Nitrogen cycles), a new ocean ecosystem component, and new control simulations that demonstrate a stable, coupled carbon-climate cycle in both ocean and land

***Related Lab Annual Report Sections: Goal 1, Priority 4***

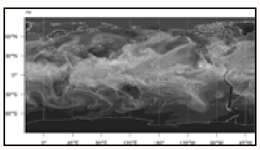
- ESSL Activities
- RAL Activities
- SERE Activities

- Software engineering: Made many improvements and progress (with CISL) on the scaling of CCSM to massively parallel architectures

When coupled together, CCSM3.5 demonstrates significant improvement to many of the system biases that plagued earlier model versions. Additionally, and finally, it is worth noting that scientists from around the globe continue to download CCSM data and the source code. Downloads of the CCSM3 source code, for instance, are nearing 900.

ESSL/MMM’s Weather Research Forecasting (WRF) model is also community built; the powerhouse in the suite of WRF models is the Advanced Research WRF (ARW) system. ARW provides users with a data assimilation capability, a variety of physics packages, and the WRF Software Environment, together with variants, such as WRF-Chem (for atmospheric chemistry modeling). In FY2007, ARW went from strength to strength, and is now the most popular (as defined by registration numbers and use) mesoscale atmospheric model in the world. As of July 2007, ARW had more than 5,300 registered users in more than 90 countries around the world, and is in operational use in approximately 20 locations. In 2007, the ARW was chosen as the basis for the new version of the NCEP Rapid Refresh modeling system.

Issued to the community in December 2006, Version 2.2 is the most recent major release of the ARW. In 2007, MMM conducted three tutorials for WRF system users (two in Boulder, Colorado, one in Korea), and two major WRF workshops. The team is currently looking at establishing an external advisory board in order to provide community input on WRF code management and community support activities.

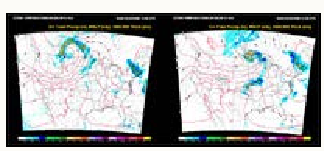


**Click to enlarge.** One frame from an animation of modeled precipitable water -- day 10 of 50-km Global ARW simulation, valid 1200 UTC 22 July 2007.

**View Animation**

The ARW continued to be updated and expanded in capability throughout this past year. Its nesting capability and adaptability have proven robust, with up to five nests being run in applications, and with the HYCOM (Hybrid Coordinate Ocean Model) being coupled to the ARW. Both of these projects were done in collaboration with the University of Miami’s Rosenstiel School of Marine and Atmospheric Science (RSMAS). In another collaborative project involving CalTech, WRF was adapted for use as a global model. This version is currently undergoing testing, but is projected to be included in the next major community release, slated for March 2008. Please see the ESSL LAR for further ARW and WRF highlights.

The Developmental Testbed Center (DTC), within RAL’s Joint Numerical Testbed, is a national facility created in 2003 to facilitate interaction between the operational and research communities in accelerating improvement of Numerical Weather Prediction (NWP) for the U.S. In 2007 the DTC:



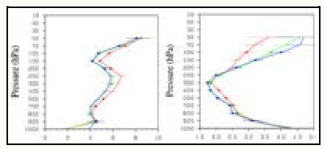
**Click to enlarge.** 3-h total precipitation (shaded), mean sea level pressure, and 1000-500 mb thickness fields for 60-h forecasts valid at 12 UTC on 3 May 2006. Right panel shows the ARW forecast and left panel shows the NMM forecast. Both WRF configurations used NAM initial and lateral boundary conditions and the same suite of physics parameterizations. For this particular forecast cycle, the ARW and NMM forecasts show rather different evolutions of the cyclone for this extended lead time.

- Conducted an extended Core Test to determine whether the small differences in forecast skill between the two dynamic cores (AWR and NMM) for 24-hour lead times also pertained to longer lead times (i.e., 60 hours). The actual runs are underway, and results will be available in early FY2008. The DTC is also performing a platform comparison to test whether forecast skill is dependent on the computing platform used to generate the forecasts.
- Continued to develop the concept of Reference and Operational Configurations for the community by creating a written document describing the process for designating these configurations, the information and support that will be provided for these configurations, and how decisions will be made with respect to retiring configurations.

- Brought a number of visitors to NCAR to provide support in the areas of physics parameterizations, ensembles, verification techniques, and idealized capability for the NMM dynamic core.
- Conducted the first joint WRF Tutorial in July 2007, covering both the NMM and ARW dynamic cores. These tutorials include lectures on the pre-processor, model, and post-processing tools, as well as practical sessions that allow the participants to gain hands-on experience building and running each component of the end-to-end system.
- Developed a state-of-the-art verification toolkit in collaboration with the NWP community. A beta release of the new Meterorological Evaluation Tools (MET) was made available in July 2007, along with a website offering extensive information on how to setup and run the package. MET uses components already present in verification systems developed at NCEP, GSD, and AFWA, as well as new components for the routine calculation of confidence intervals and significance statistics and object-based verification methods.

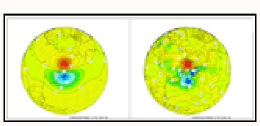
The Data Assimilation Testbed Center, organized within RAL's Joint Numerical Testbed in 2006, provides a home for testing and evaluating new data assimilation techniques, inputs, and strategies. In 2007 scientists:

- Performed a month-long evaluation of the impact of COSMIC local refractivity observations on Antarctic weather forecasts. The study found a significant positive impact of COSMIC refractivity assimilation on wind forecasts, tropospheric temperature and surface pressure. This study provided a rational and scientific basis for the operational implementation of COSMIC data in AMPS and also indicated areas of the WRF model that require further attention.



**Click to enlarge.** 36hr WRF forecast verification against Antarctic sondes: Conventional observations only (red), conventional plus COSMIC (green), and retuned conventional plus COSMIC (blue).

- Supported the Air Force Weather Agency's anticipated worldwide regional implementation of WRF-ARW and WRF-Var. Initial studies are focused on optimal data assimilation/forecast configurations on a South-West Asia regional domain. Currently, the data assimilation is performed every six hours, with the cycle being broken every twelve hours to blend back to NCEP's global forecast system. The possibility of full-cycling (i.e. continuously cycling WRF-Var and WRF-ARW without reverting back to the global model data) has been tested in DATC in 2007. Results indicate that both cycling permutations produce superior forecasts to those run without regional data assimilation, with update-cycling producing the most accurate forecasts. These results provide a benchmark for further full-cycling experiments to assess the impact of AMSU and AIRS radiances, COSMIC, and tuned error covariance.

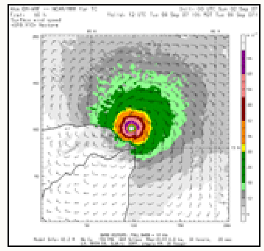


**Click to enlarge.** U-wind analysis increment response to a single temperature observation at 50N, 150W for both the "pure 3D-Var" technique (left) and the hybrid (right). Unlike the 3D-Var, the hybrid response is flow-dependent.

Other progress made in FY2007 by ESSL/MMM scientists and university collaborators included developing efficient assimilation of radiances from NOAA polar-orbiting satellites in WRF-Var, focused initially on data from the Advanced Microwave Sounding Unit (AMSU). In addition, development of unified variational/ensemble data assimilation capability for WRF was furthered by incorporating an Ensemble Transform Kalman Filter (ETKF) and flow-dependent forecast error covariances in WRF-Var.

A polar version of WRF is being implemented and tested in the Antarctic Mesoscale Prediction System (AMPS), which is run by ESSL/MMM in support of the U.S. Antarctic Program. The polar WRF modifications were originally developed by MMM collaborator, The Ohio State University, and the code reflects adaptations to better represent sea ice, and features unique to extensive ice sheets. Results thus far, from real-time runs over Antarctica, show improvement over the standard WRF.

Hurricane investigation is a growing aspect of WRF-system research and development. A new variant of the ARW, the Advanced Hurricane WRF (AHW), was further developed and tested throughout FY2007. AHW includes specialized data assimilation processes (including 3DVar and an ensemble Kalman filter) and a mixed-layer oceanic model. Current efforts are to run a reference forecast, including the simple ocean model, and two additional forecasts with experimental data assimilation for the 2007 hurricane season, all in near-real time.



**Click to enlarge.** Shown is a 60 h forecast of Hurricane Felix, predicted at Category 5 just prior to landfall. The plot shows contours of windspeed at 10 m elevation along with wind barb symbols every 40 km. The observed Felix was also Category 5 at this time, making landfall about 80 km south of the predicted location.

The incorporation of interactive chemistry capability by ESSL/ACD scientists in the Community Atmosphere Model has made considerable progress over the last year, and now encompasses a variety of options to accommodate the needs of the coupled climate model. In particular, using the implemented MOZART framework, CAM-Chem can now be configured to combine prognostic and diagnostic variables. As a result, aerosols can either be prescribed, simulated using simple input oxidant fields, or simulated using the full MOZART-4 aerosol parameterization. More details and further MOZART-3 and MOZART-4 accomplishments are available in the ESSL LAR.

In FY2007, the upper boundary of the Whole Atmosphere Community Climate Model (WACCM), another community-derived model, was extended upward to about 500 km, which is also the upper boundary of the TIME-GCM. In the process of achieving this upward extension, several modifications to the model were made, including:

- Implementation of modules to resolve the major species diffusion, which becomes increasingly important above 110 km.
- Implementation of modules and revision of codes to reflect the constituent-dependency of the specific heats, gas constant, and mean molecular weight.
- Revision of the treatment of the vertical diffusion equations for minor species and the heat conduction equation to a formulation appropriate for the upper atmosphere.
- Further WACCM and TIME-GCM details are available in the ESSL LAR.

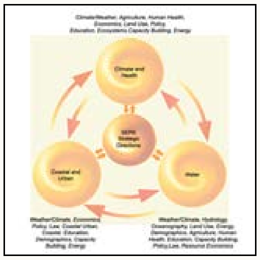
NCAR continued hosting the IGBP’s Earth System modeling project, AIMES. AIMES activities relevant to this priority include the Coupled Carbon Cycle-Climate Model Intercomparison Project (C4MIP), which investigates model benchmark and evaluation exercises to explore mechanisms that influence the response of the terrestrial carbon cycle including soil moisture and net primary production, particularly in the tropics, effects of CO2 fertilization, and disturbance and land cover. Find more details on AIMES in ESSL’s LAR.

Models, whether created by the community, individuals, or organizations, are becoming computationally ever more complex. Running such models will require petascale systems, which have between 100,000 and 1,000,000 processors. Such systems are expected to be in production by the end of this decade. It is of supreme strategic importance that the geosciences be positioned to use these systems. For the application developer, the massive levels of parallelism required to exploit these systems present daunting challenges at the algorithm level to achieve scalability.

In FY2007, CISL continued to lead the effort to understand these trends, prepared NCAR community models for the petascale, and also led the broader geoscience community toward petascale computing. In particular:

- CISL, the National Center for Supercomputing Applications (NCSA), and the San Diego Supercomputing Center (SDSC) partnered to put on the second Geosciences Application Requirements for Petascale Architectures (GARPA-2) in San Diego, California in February 2007. This meeting brought computer scientists, application experts, and vendors together for two days to report results and exchange ideas and information.

- John Dennis has continued work to further parallelize CCSM components, including POP, CICE, and, in collaboration with Tony Craig, CLM. John has demonstrated POP and CICE running on 30,000 processors, has created a prototype Parallel I/O (PIO) library for use with these components, and won time on the IBM Blue Gene/L system to do a global eddy-resolving ocean climate experiment with Frank Bryan and others.
- CISL continues to work with researchers from NCAR, University of Colorado, and IBM to integrate the High Order Method Modeling Environment (HOMME) with the Community Atmospheric Model. Accomplishments in FY2007, which includes introducing hyper-diffusivity and local mass conservation to the model, as well as completing preparations for aqua planet simulations.



**Click to enlarge.** Societal Resilience System of Systems (SRSS) diagram.

Lastly, because the interface between atmospheric processes and human wellbeing is mediated through a multifaceted array of natural and social systems, a pressing need exists to develop a conceptual framework that can guide analyses and case studies of examples (as well as counter-examples) of societal resilience. Toward this end, SERE staff are developing a "societal resilience system of systems" (SRSS) framework that will begin to unravel the complex interactions among the myriad contributors within and across the systems involved. This system was conceptualized in FY2007.

## FY2008 Plans for Strategic Priority 4

The current, long-term CCSM project plan is to develop and freeze the next version of the model, CCSM4, by the end of 2008. In addition to CCSM3.5’s improved physics, other component model improvements (e.g., introduction of dynamic vegetation) likely will be included, and new components for the carbon cycle and interactive atmospheric chemistry will be finalized. CCSM4 will be the model used to contribute to the next IPCC report.

CISL plans to continue work on CCSM enhancements to include the flux coupler, CAM, and input/output subsystem components. An important research and development objective for the latter two efforts is integration of a scalable, conservative discontinuous Galerkin-based HOMME dynamical core into CAM. The PIO library will be ported/integrated with the Earth System Modeling Framework (ESMF) to assist in the adoption of that framework in petaflops projects in general, and NCAR community models in particular.

During FY2008, it is expected that the governing framework for SRSS will be completed along with a minimum of four prototype case studies, including one from the energy industry led by Plymouth State University, which demonstrates the applicability and need for the SRSS network.

Other FY2008 plans include:

- Analyzing initial NRCM data from–and continuing experiments using–the NASA Columbia computer for another six years of climate simulations (2000-2005). This effort will include taking the next critical step of embedding ARW into CAM to undertake both current and future climate simulations.
- Quantifying the role of convective organization in the Madden-Julian Oscillation (MJO) through dynamical and numerical modeling by:
    - Designing new mesoscale parameterizations for climate models.
    - Multi-scale simulations of natural precipitating systems observed by Tropical Rainfall Measuring Mission (TRMM)/CloudSat.
    - Analysis of multi-scale convective organization in the aforementioned tropical channel model.

- Having examined the historical record of tropical cyclones in the North Atlantic to identify trends in frequency and long-period variability in FY2007, this work will be extended to other ocean basins. NCAR scientists will also utilize the new NCAR NRCM to examine environmental changes associated with these observed trends and variations of tropical cyclones.
- A full trial of the AHW has been proposed to NOAA as a collaborative effort between NCAR, NOAA, and RSMAS.
- The range of instruments that can be used within WRF-Var will be expanded to include the Advanced Infrared Spectroradiometer (AIRS) and the Special Sensor Microwave Imager/Spectroradiometer (SSMI/S). In addition, the hybrid approach for the variational/ensemble data assimilation capability for WRF will be tested in a variety of applications, including the full Ensemble Kalman Filter (EnKF) within WRF-Var to create a unified variational/ensemble data assimilation for WRF. And, to accommodate the growing user community and its needs, WRF Users Workshops and tutorials will be conducted in January and July 2008.
- The DTC will plan and execute another Core Test comparing the forecast skill of the two dynamic cores for higher resolution forecasts (e.g., grid spacing on the order of one km); add data assimilation to its end-to-end system for testing and evaluation. the DTC plans to offer the first official release of MET to the community; and continue to conduct tutorials as well as its visitor program.
- Work will continue to extend the capabilities of MET to include a broader spectrum of verification capabilities, development of an online tutorial, and inclusion of MET in the WRF Tutorial in July 2008. Members of the verification community will also be invited to join DTC staff for a workshop to be held in spring 2008 to discuss new capabilities for MET and the development of a verification system in which MET could reside.
- The DATC's Antarctic, Korean, and Taiwanese WRF NWP testbeds will be supplemented by the first reanalysis testbed, a 10-year Arctic system reanalysis based on a 10-year (2000-2010) period and the WRF-ARW enhanced with polar physics. The group will also begin to test and support the JCSDA's GSI algorithm in 2008; this s effort is part of the larger plan to work with the JCSDA (including NASA, the Navy, NOAA, and AFWA) in developing next-generation assimilation algorithms suitable for both research and operational communities.WACCM capabilities will be extended to include the top of the thermosphere, and to implement additional thermospheric and ionospheric processes in the model.
- WACCM capabilities will be extended to include the top of the thermosphere, and to implement additional thermospheric and ionospheric processes in the model.
- In anticipation of full incorporation of ionospheric processes into WACCM, a community release of the TIE-GCM will be issued, and the CMIT v. 2.0 will be transitioned to the Community Coordinated Modeling Center (CCMC).
- The massively parallel version of CMIT now in development–v. 2.5– will be tested at the Space Weather Prediction Center and at Boston University in partnership with the Center for Integrated Space Weather Modeling. These activities will set the stage for coupling space weather modeling elements into the ESM.
- CAM-Chem plans include continued evaluation of the model performance under the different options now available. Additional work will include continued use of MOZART-4 for analysis of the MIRAGE and NASA/INTEX-B field experiments, and MOZART-3 and MOZART-4 data will be published and released to the public.

*Postal Address: P.O. Box 3000, Boulder, CO 80307-3000 • Shipping Address: 1850 Table Mesa Drive, Boulder, CO 80305 • Contact*

# Strategic Goal 2 Increase Societal Resilience to Weather, Climate, and Other Atmospheric Hazards

The National Science Foundation supports the National Center for Atmospheric Research (NCAR) to advance basic research in the United States in the atmospheric and related sciences in support of the university community. As a federally-funded research and development center, NCAR is able to sustain a long-term commitment to this scientific enterprise. Our research and understanding of the atmosphere, the Earth System, and the Sun and their environments is essential to fulfilling our other strategic goals. We pursue this basic research to advance our knowledge. Concurrently, we also are able to improve the modeling, computing, and observational facilities we provide; and, to transfer the results of our work to the public and private sector.

Our research includes atmospheric chemistry; meteorology, solar physics, solar-terrestrial interactions, and the Earth's upper atmosphere; climate research; societal impacts of climate change and severe weather; biogeochemistry; water cycle; geophysical turbulence; and applied mathematics and statistical analysis. We conduct our research in close collaboration with university partners; local, state and federal agencies; and with strategic international partners and private sector sponsors. Our goal is also to make our research accessible and widely available.

**NCAR addresses four broad priorities within this goal:**

## Priority 1: Investigating Weather and Climate Information Needs and Decision Making

While decision makers in virtually all sectors of the economy could benefit from improved weather and climate information, they often have little idea of what data are currently available, and how they could benefit from this information. At NCAR, we are committed to exploring "the art of the possible" with decision makers, working with them to understand the nature of their work, how it is affected by weather and climate, and how they use information to make decisions. *Read more about this priority*

## Priority 2: Building Capacity for Coping with Weather and Climate Hazards

NCAR scientists work in partnership with stakeholder communities to research, build, and transfer state-of-the-art decision support information, tools, and systems. This effort encompasses a broad continuum of activities ranging from conducting workshops to developing operational systems and instruments. Developing greater resilience to weather and climate not only involves improved understanding of atmospheric processes, but better understanding of the decision-making process itself, and of the importance of communicating relevant information between atmospheric scientists and decision makers. It is clear that the connections between individual decision makers, as well as societies themselves, and the environment must be better understood and appreciated.

As an NSF federally funded research and development laboratory, and, as stated in our Strategic Plan, NCAR is devoted to applied research and technology transfer. While all of our programs have this responsibility, the most significant effort to support this priority occurs through our Research and Applications Laboratory. In this section, we also report on activities occurring in EOL and SERE. *Read more about this priority*

## Priority 3: Establishing New Connections with Researchers from Developing Nations

Many of the most interesting and important Earth system processes are global in scale and can only be effectively pursued with cooperation among nations and collaborative research efforts among institutions from many countries. *Read more about this priority*

## Priority 4: Supporting and Conducting Regional-Scale Investigations of Climate and Weather

As climate change and societal vulnerability to severe weather become more apparent, decision makers want to know what changes are likely to occur in particular places. Advances in computational power, modeling and analysis techniques offer opportunities for regional-scale research in the atmospheric sciences, and in the study of environmental and societal impacts. NCAR intends to move ahead rapidly in this area, conducting not only the important fundamental research that must be done but also applying that work through creation of new decision support capabilities. *Read more about this priority*





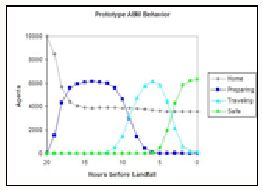
*Postal Address: P.O. Box 3000, Boulder, CO 80307-3000 • Shipping Address: 1850 Table Mesa Drive, Boulder, CO 80305 • Contact*

## *GOAL 2*, PRIORITY 1: INVESTIGATING WEATHER AND CLIMATE INFORMATION NEEDS AND DECISION MAKING

While decision makers in virtually all sectors of the economy could benefit from improved weather and climate information, they often have little idea of what data are currently available, and how they could benefit from this information. At NCAR, we are committed to exploring "the art of the possible" with decision makers, working with them to understand the nature of their work, how it is affected by weather and climate, and how they use information to make decisions.

### FY2007 Accomplishments

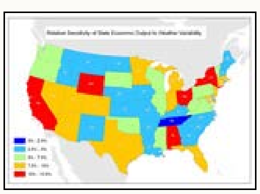
One goal of SERE is to ensure that scientific information effectively connects with the needs of decision-makers. The Weather and Climate Impacts Assessment Science Program (WCIASP) Climate seeks to examine and enhance the processes and methods for generating and communicating scientific knowledge to improve decision-making. Run by SERE/ISSE, the WCIASP focuses on critical gaps in the weather and climate arenas that are particularly challenging for decision-makers and scientists alike. These areas can be encompassed in three categories:



**Click to enlarge.** Simulated hurricane evacuation behavior in a proof-of-principle model.

1. characterizing uncertainty;
2. extreme weather and climate events; and
3. the role of climate in human health.

SERE scientists are also researching the complex interactions between climate processes, ecosystems, and human health in order to improve projections of climate impacts on human health and the health of the planet. One project that falls into this area is the “Health Risks from Climate Change and Variability in Wisconsin.” Started in FY2006 and continuing in FY2007, this project looks at the effect of extremes in temperature and precipitation on human health (morbidity) in Wisconsin and Chicago.



**Click to enlarge.** The map shows results from the Societal Impacts Program’s Overall US Sector Sensitivity Assessment which examined the sensitivity and vulnerability of state-level economic productivity to weather.

The Societal Impacts Program (SIP), a joint RAL/SERE program, aims to provide information that decision makers require. In FY2007, SIP accomplishments include completion of the Overall U.S. Sector Sensitivity Assessment, an empirical assessment of the vulnerability of the major U.S. economic sectors to weather variability. This assessment indicates that annual weather variability causes approximately 3.4% or $260B variability in annual gross domestic product. Building on this work, SIP staff initiated work on sector-specific studies with an emphasis on assessing the use and value of current and improved weather forecasts in addition to sectoral impact of weather. In 2007, this work has been focused on the transportation sector.

In other research, an internet-based survey of 1520 U.S. households nationwide was conducted to elicit information on people’s sources, perceptions, uses, and values for weather forecasts. People’s understanding of, use of, and preferences for weather forecast uncertainty information were also elicited in the survey. Preliminary results indicate that the average household accesses weather forecast information from various sources 115 times a month. Results also show

**Related Lab Annual Report Sections: Goal 2, Priority 1**

- RAL Activities
- SERE Activities

that a majority of people are willing to receive forecasts that contain uncertainty information and that people have preferences for how uncertainty information is conveyed.

Funding from the U.S. Voluntary Cooperation Program Contribution managed by NOAA's NWS International Activities Office was used to develop the "Primer on Economics for National Meteorological and Hydrological Services". This primer is primarily intended for members of the weather community with the goal of increasing their understanding of economic methods and their applicability in evaluating both the impacts of national meteorological and hydrological services (NMHS) and the associated benefits and costs of those services.

SIP members continued to lead efforts to integrate social science research in the weather community, supporting activities to develop a social science research agenda on the hurricane warning and forecast system (leading to a special issue of Natural Hazards Review published in July 2007). Members were also instrumental in publication of the first quarterly issue of Weather and Society Watch, a newsletter aimed at building a stronger, more informed societal impacts community.

### FY2008 Plans for Strategic Priority 1

To provide society, research organizations and decision makers with the information andtools they need, NCAR will conduct the following activities in FY08:

- SERE will continue development of WCIASP projects. The integrated uncertainty project will be expanded to include other water basins throughout the western U.S.
- SERE will also host the next biennial Health and Climate workshop, which will focus on the combined effects of heat stress and air pollution on human health.
- RAL and SERE will continue to analyze and publish results from the U.S. household survey on sources, uses and preferences for weather forecasts and weather forecast uncertainty information.
- Examination of the societal impacts and economic values for activities of NOAA's Hydrometeorological Testbed Center in the American River area of California.
    - Assess the use and communication of extreme weather warning information by forecasters, public officials, the media, and members of the public with a focus on how they receive, interpret, and use warning information
    - Conduct a preliminary assessment of the reliability, accuracy, and consistency of extreme weather data.
    - Develop an overview of best practices for interacting with users to introduce new decision support technologies into their working environments.





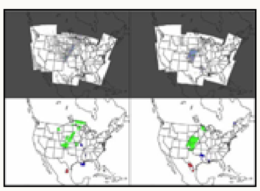
*Postal Address: P.O. Box 3000, Boulder, CO 80307-3000 • Shipping Address: 1850 Table Mesa Drive, Boulder, CO 80305 • Contact*

## *GOAL 2*, PRIORITY 2: BUILDING CAPACITY FOR COPING WITH WEATHER AND CLIMATE HAZARDS

NCAR scientists work in partnership with stakeholder communities to research, build, and transfer state-of-the-art decision support information, tools, and systems. This effort encompasses a broad continuum of activities ranging from conducting workshops to developing operational systems and instruments. Developing greater resilience to weather and climate not only involves improved understanding of atmospheric processes, but better understanding of the decision-making process itself, and of the importance of communicating relevant information between atmospheric scientists and decision makers. It is clear that the connections between individual decision makers, as well as societies themselves, and the environment must be better understood and appreciated.

As an NSF federally funded research and development laboratory, and, as stated in our Strategic Plan, NCAR is devoted to applied research and technology transfer. While all of our programs have this responsibility, the most significant effort to support this priority occurs through our Research and Applications Laboratory. In this section, we also report on activities occurring in EOL and SERE.

### FY2007 Accomplishments



**Click to enlarge.** The MET Analisys tool will provide ways of aggregating and producing graphics of teh statistics produced by he grid-to-point, grid-to-grid, and MODE tools. Above is an example of MODE-identified objects in the forecast (bottom left) and observation (bottom right) fields. Corresponding raw fields are shown in the top panels.

RAL's work to build resilience to weather hazards continues on a variety of fronts. The Aviation Weather Research Program remains focused on improved detection and forecasting of weather hazards that significantly impact the safety, efficiency, and capacity of the nation's air transportation system. FY2007 highlights include:

- A collaboration with the helicopter emergency medical services (HEMS) user community to tailor a flight path tool to meet its needs for weather information in a very narrow range of altitudes and short distances.
- Determination by the National Weather Service that NCAR's automated diagnosis and forecast systems for ceiling and visibility are viable technologies for the operational production of data grids that will flow into the NWS forecast process.
- Successful evaluation of an upgraded version of NCAR's Current Icing Product (CIP) depicting icing severity.
- Development and dissemination of a new turbulence detection and on-board quality control algorithm to Southwest and Delta Airlines for deployment on their fleets.
- Development of a Liquid Water Equivalent (LWE) real-time system.
- Definition and refinement of new concepts of how probabilistic weather forecasts can be tailored for aviation needs and integrated with automated decision support tools for improved air traffic management.

RAL also continues to address weather hazards affecting the nation's roads and highways. Highlights in 2007 include:

- Enhancement of the Maintenance Decision Support System (MDSS), a unique system that provides real-time snow and ice control guidance

*Related Lab Annual Report Sections: Goal 2, Priority 2*

- EOL Activities
- RAL Activities
- SERE Activities

for user-defined roadway segments.

- Dissemination of MDSS system software to over 60 road weather organizations (public and private), and successfully supported the Federal Highway Administration's (FHWA) annual MDSS stakeholder meeting.
- Real-time utilization of the prototype MDSS by the City and County of Denver and the E-470 Public Highway Authority during the particularly severe winter of 2006-2007. A commercial version of the MDSS is being developed and demonstrated.
- Preparation and delivery to FHWA of a major vision document titled, "Weather Applications and Products Enabled Through Vehicle Infrastructure Integration (VII)." This document discusses how probe data from millions of vehicles could be used in the future to support the diagnosis and short term prediction of weather.

And finally, a wealth of DoD research and development activities conducted by RAL include:

- Continued improvements in real-time four-dimensional data assimilation (RTFDDA) capabilities. RTFDDA assimilates observations from a variety of data feeds, preserving the data's temporal dimension during assimilation, and new analyses and forecasts are made every one to three hours, depending on the test range, providing the operational forecaster with timely information.
- Evaluation of new 3-Dimensional Variational Data Assimilation (3DVAR) techniques at the mesoscale. a number of non-standard observations that cannot be included in RTFDDA's observation-nudging scheme, such as satellite radiance, GPS, and radar, are being incorporated. 3DVAR is currently being integrated into the RTFDDA system, yielding a model-based solution that will account for all available observations.
- Successful testing of an operational ensemble of 4DWX forecasts in support of the FUsing Sensor Information from Observing Networks (FUSION) Field Trial. The ensemble system (called E-RTFDDA) extends the pseudo-deterministic, single RTFDDA realizations by running a suite of RTFDDA forecasts, all valid at the same place and time. The ensemble comprises 30 members whose differences are induced by varying initial conditions, boundary conditions, model physics, and model cores.
- Development of an operational algorithm that can both estimate an unknown chemical, biological, radiological, nuclear, and explosive (CBRNE) source and predict a refined downwind hazard from that source. To support testing and evaluation of this product, RAL is developing a virtual testing and evaluation environment (VTHREAT) that will enable simulation of a realistic CBRNE release scenario, placement of CBRNE and meteorological sensors, and extraction of the resulting synthetic sensor readings.

In FY2007, ISSE's Kathy Miller continued working with Robert McKelvey (University of Montana) and Peter Golubtsov (Moscow State Lomonosov University, Russia) on the development of game (wildlife) theoretic models, which approximate the effects of climate impacts in competitive fisheries for highly migratory fish stocks. In FY2008, the project team will incorporate results from this work into a set of workshop talks and journal papers.

Miller also helped convene a workshop in April 2007, the ***Challenge of Change: Managing for Sustainability of Oceanic Top Predator Species***, as part of Climate Impacts on Oceanic Top Predators (CLIOTOP). CLIOTOP is a broad international scientific program that focuses on building an understanding of how combined effects of environmental changes and harvesting activities affect the dynamics of tuna, sharks, billfish, and other top ocean predator species.

**Click to enlarge.** Poster session from the workshop, "*Challenge of Change: Managing for Sustainability of Oceanic Top Predator Species*" (April, 2007).

EOL also contributed to this priority with the transfer and installation of NCAR's CP-2 radar in to Australia's Brisebane-based Bureau of Meteorology (BOM), which will enable long-term scientific collaboration in the areas of nowcasting, hydrology, and weather modification. Brisbane is an excellent location for studying flash flood producing rainstorms over moderate topography, as well as sub-tropical oceanic systems. The BOM also has a first-class array of rain gauge and lightning detection systems–ideal for long-term weather and climate research. More information on this project is available in the EOL LAR.

And, last, but not least, in mid-2007, ESSL/HAO and NOAA's Space Weather Prediction Center (formerly the Space Environment Center) co-hosted a successful summit meeting to identify areas for collaboration and support of space weather prediction and mitigation activities.

## FY2008 Plans for Strategic Priority 2

In the aviation arena, RAL plans include:

- Further enhancements will be made to the HEMS tool: radar and satellite data will be incorporated; user-specific data (e.g., location of hospitals, helipads/bases, etc.); street-level maps will be made available; and a search interface created.
- Our Graphical Turbulence Guidance 2 (GTG2) product is expected to become "operational" and available on the Aviation Digital Data Service web site. This product produces forecasts of clear-air turbulence sources out to 12 hours, updated hourly. Preliminary testing of the next version, GTG3, will also commence; this version will provide probabilistic forecasts, will use all available in situ reports, and will include explicit mountain wave turbulence diagnostics
- The LWE system will be demonstrated at four sites: Pittsburgh International, Chicago O'Hare, Denver International, and Minneapolis/St. Paul airports. Data from the LWE system will be provided to airlines, pilots and deicing users via a web site and radio broadcast. The FAA will evaluate the results of the demonstration and provide final approval to use the system operationally.
- New integration concepts developed during FY07 will be further refined and feasibility analyses conducted. High-resolution ensemble model simulations will be used to create probabilistic weather forecasts with a specific tailoring from an aviation perspective.

In surface transportation, RAL plans include:

- Continued development and validation of the MDSS using Colorado as a test bed. Prototype MDSS products will be provided to the E-470 Public Road Authority and the City and County of Denver. We anticipate that Denver International Airport may also participate in the MDSS demonstration to evaluate the system's capabilities for supporting snow and ice control operations for ramp, runways, and Pena Blvd.
- Participation in the VII testbed near Detroit, Michigan to obtain data from test vehicles and begin to analyze their characteristics (e.g., quality, density, and geographical and temporal distribution). RAL will also begin the design and development of a Weather Data Translator (WDT) that will be used to parse, ingest, process, quality control, and generate advanced weather and road condition analyses utilizing vehicle probe data.

In its real-time modeling and data assimilation efforts for the DoD, RAL plans include:

- Systematic evaluation of different model physics schemes available in the WRF-RTFDDA model. An optimum suite of model physics options will be determined for each existing and new operational RTFDDA system according to the application's geographic location and dominant weather processes. Systematic errors in the final selected physics suite will be identified and improvements to the relevant model physics will be made.
- Exploration of hybrid data assimilation development with a focus on

assimilating satellite radiance and radar radial winds. Currently, studies have been undertaken with the IHOP-2002 cases to tune up the data assimilation parameters, and the implementation of the hybrid scheme for RTFDDA operations is planned during late FY08. A Variational Doppler Radar Analysis System (VDRAS) "observation-nudging" hybrid approach will also be studied, using VDRAS as a bridge for incorporating Doppler radar radial winds and reflectivity measurements into high-resolution WRF-RTFDDA through the "observation-nudging" mechanism.

- Further development of the E-RTFDDA system. Specifically, work will aim to: 1)develop and evaluate existing and new ensemble perturbation schemes; 2) develop more experience and conduct statistical verification relative to operational ensemble forecasting; 3) generate re-forecasts for the last three years and develop ensemble calibration algorithms; and 4) start to investigate a 4-D EnKF scheme which makes use of "Kalman-Gain" to define the spatial weighting factors of "observation-nudging" data assimilation.
- Development of additional types of meteorological sensors (towers, rawinsonde, and LIDAR) and the ability to dynamically place grids of chemical sensors to enhance the functionality of VTHREAT. The release of the first official version of the system is scheduled for early FY09.

In FY2008, ESSL/HAO and the NOAA Space Weather Prediction Center (SWPC) will continue to work together on areas of study including solar cycle variation, coronal events, irradiance variation, magnetospheric and ionospheric coupling and thermospheric density changes. ESSL/HAO will carry forward this work to transition key space weather modeling elements for transition and testing at the SWPC Rapid Prototyping Center. The goal of this exercise is to prioritize activities with respect to threat level and the feasibility of fast transition of basic research products. RAL is also involved in this work given the growing importance of space weather to aviation. Of particular concern are the health of flight crews repeatedly traveling over polar regions and the impact of space weather interfering with vital communications.

Science: Strategic Goal 2 previous next



*Postal Address: P.O. Box 3000, Boulder, CO 80307-3000 • Shipping Address: 1850 Table Mesa Drive, Boulder, CO 80305 • Contact*

Director's Message
Table of Contents
About NCAR
**Strategic Goals**: Science, Facilities & Technology
Metrics
Conclusion/Lab Links
Archives and Supplemental Info



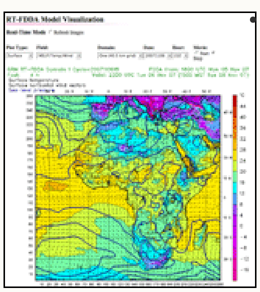
# *GOAL 2*, PRIORITY 3: ESTABLISHING NEW CONNECTIONS WITH RESEARCHERS FROM DEVELOPING NATIONS

Many of the most interesting and important Earth system processes are global in scale and can only be effectively pursued with cooperation among nations and collaborative research efforts among institutions from many countries.

## FY2007 Accomplishments

NCAR has led and participated in a variety of initiatives aimed at establishing connections in developing nations. Among these:

- With funding from the Indo-U.S. Forum, staff from NCAR and the National Centre for Medium Range Weather Forecasting in New Delhi held a weeklong workshop in India in 2007, highlighting investigations made possible through use of instrumented research aircraft. NCAR staff advised Indian researchers on developing an airborne science platform, and began planning for a Bay of Bengal tropical cyclone experiment aimed at improving forecasts of cyclone intensity and landfall. Additionally, EOL, ESSL/MMM and UOP/COMET representatives attended discussions held to define tasks in the next UCAR/NCAR MOU, which ranged from regionalizing WRF, to training the Indian Meteorological Department in modern forecasting techniques.
- EOL scientists are also pursuing collaborations with scientists in Africa to establish continuous CO2 analysis sites. Within the last year, scientists have established CO2 sites to fill in the CO2 exchange data gap in Africa, and to further understanding of Africa's role in global CO2 exchange. In FY2007, EOL scientists, in collaboration with local scientists, and other international scientists, decided to install a CO2 analyzer at the Mt. Kenya Meteorological Observatory, a World Meteorological Organization site. Pending research permits, EOL will install the analyzer in November 2007 or early 2008.




**Click to enlarge.** West Africa Demonstration Project 4DWX Home Page. Real-Time FDDA Output from 05 November 2007.

A relatively new program, the Africa Initiative (AI) is a coordinated effort aimed at building sustainable partnership between UCAR, NCAR, and UOP, and African institutions to pursue research and applications for the benefit of the African people. The initiative is based on four fundamental operating principles, concisely summarized by the overall philosophy of "enabling African solutions to African needs." A set of UCAR and NCAR co-founded pilot activities, chosen for their high probability of short-term results and ability to set the stage for longer-term collaboration, will focus on short-term weather prediction, particularly in Western Africa. This represents an intersection between needs identified by African researchers and operational meteorologists, and the expertise of UCAR, NCAR, and UOP programs.

- RAL has led three recent projects focused on West Africa and the Sahel:

  1. improvement of a modest radar network and data-distribution system within Burkina Faso and Mali;
  2. development of a part¬nership among UCAR, the Ghana

Related Lab Annual Report Sections: Goal 2, Priority 3
- EOL Activities
- RAL Activities
- SERE Activities

Meteorological Agency, and the Ghana university community to develop an opera¬tional Weather Research and Forecasting (WRF) model for West Africa; and

3. in partnership with members of the Africa Initiative, conduct of a workshop in Ouagadougou, Burkina Faso from April 2-6, 2007, for which the theme was “Improving Lives by Understanding Weather.” The workshop was attended by over 80 participants from 18 countries.

### FY2008 Plans for Strategic Priority 3

CCB will continue to help with the development of Climate Affairs programs through telementoring and travel. CCB project scientist Qian Ye will spend considerable time and effort on this activity.

Scientists at the Mt. Kenya Meteorological Observatory in Africa have begun long-term CO2 data collection. EOL scientists will begin analysis and maintenance of these data in FY2008.

Outcomes from FY2007 AI efforts are currently being evaluated to identify next steps for FY2008.

In 2007, RAL hosted a number of successful visits by delegations of African scientists and government officials. Memoranda of Understanding have recently been signed between UCAR and Burkina Faso, Mali, Ghana, and Senegal that look to developing collaborative meteorological and hydrological activities in the future. In addition, task order agreements are currently being negotiated with both Burkina Faso and Senegal to begin small radar upgrade and training programs. The long-range goal in numerical weather prediction is to develop capacity in Africa, to ensure that WRF is running operationally in Africa, is maintained by Africans, and is being adapted by Africans to meet their specific needs.



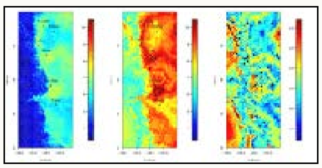


*Postal Address: P.O. Box 3000, Boulder, CO 80307-3000 • Shipping Address: 1850 Table Mesa Drive, Boulder, CO 80305 • Contact*

## *GOAL 2*, PRIORITY 4: SUPPORTING AND CONDUCTING REGIONAL-SCALE INVESTIGATIONS OF CLIMATE AND WEATHER

As climate change and societal vulnerability to severe weather become more apparent, decision makers want to know what changes are likely to occur in particular places. Advances in computational power, modeling and analysis techniques offer opportunities for regional-scale research in the atmospheric sciences, and in the study of environmental and societal impacts. NCAR intends to move ahead rapidly in this area, conducting not only the important fundamental research that must be done but also applying that work through creation of new decision support capabilities.

### FY2007 Accomplishments



**Click to enlarge.** Quantifying uncertainty. The left plot is the .025 quantile of the posterior distribution and could be used as a lower bound for the 25-year return level estimate. Similarly, the center plot is the .975 quantile and can be used as an upper bound. The right plot is the difference of the two, and thus shows the range of the 95% credible interval. The right panel also has black dots at the locations of the stations providing data for the analysis. The units are centimeters of precipitation per day (cm/day).

The output of multi-model climate experiments such as those for the IPCC or NARCCAP pose unique statistical challenges for synthesizing results and quantifying uncertainty. As a result, researchers from IMAGe's Geophysical Statistics Project (GSP) and ISSE, in collaboration with university researchers, are adapting new statistical methodology for summarizing this unique kind of data. Among the FY2007 achievements:

- Regional climate advances in this area included development of a multivariate Markov random field approach to compare differences in mean temperature and precipitation across different seasons, changes in extreme precipitation, and temperature for gridded regional model output.
- Also, a functional ANOVA approach has been explored (using a European Prediction of Regional scenarios and Uncertainties for Defining European Climate change risks and Effects project subset) to understand interactions and consistent effects from specific models.
- To address climate model biases and uncertainty, the Bayesian approach for interpreting multi-model ensembles was extended to combine results across different regions, and also for a bivariate response (temperature and precipitation).
- Another project using spatial statistics models for processes on the sphere analyzed the similarity of model biases for mean seasonal temperature and temperature trend for the models submitted to the IPCC archive. The models show substantial correlations indicating that biases are not independent across the ensemble.

### FY2008 Plans for Strategic Priority 4

FY2008 plans include extending the functional ANOVA approach for regional model output to extreme statistics, including a quantification of how extremes scale in space, from point locations to global model grid cells. The analysis of model bias will be adapted to the NARCCAP experiments.

*Related Lab Annual Report Sections: Goal 2, Priority 4*

- SERE Activities

Postal Address: P.O. Box 3000, Boulder, CO 80307-3000 • Shipping Address: 1850 Table Mesa Drive, Boulder, CO 80305 • Contact

# Strategic Goal 3 Cultivate a Scientifically Literate and Engaged Citizenry and a Diverse and Creative Workforce

Our nation is facing a significant challenge in educating the next generation of scientists. As an NSF strategic partner, NCAR contributes to national efforts to improve science literacy, inspire students, educate teachers, inform policy makers, and build a diverse workforce. At NCAR, we also recognize that the health of our institution depends on ensuring that those with aptitude and determination have opportunities in the atmospheric sciences and that they are welcomed and nurtured, regardless of gender, ethnic background, nationality, or physical ability.

**NCAR addresses four broad priorities within this goal:**

## Priority 1: Engaging a Broader and More Diverse Community

At NCAR, we are committed to increasing the presence of underrepresented groups in our workforce, and to creating an environment that welcomes a diversity of disciplines, ideas, scientific background, and approaches to problem solving. With a rich array of disciplines and a broad outreach component that spans all the laboratories, NCAR provides scientific information to stakeholders, policy makers, and the public. Through international programs, convocations of physical and social scientists, educators, and a wide range of disciplinary skills, NCAR demonstrates its commitment to engaging a broader community in the atmospheric sciences. *Read more about this priority*

## Priority 2: Enhancing Science Education

NCAR advances this priority through collaborations and relationships with visiting scientists, postdoctoral and faculty fellowship appointments, and professional development programs. *Read more about this priority*

## Priority 3: Improving Public Awareness and Understanding

This strategic priority and the previous one (enhancing formal science education) are not mutually exclusive; indeed, they overlap in significant ways. Many NCAR conferences, colloquia, and workshops are advertised and open to the public. These events enhance public awareness and understanding of the atmospheric sciences by building human and institutional capacity to deal with climate issues. *Read more about this priority*

## Priority 4: Maintaining an Innovative and Creative Workplace

Our people are our most important asset, and we prize individual professional growth, effective teamwork, and an organizational culture where all employees can realize their full potential and where achievements are celebrated and rewarded. *Read more about this priority*

Director's Message
Table of Contents
About NCAR
**Strategic Goals**: Science, Facilities & Technology
Metrics
Conclusion/Lab Links
Archives and Supplemental Info



## *GOAL 3*, PRIORITY 1: ENGAGING A BROADER AND MORE DIVERSE COMMUNITY

At NCAR, we are committed to increasing the presence of underrepresented groups in our workforce, and to creating an environment that welcomes a diversity of disciplines, ideas, scientific background, and approaches to problem solving. With a rich array of disciplines and a broad outreach component that spans all the laboratories, NCAR provides scientific information to stakeholders, policy makers, and the public. Through international programs, convocations of physical and social scientists, educators, and a wide range of disciplinary skills, NCAR demonstrates its commitment to engaging a broader community in the atmospheric sciences.

### FY2007 Accomplishments

In Spring 2007, NCAR and the University of Colorado Diversity Initiative collaborated on a workshop designed to engage graduate students in a series of career planning activities for the express purpose of preparing them for rewarding and productive postdoctoral opportunities in a broad spectrum of science and engineering fields. The workshop was particularly aimed at engaging participants from underrepresented groups in the geosciences. Fifteen graduate students participated in the workshop, along with 15 presenters and panelists.


**Click to enlarge.** CCB has continued to update its El Niño Web site, most recently producing a Spanish version.

In addition to the above-mentioned effort, CCB has continued to update its El Niño Web site, which ensures that the plethora of existing El Niño resources is put within easy reach of students, teachers, decision makers, etc. The updates include an extensive listing of links to El Niño information in Spanish and, to a lesser extent, Portuguese, was updated and expanded by CCB summer visitors, who coordinated biweekly updates. Several PowerPoint presentations on such topics as El Niño Affairs and Climate Affairs, created by CCB staff, were also translated into Spanish and added to the site.

Also, a joint SERE/RAL program, the Weather and Society * Integrated Studies (WAS*IS) continued in FY2007. This program facilitates a grassroots connection between meteorology and social science through creation of an interdisciplinary community of practitioners, researchers, and stakeholders who are passionate about establishing this connection. WAS*IS provides this community with opportunities to learn and discuss related tools and concepts at both national and international workshops–to date, 145 people have participated in these WAS*IS forums.

**Click to enlarge.** Weather and Society * Integrated Studies (WAS*IS) continued in FY2007. This program facilitates a grassroots connection between meteorology and social science.

With NCAR support, the UCAR Education and Outreach (EO) office added new bilingual content (in English and Spanish) to its educational site, Windows to the Universe. The Windows to the Universe audience is now greater than 20 million users per year from around the world, with about 25% of the users accessing Spanish-language sections of the Web site. These resources were brought to the attention of bilingual science teachers in workshops in the metro-Denver area, and at regional and national meetings of science education organizations. And, as a result, in November 2006, UCAR EO staff was invited to present and share these bilingual educational resources on at the Seventh Annual Convention of Professors of the Natural Sciences in Puebla, Mexico. Also, a session at the Fall AGU meeting on


**Click to enlarge.** The "Windows to the Universe"

Related Lab Annual Report Sections: Goal 3, Priority 1
- CISL Activities
- EOL Activities
- SERE Activities

website has added a large amount of bilingual content.

Interhemispheric Collaboration on Geoscience Education in Latin America was convened by the EO team in early FY2006, and was followed by an AGU session at the Spring meeting in Acapulco on Climate and Global Change Education and Capacity Building in Latin America, co-convened by EO and IAI. Additionally, in June 2007, EO reps presented these resources to science educators in Santiago, Chile, at the International Educared Conference, which was attended by approximately 1,000 teachers from across Chile, and at a UNESCO science education conference in Argentina, which included both a workshop and Share-a-Thon.

**Click to enlarge.**Twenty NCAR female scientists worked with 50 middle school-aged Girl Scouts to learn about science careers.

In September, the fourth annual workshop, Girl Scouts at NCAR: Changing the Outlook on Science, One Girl at a Time, brought 20 female scientists together with 50 middle school girls. Co-organized by NCAR's Advanced Study Program (ASP) post-docs, NCAR scientists, and EO staff, the scouts had a chance to explore science via hands-on activities, links to World Wide Web resources on weather and climate, and through stories about the scientists' interests and careers in the atmospheric sciences.

EOL, HAO, and other NCAR staff participated once again in the Expanding Your Horizons Conference at CU Boulder in February 2007. The annual conference was held in the CU engineering center, with close to 200 girls in attendance from schools along the Front Range. The Boulder Branch of the American Association of University Women and the University of Colorado at Boulder organize this event to encourage pre-teen and teenage girls to study math and science, to increase their awareness of the options available in non-traditional careers, and to meet women whose careers depend on math, science, engineering, and technology.

NCAR scientists also participated in the Wonder of Science Saturday, an event held at Boulder's 29th Street Mall, in September 2007. This event provided the public with an opportunity to learn about different scientific organizations in the area, and its primary focus was on science education of children and adults. EOL performed a series of radiosonde weather balloon launches that gave people a rare opportunity to learn first-hand about the technology used to capture atmospheric profiles of pressure, temperature, relative humidity, and wind, and view data collected in real-time.

**Click to enlarge.**Public outreach sometimes happens in serendipitous ways. Nick Potts, an EOL Engineering Intern from the University of Florida, stands with John Handley, a train conductor from Hickman, Nebraska. Handley is holding a dropsonde he found hanging from a telephone wire on his way home from work one morning in July. After taking apart the dropsonde, which was dropped from the Driftsonde lauched in Wyoming in preparation for the T-AMMA field campaign, he found the name of an EOL Technician on some of the components. A quick web search and a phone call later, and Nick Potts headed off to Nebraska to

Students at all levels are a critical audience that NCAR serves. To the greatest degree possible, we try to create opportunities for real-life work/learning opportunities, particularly for students underrepresented in the geosciences. As an example, EOL saw fantastic response to its call for applications to its Summer Undergraduate Engineering program in FY2007. The lab received almost 100 resumes from mechanical, electrical and computer, aerospace, optical, environmental, chemical, and industrial engineering students–15 from women, and six through the National Society of Black Engineers. (The announcement was also posted with the Society of Hispanic Professional Engineers.) Four interns were hired, and worked with EOL engineers in Summer 2007.

EOL also emphasizes inclusion of diversity in its hiring practices and has instituted new internal practices in FY2007 to ensure that a measurable and fair process is followed for every new hire. Hiring managers must complete a form outlining how and where the job was advertised, what effort was made to solicit applications from females and underrepresented minorities, and justification for the final interview pool and hire. Also, the EOL Women's Group continues to bring together women at all levels in the laboratory–mechanics, technicians, administrators, scientists, data managers, managers, etc., providing a forum in which women can share experiences and discuss lab topics of mutual interest.

meet with Handley and retrieve the sonde. Later, the sonde was found to have critical data which helped EOL engineers make final adjustments for the successful T-AMMA campaign.

NCAR research and administrative staff again supported the Significant Opportunities in Atmospheric Research and Science (SOARS) program, and other UCAR diversity activities. Twenty protégés from across the United States and Puerto Rico completed the 2007 summer SOARS program. Support for these new and returning protégés came from throughout NCAR, with each of the five laboratories contributing at least one staff or scientist to serve as a mentor. In total, 32 NCAR employees from nine different divisions participated as research mentors, writing/communication mentors, or community mentors.

During the past year, SOARS and CISL continued collaborating beyond the end of the summer program, co-funding protégé Marcus Waldman to carry on work with research mentor Siddhartha Gosh (CISL) during the academic year. This is a promising model for establishing long-term relations between SOARS protégés and NCAR laboratories.

The Societal Impacts Program (SIP), a joint RAL/SERE program aims to provide information that decision makers require. In FY2007, SIP accomplishments include completion of the Overall U.S. Sector Sensitivity Assessment, an empirical assessment of the vulnerability of the major U.S. economic sectors to weather variability. This assessment indicates that annual weather variability causes approximately 3.4% or $260B variability in annual gross domestic product. Building on this work, SIP staff initiated work on sector-specific studies with an emphasis on assessing the use and value of current and improved weather forecasts in addition to sectoral impact of weather. In 2007, this work has been focused on the transportation sector.

In other research, an internet-based survey of 1520 U.S. households nationwide was conducted to elicit information on people’s sources, perceptions, uses, and values for weather forecasts. People’s understanding of, use of, and preferences for weather forecast uncertainty information were also elicited in the survey. Preliminary results indicate that the average household accesses weather forecast information from various sources 115 times a month. Results also show that a majority of people are willing to receive forecasts that contain uncertainty information and that people have preferences for how uncertainty information is conveyed.

Funding from the U.S. Voluntary Cooperation Program Contribution managed by NOAA’s NWS International Activities Office was used to develop the “Primer on Economics for National Meteorological and Hydrological Services”. This primer is primarily intended for members of the weather community with the goal of increasing their understanding of economic methods and their applicability in evaluating both the impacts of national meteorological and hydrological services (NMHS) and the associated benefits and costs of those services.

SIP members continued to lead efforts to integrate social science research in the weather community, supporting activities to develop a social science research agenda on the hurricane warning and forecast system (leading to a special issue of Natural Hazards Review published in July 2007). Members were also instrumental in publication of the first quarterly issue of Weather and Society Watch, a newsletter aimed at building a stronger, more informed societal impacts community.

### FY2008 Plans for Strategic Priority 1

Among the FY2008 plans:

- WAS*IS activities began FY2008 with a National Weather Service (NWS) workshop in Kansas City, MO. This event brought together all NWS employees who have gone through the WAS*IS workshop to strategize ways to integrate social science into the NWS paradigm at 120+ weather forecast offices, as well as at the broader organizational level. The SIP will also hold a WAS*IS workshop in Boulder in Summer 2008, contingent upon funding. This workshop will focus on building an interdisciplinary community of practitioners, researchers, and stakeholders, and include discussions of tools, concepts, and methods related to integrating social science and meteorology.

- A proposal prepared for developing an El Niño Affairs program in South America is being distributed to interested parties in the region, in hopes of securing funds in FY2008.
- In the coming year, EO will continue its efforts to promote use of its educational resources by a diverse international community and by individuals historically underrepresented in science. Toward this end, EO will continue Spanish translation of educational resources EO Web sites, including Windows to the Universe, and will continue to move forward on collaborations with science education colleagues in Latin America. In late 2007, EO will offer an expanded BSTARS program with the support of the NSF Opportunities for Enhancing Diversity in the Geosciences program. In addition to the one-day conference for 120 bilingual science educators, there will be a Saturday workshop and distance learning course offered during winter and spring. This year, additional program partners include the Colorado MESA (Math and Science Excellence) program and Univision Colorado (Spanish language News). If successful, this program should be scalable to the national level through the national MESA program.
- EO has also initiated a new Citizen Science program with support from NCAR. One of our new Citizen Science campaigns, Measure Your World, involves close collaboration with science educators in Chile and Mexico to engage learners in three countries on a collaborative project to estimate the Earth's radius through international teams. This campaign will began in late September 2007.
- EO and ASP plan to continue to collaborate with the NCAR over the coming year to implement the fifth year of the "Girl Scouts at NCAR" program.
- The new SOARS model of continuing interaction between science students and mentors is a promising model for establishing long-term relations between SOARS protégés and NCAR laboratories. SOARS has set aside additional funds to co-fund other protégés to continue their summer research with their host laboratory. Also, the NCAR Diversity Committee is working in collaboration with UCAR to build upon the success of the SOARS program to create NCAR opportunities for graduate students and postgraduates from underrepresented groups.

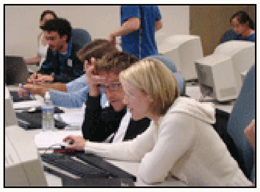



*Postal Address: P.O. Box 3000, Boulder, CO 80307-3000 • Shipping Address: 1850 Table Mesa Drive, Boulder, CO 80305 • Contact*

## *GOAL 3*, PRIORITY 2: ENHANCING SCIENCE EDUCATION

NCAR advances this priority through collaborations and relationships with visiting scientists, postdoctoral and faculty fellowship appointments, and professional development programs.

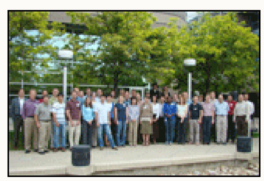
### FY2007 Accomplishments



**Click to enlarge.** The ASP Summer Colloquium was held 4-15 June 2007. Morning lectures were followed by afternoon tutorials. Above, students participate in a hands-on computer tutorial.

The lynchpin in ensuring development of science education opportunities at NCAR, for students and scientists at the graduate level and above, SERE's Advanced Study Program sponsored 28 postdoctoral fellows, providing each fellow with salary, travel and relocation funds, benefits, and computer costs, as well as administrative support. ASP also supported nine graduate students through its NCAR Graduate Fellowship (NGF) Program, Summer Colloquium series and Graduate Visitor Program (GVP). NGFs carry out their thesis research in full-time residence at NCAR, while GVP fellows come to NCAR for visits of three to 12 months in pursuit of their thesis research.

For several decades now, SERE's ASP has hosted at least one 2-week colloquium every summer on an emerging science topic of interest to the NCAR community. Designed for graduate students in a new or rapidly developing area of research for which good course materials may not yet be available, the colloquia have both a lecture component and a hands-on tutorial component. This year's colloquium, entitled "*Regional Biogeochemistry: Needs and Methodologies*", was hosted by an ASP postdoctoral Fellow, and included 50 graduate student attendees, and 41 presenters.



**Click to enlarge.** The ASP and Early Career Scientist Assembly (ECSA) host an annual forum on future scientific directions at NCAR. The objective of this forum is to bring together junior faculty and members of NCAR's ECSA to discuss selected topics in the geosciences. Above are the participants of the 2007 Junior Faculty Forum at NCAR, held 9-11 July 2007.

Beginning in 2003, ASP and the Early Career Scientist Assembly (ECSA) began hosting an annual Junior Faculty Forum at NCAR on future scientific directions. The Forum targets two to three specific topics of interest based on feedback from early career staff from NCAR and the university community. In FY2007, topics included: 1) Geophysical and statistical challenges in detection/attribution of regional climate change, and 2) Coupling terrestrial and atmospheric water dynamics to improve predictability in a changing environment. A total of 27 participants came to NCAR to meet with ECSA staff, and to discuss and to write papers on these topics.

During FY2007, NCAR also supported professional development workshops offered by EO at venues across the country, with an emphasis on the National Science Teachers Association's (NSTA) national and regional conferences, and state-based professional development opportunities. These venues allow large numbers of teachers to be reached at low cost, providing a cost-effective approach to professional development. NCAR reached out to more than 2,700 teachers through this program in FY2007.

NCAR also provides support for the office of the National Earth Science Teachers Association (NESTA), a nonprofit educational organization of approximately 1,000 members (more than 90% are K-12 geoscience teachers) that works to advance and improve Earth science education at all levels. NCAR support is critical, as NESTA moves to provide services to existing members, as well as the

Related Lab Annual Report Sections: Goal 3, Priority 2

- CISL Activities
- EOL Activities
- SERE Activities

broader Earth and Space Science education community.

Support from NCAR over the past year has also enabled EO to continue development of the NCAR Online Education program, with an initial focus on climate and global change through the Climate Discovery online course sequence: "Introduction to Earth's Climate," "Earth System Science: A Climate Change Perspective," and "Understanding Climate" (due Winter 2008). And, with completion of the Sixth NCAR Undergraduate Leadership, which had just over 20 competitively chosen participants attending, more than 120 undergraduate students have participated in this program since its founding.

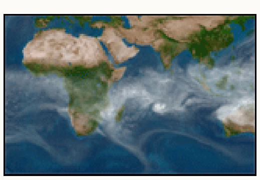
CISL's Summer Internships in Parallel Computational Science (SIParCS) Program is a prototype partnership between NCAR's supercomputing center and selected universities. It offers a significant opportunity to make a positive impact on the quality and diversity of the workforce needed to use and operate 21st century supercomputers.

**Click to enlarge.**These interns worked at NCAR in the mutually beneficial SIParCS program. The CISL-based SIParCS program challenges students in applied mathematics and computational science to help solve real-world problems associated with CISL's mission to support the atmospheric and related sciences. The students gain valuable work experience, and CISL is cultivating a skilled workforce for future supercomputing centers.

SIParCS targets students with a background in computational science, applied mathematics, computer science, or the computational geosciences. The program endeavors to provide opportunities for these exceptional students to gain practical experience with a wide variety of parallel computational science problems by working with the high performance computing systems and applications related to NCAR's Earth System science mission. Ultimately, SIParCS aspires to help address shortages of trained scientists and engineers capable of maintaining and using these high-end systems to achieve the goals of 21st century computational geoscience research. The internships are 10-12 weeks in duration.

As is true for NCAR's other labs, EOL is strongly engaged in science education at all levels. EOL conducted a small pilot program that exposes local high school students of high academic caliber to various EOL activities and specialized projects. In FY2007, EOL hired a Boulder High School senior to work with data collected from the driftsonde during the T-AMMA campaign in Africa last year.

In addition to our efforts with students of all ages, NCAR hosts numerous national and international workshops and colloquia. Among them is Institute for Mathematics Applied to Geosciences' (IMAGe) Theme-of-the-Year (TOY), which focuses on a particular area of the geosciences or applied mathematics that impact NCAR's scientific mission. The FY 2007 TOY focused on Statistics for Numerical Models. Numerical models are vital to simulate geophysical, chemical, and ecological processes and to understand the relationship among components in the Earth system. As models have become larger and more complex, their construction, validation, and analysis are no longer amenable to simple approaches and statistical summaries. Statistical science has advanced in the past 20 years to handle the interpretation of complicated multivariate, spatial, and temporal data sets, and it is well suited to tackle the massive outputs from numerical experiments that are now the norm in the geosciences. The goals of this TOY are to match cutting-edge statistical methods to the needs of geophysical model development and to make statistical scientists aware of the particular scientific issues and research in the geophysical modeling community.



**Click to enlarge.**This excerpt from an image of total integrated global water vapor was produced from data generated by the CCSM CAM3 model and shows a well-developed tropical cyclone over the

Additionally, many of CISL's outreach efforts are conducted through its Visualization Lab, a visual supercomputing facility that supports collaborative technologies, data analysis and visualization, and theater-style presentations in wide-format, high-resolution, stereo 3D. In FY2007, the Visualization Lab staff continued its successful partnership with NCAR's Public Visitor Program and supported approximately 180 presentations, AccessGrid sessions, and general meetings involving over 2,100 participants (a 25% increase from last year). These events included presentations to K-12 audiences, Indian Ocean. Animations produced from images like this are used in presentations and other education and outreach efforts to help foster public awareness and understanding of the atmospheric and related sciences.

scientific and corporate visitors, and government officials including VIP visitors from the National Science Foundation, the Office of Management and Budget, NOAA, the British Foreign Consulate, and the Chinese Government, to name a few. The CISL Visualization Lab also continued its important role as an outreach liaison with film and television organizations by providing a venue for television interviews with NCAR staff and by developing digital media that was used in productions by the Weather Channel, Seoul Broadcasting System, NBC WeatherPlus, and the Discovery Channel, among others.

The last highlight for this priority is to note that at the first NSF Facilities Users' workshop occurred in late September 2007 at NCAR (see Goal 5, priority 1 for additional workshop details), as an education and outreach component, EOL presented tutorials for students and early-career scientists on our facility request process.

### FY2008 Plans for Strategic Priority 2

Among the FY2008 plans:

In FY2008, ASP will make eight to 15 Graduate Visitor Program appointments, will develop and host another summer colloquium and the annual Junior Faculty Forum of Future Scientific Directions. ASP support will also be provided to the AIMES Young Scholars Network (YSN). SERE/ASP plan to pursue joint projects with the University of Colorado Diversity Initiative in areas of Postdoctoral Preparation Workshops, and SERE will continue supporting the ECSA, as well as individual early career scientists through administration of travel and visitor programs. In addition, SERE/CCB will develop and expand research and educational programs on climate and ethics by convening a high-level workshop with Minority Serving Institutions in partnership with Dillard University located in New Orleans, LA, and organize and convene a workshop designed to enhance diversity in the geosciences.

CISL places a high priority on its SIParCS program, and will continue its development in FY2008/2009. CISL plans to further broaden the candidate pool by running an open solicitation for all positions. In FY2008, our budget for the visitor program will increase to maintain eight to 10 summer intern positions across CISL, and it also plans to further integrate visitor activities by including travel support for a carefully chosen number of visiting scientists.

Based on the advice of the IMAGe advisory board and the support of NCAR's scientific community in the turbulence program, the next TOY will be titled Geophysical Turbulent Phenomena. This program is co-directed by Annick Pouquet and Professor Keith Julien (University of Colorado, Applied Mathematics Department). In this effort, IMAGe will also partner with the Institute for Pure and Applied Mathematics, an NSF Mathematics Institute. Planned 2008 workshops include:

- Observation and Experimentation
- Theoretical Methodology and Modeling
- Computational Methods, Scientific Computing and Visualization
- Turbulence Summer School for cross-disciplinary training in mathematical, computational, atmospheric and ocean sciences

EOL's pilot high school internship effort will, pending evaluation, also continue.

ESSL will begin two activities in FY2008, breakfast meetings between the lab Director and young scientists will take place on a monthly basis; and, a targeted program to get post-doctoral fellows acquainted at depth with large modeling activities at NCAR will be the second focus. This latter will be progressively put in place in conjunction with the NCAR directorate. This new program will initiate momentum for the Earth System Model development and will be carried forward for years to come.

Support from NCAR in FY2008 for education and outreach activities offered by UCAR EO will support ongoing successful programs, as well as new initiatives begun in 2007. The NCAR Undergraduate Leadership Workshop–the seventh in the series–is planned for June 16-20. NCAR will also continue to support the NESTA office and journal. During 2008, the NCAR Online Education Climate Discovery course sequence will be completed and offered in its entirety at least once over the course of the fiscal year, and perhaps more frequently if staffing and demand allows.

UCAR EO also continues to be committed to professional development workshops for teachers across the country at NSTA meetings in Detroit (October), Denver (November), Birmingham (December), and Boston (March), as well as organizing and offering the AGU GIFT workshop for teachers in San Francisco. These workshops will highlight our extensive resources in climate and global change education, and International Polar Year-related resources, which have been developed with NCAR's support. Additional opportunities to offer professional development workshops will arise over the course of the year, and we will participate if staffing and funding allow.



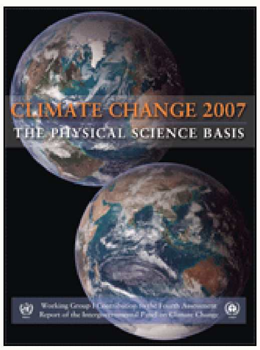

*Postal Address: P.O. Box 3000, Boulder, CO 80307-3000 • Shipping Address: 1850 Table Mesa Drive, Boulder, CO 80305 • Contact*

NCAR is sponsored by the National Science Foundation.

## *GOAL 3*, PRIORITY 3: IMPROVING PUBLIC AWARENESS AND UNDERSTANDING

This strategic priority and the previous one (enhancing formal science education) are not mutually exclusive; indeed, they overlap in significant ways. Many NCAR conferences, colloquia, and workshops are advertised and open to the public. These events enhance public awareness and understanding of the atmospheric sciences by building human and institutional capacity to deal with climate issues.

### FY2007 Accomplishments




**Click to enlarge.** The Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change is now available for purchase from the Cambridge University Press.

Perhaps most notable of the FY2007 accomplishments under this priority is wide public recognition of climate change as an issue, and the publication of the AR4 report. In addition to the CCSM, NCAR and our colleagues played significant roles in generating this report. Our researchers served as convening lead authors, lead authors, and contributing authors. They reviewed various chapters of the report and contributed to the Technical Summary and Summary for Policy Makers for the IPCC's Working Groups 1 and 2. NCAR and community research featured prominently throughout the report, which garnered a huge amount of media attention, and also led NCAR researchers providing expert testimony to U.S. Congressional committees, as well as briefings to individual politicians.

Outside of the AR4 excitement, NCAR continued its many efforts to raise public awareness of scientific questions and techniques. For example, CISL provided training workshops in NCL (NCAR Command Language), our open source visualization software, running four workshops in FY2007: one at the Asia Pacific Economic Cooperation Climate Center (APCC) in Bussan, South Korea, and three at NCAR.

Many public visitors to NCAR come through our websites. With support from NCAR and NSF Division of Atmospheric Sciences, new development efforts to the Windows to the Universe Web site focused on the International Polar Year (IPY), including a new "Earth's Polar Regions" section that provides information about the Earth's poles, polar weather, and its association with Earth's climate. Additionally, "Postcards from the Field," which provide reports from field studies in near-real time (in English and Spanish) was expanded in FY2007.

During 2007, NCAR and its laboratories developed a new website devoted to promoting its mission, the work of its scientists, its many facilities and models, collaboration and career opportunities, and the daily offering of scientific events, seminars, and outreach activities - to name just a cross-section of the content. The NCAR website navigates seamlessly with its laboratory websites, and allows visitors to 'drill down' for greater levels of detail within a related family of websites.

**Click to enlarge.** The new NCAR website promotes NCAR's mission and identity.

NCAR support also enabled development of a new Citizen Science emphasis in EO during 2007. With emphasis on youth and families, the public is encouraged to observe aspects of their environment and share their results with others around the country to gain

### Related Lab Annual Report Sections: Goal 3, Priority 3

- CISL Activities
- EOL Activities
- SERE Activities

a better understanding of a scientific problem while becoming more engaged in the natural world. The past year saw development of both Measure Your World (mentioned above) and the Great World Wide Star Count (GWWSC). This latter campaign, which began October 1, 2007, engages the global public in observations of the night sky, and builds their understanding of the impact of the built environment on star visibility.

### FY2008 Plans for Strategic Priority 3

- CISL staff expect to hear the outcome of an internal proposal to offer one free yearly NCL workshop at qualifying UCAR member universities, starting in FY2008. CISL staff also plan to offer two to three local workshops, and have been invited to present one at the Eurasia Institute of Earth Sciences in Istanbul, Turkey. Research will be conducted to determine the feasibility of offering similar training courses for PyNGL and PyNIO; this would most likely involve a collaborative effort with experts from the University of Colorado who already offer a Python scientific training course. It is important to note that our community contribution in this area is not simply training on the NCL tool: it is fundamental training in the important practice of Earth system data analysis.
- CCB's Climate Affairs program continues to expand and be included in educational activities around the world. Attempts to serve as a catalyst to the development of climate, water, and/or weather programs will be continued during FY2008 and FY2009. Also, as a first step in building interest in the ECNU's Coastal Affairs Center, ECNU and NCAR will co-sponsor a conference in July 2008, bringing undergraduates from universities around the world together to share discussions, hear keynote speeches, and attend symposia on the science, technology, and education issues that surround climate, water, and weather.
- During 2008, EO will continue its emphasis on informal science education, leveraging the content and audience of the Windows to the Universe site, and expanding its Citizen Science efforts. IPY Web content, as well as climate and global change topics will be expanded, and scientist use of the Postcards from the Field interface will be promoted, so as to share more effectively the excitement of work in the field with the public.

Director's Message
Table of Contents
About NCAR
**Strategic Goals**: Science, Facilities & Technology
Metrics
Conclusion/Lab Links
Archives and Supplemental Info

NCAR is sponsored by the National Science Foundation.

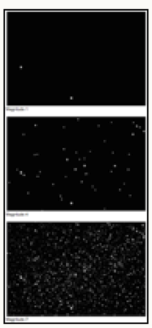
## *GOAL 3*, PRIORITY 4: MAINTAINING AN INNOVATIVE AND CREATIVE WORKPLACE

Our people are our most important asset, and we prize individual professional growth, effective teamwork, and an organizational culture where all employees can realize their full potential and where achievements are celebrated and rewarded.

### FY2007 Accomplishments

In addition to broadening NCAR's career development and leadership training during the past year, FY2007 brought an even more expanded variety of training programs to all staff. Additionally, the "Communicating Science" collaboration within the institution continues to identify courses, workshops, and resources that can help staff members to hone the oral, writing, and presentation skills they require to clearly and engagingly explain their research and its value to society to a broad range of audiences. A Communicating Science Journal Club, which formed in Fall 2006, draws staff to bi-monthly meetings to discuss new publications and reports that bridge science and education, pedagogy, public outreach, and new communication technologies.

EOL is instituting an internal sabbatical for ladder-track scientific and engineering staff, which is intended to increase their productivity through uninterrupted research or laboratory work. Sabbatical will allow researchers to pursue research leading to publication, publication writing, instrument development, development of major science plans, and participation as scientists in a field project. EOL staff might also use this time to write, for example, one or more chapters of a thesis or dissertation, depending on circumstances.



**Click to enlarge.** These images show the extent to which ambient light can affect our views of the nighttime sky. In the Magnitude 1 chart, the constellation Cygnus is almost completely obscured. In the Magnitude 7 chart, however, numerous stars are clearly visible. (Images courtesy UCAR Office of Education and Outreach.)

NCAR support also enabled development of a new Citizen Science emphasis in EO during 2007. With emphasis on youth and families, the public is encouraged to observe aspects of their environment and share their results with others around the country to gain a better understanding of a scientific problem while becoming more engaged in the natural world. The past year saw development of both Measure Your World (mentioned above) and the Great World Wide Star Count (GWWSC). This latter campaign, which began October 1, 2007, engages the global public in observations of the night sky, and builds their understanding of the impact of the built environment on star visibility.

### FY2008 Plans for Strategic Priority 4

NCAR will continue expanding its training and educational options to staff, and the Communicating Science will build on its existing success. EOL will evaluate its sabbatical plans, and share any insights gained with our Human Resources department and the other NCAR labs.

**Related Lab Annual Report Sections: Goal 3, Priority 4**

- CISL Activities

# Strategic Goal 4 Provide Robust, Accessible, and Innovative Information Services and Tools

NCAR’s scientific research programs work to provide more accurate advance warning of extreme weather, more skillful prediction of space weather events, and making better projections about regional impacts of global climate change. Toward this end, NCAR provisions, operates, and maintains supercomputing facilities and cyberinfrastructure to advance our understanding of the atmospheric and related sciences. Meeting the challenge of providing facilities sufficient for this research is fundamental to NCAR's fourth strategic goal.

NCAR designs, develops, and maintains community models, modeling frameworks, and data analysis and visualization tools that are openly available to the community. In addition, NCAR collaborates with the community on research activities in computational science, applied mathematics, and geostatistics. These efforts are pursued with the aim of developing novel, improved techniques for attacking key scientific problems and providing meaningful results for society.

NCAR's Computational and Information Systems Laboratory is a world leader in supercomputing and cyberinfrastructure, providing services to more than 60 UCAR member universities, as well as NCAR and the larger geosciences community. CISL also performs basic and applied research in IT, computational science, and mathematics.

**NCAR addresses four broad priorities within this goal:**

## Priority 1: Enhancing Capability and Capacity of NCAR Supercomputing

The hallmark of supercomputing at NCAR has been provision of robust, reliable, effective, and efficient production computing with state-of-the-art storage, data analysis, data visualization services and tools for the user community. CISL increases the computational capacity available to our scientific community on a regular basis. Peripheral resources that complement and supplement the high-end computing environment are upgraded and enhanced as appropriate to match the growth in compute capacity. *Read more about this priority*

## Priority 2: Developing and Providing Advanced Services and Tools

For nearly 50 years, NCAR has provided a computational environment to satisfy the institution's overall mission of providing robust, reliable, accessible, innovative, and advanced services to the university community and the broader scientific community. NCAR also advances atmospheric science by creating integrated software and data system services that are at the heart of today's state-of-the-art observing systems. We provide classic computational services through our high performance computing production environment with mass storage, network connectivity, data analysis, visualization, research data stewardship, and data distribution services. In addition, NCAR continually evaluates opportunities to provide services designed to enable Earth System science for the entire community of users such as TeraGrid integration, experimental computing systems, and an Earth system knowledge environment. NCAR continually improves its observational data products and services to increase overall functionality, accessibility, reliability, and ease of maintenance. This work often has broad community impacts when the technologies are shared and distributed to outside users and agencies. *Read more about this priority*

## Priority 3: Conducting Research in Computer Science, Applied Mathematics, Statistics, and Numerical Methods

The research activity within CISL enhances the computational infrastructure at NCAR and supports more efficient scientific computation and simulation. This research is necessary to maintain an innovative computational facility and to lead the geophysics community in incorporating new numerical methods and models. Given this broad priority, the research in CISL must span several disciplines and address computational science at many levels. Integrated with the computational science are areas of applied mathematics that include data analysis, models for multiscale processes, and techniques for assimilating data into numerical models. Because these different elements are coordinated through a single Lab, there is an easy transfer of technology and ideas from prototypes and theoretical results in IMAGe to implementation and workflow issues in CISL, and finally into tools and models for the communities served by CISL. There is also a valuable reverse transfer whereby emerging computational capability and data storage concepts spur particular research that takes advantage of these features. *Read more about this priority*

## Priority 4: Creating an Earth System Knowledge Environment

NCAR continues to develop an Earth System Knowledge Environment (ESKE), new cyberinfrastructure that combines models, data, experiments, collaborative tools, and information resources in a way that fosters knowledge sharing and accelerates scientific workflow. NCAR is creating integrated, collaborative problem-solving environments that advance the community's ability to engage in research and scientific discovery. Efforts span modeling frameworks, data and knowledge management and access, collaboration, and analysis and visualization. *Read more about this priority*



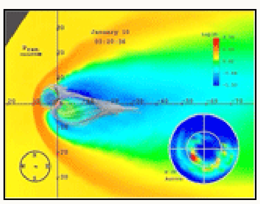

*Postal Address: P.O. Box 3000, Boulder, CO 80307-3000 • Shipping Address: 1850 Table Mesa Drive, Boulder, CO 80305 • Contact*

## *GOAL 4*, PRIORITY 1: ENHANCING CAPABILITY AND CAPACITY OF NCAR SUPERCOMPUTING

The hallmark of supercomputing at NCAR has been provision of robust, reliable, effective, and efficient production computing with state-of-the-art storage, data analysis, data visualization services and tools for the user community. CISL increases the computational capacity available to our scientific community on a regular basis. Peripheral resources that complement and supplement the high-end computing environment are upgraded and enhanced as appropriate to match the growth in compute capacity.

### FY2007 Accomplishments

In January 2007, NCAR selected the University of Wyoming and the State of Wyoming as foundational partners for creation of the expanded NCAR Supercomputing Center (NSC). Leading up to this event, CISL managed all aspects of the project discovery phase and prepared the broader community to support a management decision to re-establish the NSC in a new location. In particular, CISL facilitated the process of exploring partnerships to enable construction of an expanded NCAR supercomputing facility by conducting discussions with potential facility partners, performing technical and financial feasibility studies of partner proposals, and supporting NCAR and UCAR management in discussions of the project with members of the community, the UCAR Board of Trustees, and NSF.



**Click to enlarge.** This is a visualization of a coronal mass ejection impacting the Earth's magnetosphere. These phenomena can have significant impacts on satellites, astronauts, and systems ranging from GPS to power grids. Significant challenges in this field that will benefit from petascale computing include first-principles modeling of solar convection and its contribution to the 22-year solar cycle, and crucially, modeling the emergence of magnetic flux from the solar convection zone and the conditions that lead to solar flares and coronal mass ejections. (Image courtesy of Michael Wiltberger, NCAR HAO.)

Subsequent to hosting the NSF-funded High Performance Computing in the Geosciences Workshop at NCAR in September 2006, CISL provided geosciences researchers with an additional interactive forum to discuss and debate community high-performance computing requirements during a Town Hall session at the Fall 2006 AGU meeting. CISL personnel also presented their ideas and plans to University Corporation for Atmospheric Research members–which include representatives from each of UCAR's member universities–and its Board of Trustees, to inform and get input from both groups. CISL staff also assisted various University of Wyoming and state officials with the preparation of support materials and conducting the question-and-answer sessions with Wyoming legislators–required for passage of the project-funding legislation. An NSC Project Office was created within CISL, and the staff assigned to this office is working with University of Wyoming personnel on a joint proposal to NSF to construct and operate the NSC.

Supercomputers–and supercomputing centers–are required to investigate fully today's complex geoscience questions. Maximizing the efficiency of these centers requires developing the concept of a Grid that can federate computational resources, data, and skill sets, forming a whole that is greater than the sum of its parts. Because of the strategic importance of grid technology, NSF persuaded NCAR to join the TeraGrid in FY2006.

As of FY2007, deployment of the NCAR TeraGrid node is complete, and focus has shifted to preparing NCAR for its role as a TeraGrid resource provider. NCAR's TeraGrid node consists of the IBM Blue Gene/L supercomputer, a 100-TB storage cluster, an Earth System Grid data server, and a visualization node, all connected to a 10-Gbps hub switch that is connected to the TeraGrid wide area

***Related Lab Annual Report Sections: Goal 4, Priority 1***

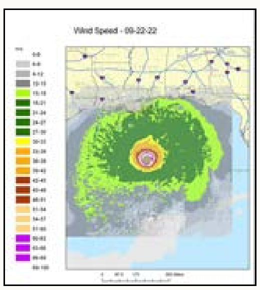
- CISL Activities

network.

In FY2007, CISL deployed the first phase of the Integrated Computing Environment for Scientific Simulation (ICESS), in which the IBM POWER4 computer was replaced by an IBM POWER5+ system. This increased the total computing capacity at NCAR by more than a factor of two beyond FY2006 levels. The increased computing capacity has also increased the average rate at which data are archived on the Mass Storage System (MSS), from 50 to 75 TB/month. Associated data analysis services are being upgraded to create a comprehensive environment capable of supporting low-end data processing through high-end visualization. A high-bandwidth, high-capacity shared file system has been installed to provide users with a large local storage area that can be used for advanced analysis and visualization needs.

**Click to enlarge.** Frost is the 2,048-processor IBM Blue Gene/L system at NCAR. One quarter of this resource has been allocated to the TeraGrid, amounting to 4.5 million CPU hours of computer time annually. The system has been in production as a TeraGird resource since August 1, 2007. Frost is attached to a storage cluster, a visualization node, and has access to the multi-petabyte NCAR Mass Storage System. As a TeraGrid Resource Provider, NCAR is committed to offering a network of computational, data, and knowledge resources to multidisciplinary groups of researchers, students, educators, policy makers, and impact and assessment communities around the world.

CISL staff organized and hosted the eighth biennial session of Computing in Atmospheric Sciences (CAS2K7). Computer experts, scientists, and industry leaders gathered in Annecy, France during September 9-13, 2007, to discuss the status and future of high-performance computing for weather prediction and climate modeling. The conference provides the opportunity for supercomputing industry leaders to hear about their customers' needs and present their product roadmaps, for scientists to exchange ideas and share experiences about computing resources and applications, and for data experts to discuss innovative methods for accessing, distributing, and archiving data.



**Click to enlarge.** MMM's Hurricane WRF model output in netCDF format in ArcMap overlaid with demographic and infrastructure data.

Also, a GIS Strategic Initiative, led by ISSE project scientist Olga Wilhelmi, is an interdisciplinary effort that integrates Earth system, environmental and social sciences through spatial analysis and interoperability of georeferenced information. The initiative promotes and supports the use of GIS as both an analysis and an infrastructure tool in atmospheric research and to address broader issues of geoinformatics and spatial data management. In FY2007, the GIS Initiative staff worked toward interoperability between weather and climate models and GIS analysis tools.

### FY2008 Plans for Strategic Priority 1

During FY2008, the IBM POWER5+ system will be replaced by an IBM POWER6 system that is expected to provide at least a 2.5-fold increase over FY2007 performance levels. This will keep CISL at or above the compute capacity goal outlined its Strategic Plan. However, when installation of the POWER6 is complete, the NCAR Mesa Lab machine room will be within 10 percent of its operational power and cooling limits.

The increased computational capacity at NCAR, as well as the demand from NCAR scientists to import data from external computational facilities and/or observational field projects creates an increase in the demand for archival storage. Detailed plans will be made to carefully map the MSS needs and costs through the transition to the NSC. CISL plans to carefully examine MSS user policies and requirements, and then engage storage vendors to propose an overall solution to the MSS growth issues for 2008-2012 and perhaps beyond. At a minimum, another library must be added to the MSS during both FY2008 and FY2009 to increase the total archival storage capacity available at NCAR. Finally, CISL will deploy a large storage area network within the supercomputing environment to provide users with the most effective and efficient methods of data management across the machines.

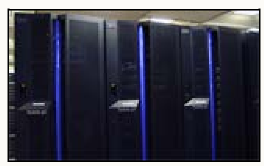
An allocation model for TeraGrid users–with quotas–has been established for the NCAR MSS. CISL's TeraGrid supercomputing resource, the Blue Gene/L, was acquired with a Major Research Infrastructure (MRI) grant from the NSF in spring 2005, and will be three years old in April 2008. It has been used to scale models up to high levels of parallelism, but as Blue Gene/L ages, a replacement system needs to be acquired to maintain a credible supercomputing presence on the TeraGrid. CISL is therefore planning to acquire a follow-on system in the FY2008 timeframe. This will allow CISL to better serve the supercomputing needs of UCAR, the TeraGrid, and partner institutions in the proposed Wyoming-based NSC.

In FY2008, the GIS Initiative will continue to work on improving compatibility, accessibility and accuracy of weather (i.e., WRF) models with GIS environment. We plan to investigate conversion mechanisms between sphere-based models and ellipsoid-based GIS data. Through participation in "The Potentials of and Limits to Adaptation in Norway" (PLAN) project, we will work on integrating quantitative and qualitative information in a GIS environment and, thus, improving methodologies for assessing societal vulnerability and adaptive capacity to climate change.

## *GOAL 4*, PRIORITY 2: DEVELOPING AND PROVIDING ADVANCED SERVICES AND TOOLS

For nearly 50 years, NCAR has provided a computational environment to satisfy the institution's overall mission of providing robust, reliable, accessible, innovative, and advanced services to the university community and the broader scientific community. NCAR also advances atmospheric science by creating integrated software and data system services that are at the heart of today's state-of-the-art observing systems. We provide classic computational services through our high performance computing production environment with mass storage, network connectivity, data analysis, visualization, research data stewardship, and data distribution services. In addition, NCAR continually evaluates opportunities to provide services designed to enable Earth System science for the entire community of users such as TeraGrid integration, experimental computing systems, and an Earth system knowledge environment. NCAR continually improves its observational data products and services to increase overall functionality, accessibility, reliability, and ease of maintenance. This work often has broad community impacts when the technologies are shared and distributed to outside users and agencies.

### FY2007 Accomplishments



**Click to enlarge.** Blueice is a supercomputer based on the IBM POWER5+ processor and the High Performance Switch communication technology. When it was installed, it effectively doubled the high-end computing resources available at NCAR. CISL bears the ongoing responsibility to provide the numerical simulation community with resources that offer the optimal combination of computational capability and capacity that can be used effectively. This facility supports the NCAR strategic priority of "Enhancing capability and capacity of NCAR supercomputing.

NCAR's TeraGrid activities in FY2007 have already resulted in a number of new and interesting technical and scientific collaborations. NCAR demonstrated co-scheduling of Blue Gene/L systems with SDSC at Supercomputing 2006 in Tampa, Florida. CISL's TeraGrid system administration staff has conducted tests of GPFS-WAN filesystem performance with SDSC, and has set up a Storage Resource Broker (SRB) instance with SDSC that enabled the first cross archiving of data between SDSC and NCAR to provide a semblance of disaster-recovery capability. This is being applied first to CISL's research datasets. This activity is also helping to prototype Chronopolis, a strategic collaboration in long-term digital preservation between NCAR, SDSC, and others.

NCAR also continued to develop the next-generation user interface for its new metadata database tool and enhance its links to the Community Data Portal. For more information on this effort, see Priority 4 below.

Data Assimilation (DA) refers to combining observations with a numerical model to give an improved estimate of a process or physical variable. NCAR has a large number of researchers for whom DA is an essential part of their ongoing or planned research. IMAGe's goal is to develop general methods and software to improve the DA usability for researchers. A centerpiece of this effort is the Data Assimilation Research Testbed (DART), a software system that allows a scientist to rapidly incorporate new models or new kinds of observations for assimilation.

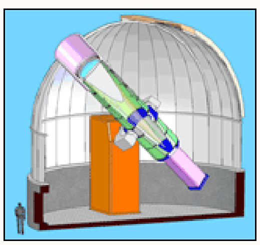
An important activity is applying DART to specific science problems. During FY2007, work continued on assimilating GPS occultation observations (COSMIC program) and the application to the WRF single-column model. A highlight is the successful assimilation of MOPITT instrument radiance observations using the NCAR Community Atmosphere Model. The most important aspect of this accomplishment is integration of the tracer transport within the model so the advection is consistent with the model winds. Also, assimilation is directly based on a version of the satellite radiances, not on retrieved CO concentrations.

The NCAR Command Language (NCL) is a free, interpreted language designed specifically for scientific data processing and visualization. NCL has robust file input and output. It can ingest data in netCDF, HDF4, HDF4-EOS, GRIB1, GRIB2, binary, and ASCII formats. The world-class graphical outputs are highly customizable.

CISL officially released version 4.3.0 of NCL, and it is now available for download from the Earth System Grid (ESG). The GRIB2 reader is the significant new feature in this release. In addition, there are 14 new functions, 12 new color tables, updates to 15 functions, four new resources, and many bug fixes. NCL is a data processing and visualization tool of global importance to our user community. For example, the NCL team recently trained NOAA staff on its use, and just received an all-expenses-paid request to train scientific users in Istanbul, Turkey.

Like CISL, EOL provides the university research community with many tools and services it might not otherwise be able to afford or find. In 2007, development continued on the EOL Metadata Database and Cyber Infrastructure (EMDAC). A next-generation user interface has been created, which enhances links between EMDAC and the UCAR Community Data Portal (CDP). EOL has also developed tools to make it easier for EOL facilities users to manage their datasets via EMDAC. EOL also provides users with information on using these tools. To improve its efficiency, stability, and ease of use, EOL's Mass Store Retrieval tool will be incorporated into EMDAC.

Among other upgrades, EOL installed a Satcom system onboard the GV that provides a new paradigm for operating and communicating with research aircraft. The installation of the new Satcom system on the GV underscored the importance of such communications capabilities on the C-130, which currently is involved in the majority of field research requiring aircraft. We were recently able to install a state-of-the-art Inmarsat Satcom system on the C-130, which creates a bandwidth comparable to the GV.



**Click to enlarge.** Concept drawing of the COSMO 1.5-meter coronagraph and dome. The telescope is a simple tube structure on an equatorial mount. The diameter of the dome is 12.2 meters.

In FY2007, the ESSL/HAO Community Spectro-polarimetric Analysis Center (CSAC) completed development of the GRID Milne-Eddinton inversion code (MERLIN), and the development and implementation of data calibration/conditioning software for the Diffraction Limited Spectro-polarimeter (DLSP), the SST Spectro-polarimeter, and the Hinode Spectro-polarimeter. These efforts will provide data services – including data reduction, inversions, and data visualization – to those involved in the measurement and interpretation of solar vector magnetic fields, a rapidly growing community.

This year also saw improvements to the data services offered through the ESSL/HAO to the Mauna Loa Solar Observatory (MLSO). Observing and processing software was modified to take high time-resolution (10 seconds) of Mauna Loa Halpha images to meet the needs of a community joint-observing campaign with Hinode, STEREO and other NASA missions. All of the Solar Maximum Mission (SMM) coronagraph data were made available online, and Mauna Loa observations were also added to community-based software packages including SolarSoft, Solar Weather Browser and FESTIVAL, and the community-based Virtual Observatory known as AstroGrid.

## FY2008 Plans for Strategic Priority 2

CISL views its TeraGrid-related activities as strategic areas of development. Testing and deployment of wide area, global parallel file systems will continue using the storage cluster in NCAR's TeraGrid node. Funding for the Visualization and Analysis Platform for Ocean, Atmosphere, and Solar Researchers (VAPOR) project runs out at the end of FY2008. Since VAPOR is considered strategic to a petascale supercomputing environment that will produce multi-terabyte history files, CISL is working to broaden the utility and appeal of VAPOR to new communities, and we have included some support for VAPOR in the NSF Track-1 proposal. We will continue to pursue other proposal opportunities with the

VAPOR team.

The application of DART to estimating concentrations of atmospheric constituents will be expanded to the radiances measured by the MOPITT instrument. This is the first step in DART becoming the data analysis core for a satellite simulation facility, which will be pursued in collaboration with ESSL's Atmospheric Chemistry Division.

Plans for NCL and Python software development and support are largely based on continuing dialogs with the scientific community and on results from a survey conducted in FY2006. FY2008 goals are to release NCL, PyNGL, and PyNIO under an open source license, release new features and science enablers, and continue to provide high-quality consulting support and training services for the user community.

In FY2008 and 2009, EOL will solicit feedback from the community to continue evolving EMDAC to meet user requirements, and will enhance current infrastructure to streamline overall internal data management activities. EOL will also continue developing a single, integrated codebase for the Field Catalog, which provides a secure and robust platform from which to plan future projects.

In the coming year the HAO CSAC will:

- Begin the Milne-Eddington inversion of Hinode Data, including implementing the genetic algorithm initialization for MERLIN, and the GUI, as well as integrating the HINODE database
- Implement LILIA (LTE Inversion based on the Lorien Iterative Algorithm) detailed inversion
- Generalize AZAM (azimuth ambiguity) to accept data from any data source
- Implement simulated annealing azimuth ambiguity resolution for automatic processing
- Host a community workshop to address community needs
- Sponsor graduate student visits

Science: Strategic Goal 4 previous next

# *GOAL 4*, PRIORITY 3: CONDUCTING RESEARCH IN COMPUTER SCIENCE, APPLIED MATHEMATICS, STATISTICS, AND NUMERICAL METHODS

The research activity within CISL enhances the computational infrastructure at NCAR and supports more efficient scientific computation and simulation. This research is necessary to maintain an innovative computational facility and to lead the geophysics community in incorporating new numerical methods and models. Given this broad priority, the research in CISL must span several disciplines and address computational science at many levels. Integrated with the computational science are areas of applied mathematics that include data analysis, models for multiscale processes, and techniques for assimilating data into numerical models. Because these different elements are coordinated through a single Lab, there is an easy transfer of technology and ideas from prototypes and theoretical results in IMAGe to implementation and workflow issues in CISL, and finally into tools and models for the communities served by CISL. There is also a valuable reverse transfer whereby emerging computational capability and data storage concepts spur particular research that takes advantage of these features.

RAL also makes significant contributions to this priority area through the work of its Verification Group, led by Barbara Brown. In an effort to address the limitations of traditional, relatively simple performance metrics, RAL has developed new verification approaches and tools that provide more meaningful and relevant information about forecast performance. The focus of this effort is on diagnostic, statistically valid approaches, including object-based evaluation of precipitation and convective forecasts and other approaches (e.g., distribution-based) that can provide more useful information about forecast performance. Development and dissemination of new forecast verification approaches requires research and application in several areas, including statistical methods, exploratory data analysis, statistical inference, pattern recognition, and evaluation of user needs.

## FY2007 Accomplishments

RAL scientists are working to understand weather extremes, particularly with regard to convection. Initial work in this area has focused on identification of useful measures of large-scale environments that are relevant for severe thunderstorm formation based on NCAR global model reanalysis data. These data have been used to investigate trends in the large-scale environmental characteristics, as well as spatial and extreme value distribution attributes. This work has led to the identification of several statistical challenges/new areas for research with regard to modeling extreme values in a spatial context; addressing the issue of multiple comparisons inherent in working with gridded data; and making inferences about changes in distribution parameters.

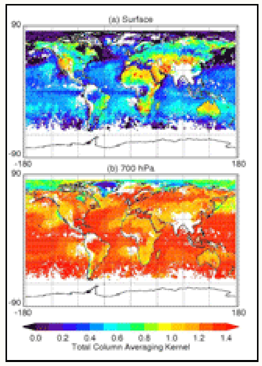
A more recent area of inquiry within RAL has been fueled by the U.S. Joint Planning and Development Office's mandate to transform use of the nation's airspace by 2025. Inherent in this charge is a rethinking of how weather data is acquired, stored, and disseminated to the aviation community. While graphical presentations of weather data are useful to human users, there is also a need for machine-to-machine data dissemination to provide data to decision support tools and systems that manage air traffic. The challenge is to provide four-dimensional weather data using standard formats for the request and delivery. To address this problem, NCAR-RAL has teamed with MIT-Lincoln Labs and NOAA-Global Systems Division to explore standards-based, net-centric data access. The goal of this research is to create a virtual weather database spanning more than one physical location, organization, and data system.

For the past decade, NCAR's Geophysical Statistics Project (GSP) has led training and research efforts that emphasize the synergy between the geosciences and

**Related Lab Annual Report Sections: Goal 4, Priority 3**
- CISL Activities
- RAL Activities

the statistical sciences. Aside from basic methodological and theoretical statistical research, GSP has had a strong training component, supporting from four to six postdoctoral visiting scientists. In FY2007, a project reconstructing Northern Hemisphere temperatures was completed based on the original proxies of Mann Bradley Hughes. Uncertainty in the reconstruction is quantified using a statistical ensemble that facilitates drawing complex inferences about decadal maxima of the reconstructed series.

In another area, Space-Time Modeling of Atmospheric Carbon Monoxide, a simple dynamical model with stochastic components has successfully assimilated carbon monoxide (CO) satellite retrievals from the MOPITT instrument. This project is an alternative to using more complex atmospheric transport models, and it includes statistical standard errors for the estimated concentrations.




**Click to enlarge.** Comparison of MOPITT sensitivity to CO at the surface and at 700 hPa.

The Method for Object-based Diagnostic Evaluation (MODE), developed by RAL and ESSL/MMM provides a new approach for diagnostic evaluation of spatial forecasts that directly measures the performance of the forecasts in terms of specific attributes – spatial displacement, intensity, storm size, and so on – and attributes may be designed to represent the use of the forecast for specific applications. In 2007 MODE was implemented as a tool in the DTC's Model Evaluation Tools (MET) and has been disseminated to the NWP community.

The RAL Verification Group has also organized and coordinated an intercomparison project (ICP) for spatial forecast verification methods, involving scientists from around the world who are developing new methods for evaluation of spatial forecasts. The project will include applications of all of the methods to the same real and idealized datasets, and comparisons of the capabilities of the various methods, with a goal of determining which methods should be applied to achieve different goals, and to identify the kinds of information that each method can provide.

The NCAR reanalysis dataset has been analyzed to include two important severe weather indicators, Convective Available Potential Energy (CAPE) and vertical shear. Analyses of trends in CAPE, Shear, and functions of these variables, such as CAPE x Shear, were applied to the global set of gridpoints included in this dataset. The focus of this work has begun to shift to consider the evaluation of convective extremes in projections of a changed climate. Output of the NCAR Community Climate System Model (CCSM3), AB1 scenario, are being used to represent the current climate and will be used to compare to results associated with the reanalysis data. These analyses are being done in collaboration with H. Brooks at the NOAA National Severe Storms Laboratory and P. Marsh at the University of Oklahoma.

RAL engineers have instantiated a gridded weather products server using a Web Coverage Service (WCS). Using the WCS specification, NCAR-RAL now distributes a variety of three-dimensional gridded weather products including analyses and forecasts of icing, turbulence, winds, and temperatures. Additionally, the data available through the WCS services were exposed in a catalog as an Open Geospatial Consortium Catalogue Service which allows the automated discovery of data as it comes in and provides information about the data that may be accessed through the WCS services. This includes information such as the quality of the data, the organization that originally created or gathered it, the data format in which it is available, and its geographic extent.

### FY2008 Plans for Strategic Priority 3

FY2008 will see the analysis of computer models expanded to validation of the Thermosphere Ionosphere Electrodynamic General Circulation Model climatology with observations, and the functional data approach developed in combination with the analysis of regional climate fields. The paleoclimate reconstruction problem will be cast as a hierarchical model and estimated using Monte Carlo/ensemble methods in the DART framework. The assimilation of CO with a statistical model and parameter will also be integrated into DART and tested using a long period of MOPITT retrievals and aircraft observations.

MODE will be applied to additional datasets and types of forecasts. An initial effort will be made to examine ensemble forecasts of precipitation from an object perspective. MODE will also be applied to convective and precipitation forecasts as part of NCAR's program on Short Term Explicit Prediction. The concept of user-focused verification will be further developed and presented to the forecasting and verification communities. And a workshop will be held in the spring for participants in the intercomparison project to begin discussion of project results.

Techniques developed with the reanalysis data will be applied to output of the CCSM3 to determine whether the characteristics of CAPE and Shear based on GCM output for an unchanged climate are consistent with the characteristics of these parameters in the reanalysis data. Subsequently (assuming consistency is found), the parameters will be analyzed using CCSM3 output for changed climate scenarios to study how the frequency and intensity of environments conducive to severe weather activity can be expected to change under a future climate scenario. The aim of this work is to determine the current distributions of environments conducive to severe weather, and study how these environments are changing.

## *GOAL 4*, PRIORITY 4: CREATING AN EARTH SYSTEM KNOWLEDGE ENVIRONMENT

NCAR continues to develop an Earth System Knowledge Environment (ESKE), new cyberinfrastructure that combines models, data, experiments, collaborative tools, and information resources in a way that fosters knowledge sharing and accelerates scientific workflow. NCAR is creating integrated, collaborative problem-solving environments that advance the community's ability to engage in research and scientific discovery. Efforts span modeling frameworks, data and knowledge management and access, collaboration, and analysis and visualization.

### FY2007 Accomplishments

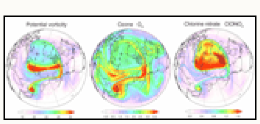
**Click to enlarge.** This is a snapshot of the new Community Data Portal (CDP) homepage, which now reflects a more thematic interface to our broad digital asset holdings. We are currently developing a next-generation Semantic Web-based system, and this thematic approach is one step along that path. The CDP has now grown into what is commonly referred to as a "science gateway," where data, models, tools, and knowledge are managed and made available for community access. The CDP serves as a primary foundation for our development of an Earth System Knowledge Environment (ESKE).

The Community Data Portal serves as our premier institutional repository for data, models, frameworks, IPCC analyses, and more. This portal is cyberinfrastructure—a core capability on which the whole institution relies. It provides sustainability by allowing individual groups to publish and manage their holdings while reducing redundant data service development efforts across our organization. At the recent CISL Strategic Retreat, we identified the CDP as a core foundation framework for the ESKE.

The CDP currently hosts a number of models, datasets, frameworks, analyses, and other scientific holdings such as Daymet, ESMF, Megan, Mozart, Rose, Socrates, TUV, the Earth System Curator, and WACCM. In FY2007, we expanded CDP capabilities so it now supports remote data upload/management for field projects, and it has been used to good effect in MILAGRO (Megacity Initiative: Local and Global Observations), with ACME coming up soon. The Cyberinfrastructure Strategic Initiative (CSI) funding has served as either a strategic core or a contributing element of CISL's part in various funded and unfunded CDP projects, including the:

- Earth System Grid (DOE, climate data, IPCC)
- Virtual Solar Terrestrial Observatory (NSF, solar-terrestrial)
- Cooperative Arctic Data and Information Service (NSF, polar data)
- Global WMO Information System (WIS)
- THORPEX Interactive Grand Global Ensemble (TIGGE)
- GIS IPCC Portal
- GoogleEarth/CDP Opportunity Fund project (CISL+ACD)

The CDP is an important part of outstanding proposals as well, such as the Virtual Operations Center (NSF) and Chronopolis (NSF).



**Click to enlarge.** Concept drawing of the COSMO 1.5-

The Earth System Modeling Framework collaboration is building high-performance, flexible software infrastructure to increase ease of use, performance portability, interoperability, and reuse in climate, numerical weather prediction, data assimilation, and other Earth science applications. The ESMF defines

**Related Lab Annual Report Sections: Goal 4, Priority 4**

- CISL Activities

meter coronagraph and dome. The telescope is a simple tube structure on an equatorial mount. The diameter of the dome is 12.2 meters.

an architecture for composing complex, coupled modeling systems, and includes data structures and utilities for developing individual models.

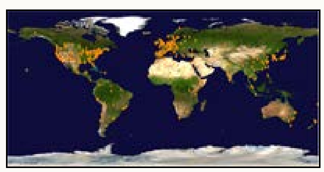
Led by ESSL/HAO computer scientist Peter Fox, the Virtual Solar Terrestrial Observatory and Data Systems and Solar-Terrestrial Informatics efforts are an integrative activity that supports solar, solar-terrestrial, and space physics science carried out by HAO and its communities. To date, emphasis has been placed on providing virtual observatory access to HAO and community data holdings including data integration, robust and high-performance web services for data query and access, and re-use of existing underlying data infrastructures.

The Earth System Curator will be a set of tools, based on this extended ESMF schema that allows modelers to archive and query models, experiments, model components, and model output to test the technical compatibility of model components, and to assemble and run multi-component models.

During FY2007, the ESMF and Earth System Curator efforts focused on second-round ESMF goals, on developing a system architecture, and on supporting collaborations for the Earth System Curator. In particular:

- ESMF build rework and performance optimization was completed to satisfy the CCSM Stage 1 evaluation plan: quantitative criteria were met.
- National Unified Operational Prediction Capability (NUOPC) operational partnership identified ESMF as the basis for the next global numerical weather prediction system, target 2015.
- The MAPL software toolkit, a usability layer for ESMF developed at NASA, was used to couple GEOS-5, Modular Ocean Model 4 (MOM4), and the MIT General Circulation Model (MITgcm).
- The Earth System Curator project defines a distributed architecture based on the Geophysical Fluid Dynamics Laboratory (GFDL) Run-time Environment, plus the NCAR CDP. The Curator project and the Numerical Model Metadata (NMM) group at the University of Reading collaborate to extend the NMM schema for the ESMF hierarchical architecture.

The Earth System Grid (ESG) integrates large-scale data and analysis servers located at numerous national labs and research centers to create a powerful environment for next-generation climate research.



**Click to enlarge.** This map shows the geographic locations of the sites that use the Earth System Grid (ESG) to acquire climate simulation data, IPCC coupled model results, the CCSM climate model, and an array of analysis and visualization tools. ESG provides services to over 6,000 registered users around the world.

The ESG enterprise now:

- Supports more than 6,000 registered users from around the globe
- Manages more than 180 TB of data, models, and tools
- Has delivered more than 300 TB of data

ESG is a source for the CCSM source code distribution and for analysis and visualization tools. Both the ESG and CDP have been refactored to leverage Java frameworks such as Spring and Hibernate, which will provide significant improvements in maintainability and extensibility.

More importantly, ESG represents an opportunity. It is NCAR's first service to the TeraGrid: a Science Gateway. Leveraging the TeraGrid, we hope to expand the community of users to include the Purdue Climate Change Research Center.

## FY2008 Plans for Strategic Priority 2

CISL intends to leverage the CDP institutional repository to continue pursuing and supporting various strategic endeavors such as WMO Information System (WIS), THORPEX Interactive Grand Global Ensemble (TIGGE), and national digital preservation efforts. We will continue to unify the cyberinfrastucture base where we can harmonize technology across many different labs, projects, and agencies to avoid stovepiping and redundant efforts. CDP is a cornerstone of our

ESKE effort, and it will be used in the definition and development of that unifying vision.

The collaboration between CDP and the Earth System Curator is mutually beneficial, and is laying the architectural groundwork for a future Earth System Knowledge Environment.

The ESG project will continue, thanks to a recently funded DOE SciDAC-2 proposal. The follow-on project, called ESG Center for Enabling Technologies (ESG-CET), is an aggressive thrust that expands the original ESG to a global scale, encompasses computation, and includes NOAA as a collaborating partner.

Throughout 2008, the ESSL/HAO Virtual VSTO project will continue to develop and implement modern computer science and software engineering approaches. These include, for example, rapid prototyping, agile development and design iteration, extensive partnering with scientists, computer scientists, and community developers, open-source development, publication, and dissemination of current efforts, and best practices in solar-terrestrial research and data sharing.

NCAR is sponsored by the National Science Foundation.

# Strategic Goal 5 Provide World-Class Ground, Airborne, and Space-Borne Observational Facilities and Services

Observations of our atmosphere, Earth system, and Sun are the basis for many scientific discoveries. The ability to make these observations is fundamental to meeting the science goals of NCAR and the community we serve.

On behalf of NSF, NCAR develops and deploys world-class ground, airborne, and spaceborne observational facilities and services that range from providing technical assistance on instrument deployment, to the organization of field campaigns with hundreds of participants and multiple locations.

**NCAR addresses three broad priorities within this goal:**

## Priority 1: Enabling Innovative Field Experiments and Measurement Campaigns

The accuracy, robustness, and performance of weather, climate, and chemistry models depend on sound theory and accurate measurements. NCAR leadership in the area of field program planning and implementation provides a critical service to the community, and we are proud of our achievements in this area. The Earth Observing Laboratory maintains a large suite of NSF-funded state-of-the-art Lower Atmospheric Observing Facilities to collect data that will advance understanding of atmospheric and Earth processes in support of community research.

Maintaining flexibility and responsiveness, NCAR serves as the coordination point for scientific field campaigns, offering services ranging from advice and consultation during the initial stages of planning to field design and project implementation plans, tailored and specialized logistics support, the fielding, operation, and maintenance of scientific instrumentation, real-time data communication, organizational and operational management, and the coordination of educational activities. *Read more about this priority*

## Priority 2: Developing New Instrumentation

Advances in research on weather, climate, the water cycle, chemistry and dynamics of the upper troposphere/lower stratosphere, space weather and solar physics, and biogeosciences all require capabilities that stretch beyond those provided by EOL's current suite of airborne and ground-based instruments. NCAR is tasked with developing a new generation of robust, inexpensive, easily deployable, and versatile instrument systems to address the university community's need for these instruments, which facilitate their research efforts. Our extensive and talented scientific and engineering staff continually creates and test new instrumentation for studying the links between atmospheric composition and the biogeosciences, with systems for quantifying the surface-atmosphere exchange of gases and aerosols on whole-plant, whole-canopy, and regional scales using mobile laboratories and research aircraft. *Read more about this priority*

## Priority 3: Installing Initial Instrument Suite and Beginning Operations of the NSF/NCAR Gulfstream V (GV) Aircraft

FY2006 heralded the debut of the nation's most advanced research aircraft, the NSF/NCAR Gulfstream V (or GV, formerly referred to as HIAPER). In FY2007, the GV began flying, performing its mission of serving the National Science Foundation's and our university community's environmental research needs for the next several decades. *Read more about this priority*




*Postal Address: P.O. Box 3000, Boulder, CO 80307-3000 • Shipping Address: 1850 Table Mesa Drive, Boulder, CO 80305 • Contact*

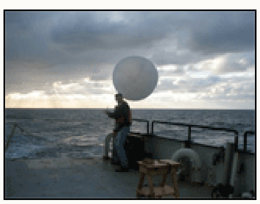
# *GOAL 5*, PRIORITY 1: ENABLING INNOVATIVE FIELD EXPERIMENTS AND MEASUREMENT CAMPAIGNS

The accuracy, robustness, and performance of weather, climate, and chemistry models depend on sound theory and accurate measurements. NCAR leadership in the area of field program planning and implementation provides a critical service to the community, and we are proud of our achievements in this area. The Earth Observing Laboratory maintains a large suite of NSF-funded state-of-the-art Lower Atmospheric Observing Facilities to collect data that will advance understanding of atmospheric and Earth processes in support of community research.

Maintaining flexibility and responsiveness, NCAR serves as the coordination point for scientific field campaigns, offering services ranging from advice and consultation during the initial stages of planning to field design and project implementation plans, tailored and specialized logistics support, the fielding, operation, and maintenance of scientific instrumentation, real-time data communication, organizational and operational management, and the coordination of educational activities.

## FY2007 Accomplishments

In the early part of FY2007, the NSF/NCAR Facilities Assessment Team developed an interactive database that will be populated with descriptions of systems, platforms, networks, and emerging technologies that are provided by community experts. Supported on a Web site, the database will provide descriptive information on atmospheric science facilities and instrumentation in a consistent, easy-to-read format as a resource for the broad atmospheric science and related communities.



**Click to enlarge.** EOL scientist Bill Brown does a last minute check of atmospheric conditions before he launches a sounding balloon off the R/V Knorr during CLIMODE, an experiment which studied the loss of heat from the North Atlantic sea into the atmosphere.

EOL revised and updated its Virtual Operations Center (VOC) proposal based on feedback from reviewers and a Town Hall Meeting that occurred at the annual American Meteorological Society meeting in January 2007. In the summer of 2007, the NSF modified the direction and scope for the VOC proposal, recommending that it be a part of the Mid-Sized Infrastructure (MSI) proposal process. Preliminary MSI proposals will be solicited in the fall of this year and the highest priority subset will be asked to submit a full proposal in the spring of 2008, with awards expected by October 2008. We intend to submit a revised VOC proposal under these new guidelines and timeline.

**Click to enlarge.** Twice a year, EOL hosts the Observing Facilities Assessment Panel (OFAP), an NCAR-driven community process that provides technical and operational assessment of requests associated with the use of NSF's Lower Atmospheric Observing Facilities in the field.

Twice a year, EOL hosts the Observing Facilities Assessment Panel and coordinates among panel members, PIs, facility providers, EOL staff, and NSF to assess the feasibility and cost of NSF-funded field projects. The OFAP is an NCAR-driven community process that provides technical and operational assessment of requests associated with the use of NSF's Lower Atmospheric Observing Facilities in the field. The panel, which is composed of a diverse pool of scientists with broad experience in observational studies of Earth system sciences, meets at NCAR to provide valuable feedback and evaluation to facility managers and the user community concerning experiment design, data management issues and the appropriate and efficient use of NSF resources

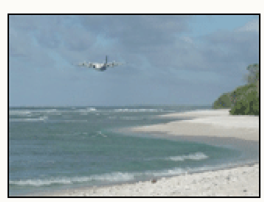
***Related Lab Annual Report Sections: Goal 5, Priority 1***

- EOL Activities
- ESSL Activities

as related to a specific field campaign. OFAP meetings occurred per usual in 2007.

Among the 2007 field programs that NCAR participated in are:

- The Meteor Crater Experiment (METCRAX) program, which is investigating the structure and evolution of temperature inversions - or cold-air pools - that form on a daily basis in topographic basins and valleys. As part of this research, a one-month-long field experiment was conducted in October 2006 in Arizona's Meteor Crater, a simple near-ideal topographic basin formed by the impact of a meteor. In this basin, the physical processes leading to the buildup and breakdown of temperature inversions and the formation of atmospheric seiches (atmospheric oscillations in the basin caused by wind disturbances at the basin crest) can be studied without the difficulties introduced by more complex topography. In support of the METCRAX experiment, EOL provided an integrated sounding system (ISS) – a self-contained meteorological observing system – and seven integrated surface flux facilities (ISFF).
- Inhibition of Snowfall by Pollution Aerosols (ISPA 2006) – ISPA studies the link between pollution aerosols and snowfall rates in the Mount Werner area near Steamboat Springs, Colorado. EOL provided the ISS-Multiple Antenna Profiler (MAPR) facility in early 2007 to obtain temperature and humidity profiles with altitude, cloud top height and temperature, depths of the snow layer, crystal fall speed and riming extent. Data gathered from the experiment will be checked for quality control and offered to the research community as a data product in FY2008.
- EOL supported CHATS (see project description under Goal 1, Priority 2), deploying an ISFF and the Raman-shifted, Eye-safe Aerosol Lidar (REAL) in a walnut grove in Dixon, California during March and April 2007. Data gathered from the experiment was checked for quality in FY2007 and will be offered to the research community as a data product in FY2008.
- The CLIvar MOde water Dynamics Experiment (CLIMODE)–The CLIMODE project is another CLIVAR-related oceanographic project that intends to clarify the effect of dynamics of 18-degree water (EDW) by describing the formation, evolution, storage, dispersal and large-scale consequences of EDW. The expected end result is a better understanding of air-sea fluxes in high exchange regions of the ocean and improved ocean physics parameters for inclusion into climate models. In February and March of 2007, EOL deployed a shipborne ISS to contribute to these measurements by providing basic wind and thermodynamic profiles for the boundary layer by providing measurements of vertical wind and Doppler spectra continuously within over the oceans surface. Data will be made available in FY2008.
- The Pacific Atmospheric Sulfur Experiment (PASE) took place in August and September of 2007. EOL provided the C-130 research aircraft to PASE researchers, who are taking a comprehensive look at sulfur chemistry in a pristine marine trade wind system. The base of operations for this experiment is Christmas Island, Kiribati, a remote area that offers a highly stable trade wind inversion with little chance of precipitation, high solar intensity and horizontal winds constant in direction and speed over several days.



**Click to enlarge.** The NSF/NCAR C-130 flies by a beach on Christmas Island during the PASE project in August, 2007.

In FY2007 ESSL/HAO continued to support development and operation of community instruments in collaboration with the National Solar Observatory (NSO), including spectro-polarmetric post-focus instrumentation at the NSO Dunn Telescope at Sacramento Peak Observatory at Sunspot, NM. These instruments provide detailed information on atmospheric and solar phenomena, which scientists use to improve their understand of space weather, as well as the Earth and Sun system interactions. Details on the many exciting instruments supported by HAO are available in the ESSL LAR.

### FY2008 Plans for Strategic Priority 1

EOL is developing a strategic partnership with Colorado State University to create a national radar facility. Both institutions support 10-cm, multiparameter Doppler radars that will be jointly operated in this new partnership. A key objective is to create a national test bed that other institutes and agencies can use for research and education. The radars will be in continuous operation, and university students will be encouraged to propose small (less than 20-hour) projects for collecting thesis-related research data. In FY2008, the two institutes will formalize plans.

EOL's Facilities Assessment Team has begun asking community members to submit information on instruments and facilities, and is asking them submit revisions to resources already included in the database. Seven subcommittees met separately in May to review the information submitted thus far. In late September 2007, a larger community workshop followed the planned NSF Facilities Users' Workshop to gain input on database and capabilities gaps. EOL will continue to support maintenance of this Web site in FY2008/2009, and thereafter.

The HIPPO study will measure cross sections of concentrations of atmospheric and greenhouse gases approximately pole-to-pole, from the surface to the tropopause, four to six times, during different seasons, over a 2.5- to 3-year period beginning in 2008. The scientific questions motivating HIPPO focus on understanding global sources and sinks for CO2, CH4, and other carbon cycle gases, and more broadly determining large-scale rates of tracer transport in the atmosphere. This experiment would not be feasible without the GV, and will establish a new paradigm for facility allocation. It is the first time that NSF has approved a multi-year allocation of an observational platform. Such allocations may become more common with the GV.

EOL will provide driftsonde support for the proposed THORPEX Pacific Asian Regional Campaign experiment in September of 2008. T-PARC is a multi-national field campaign that addresses the shorter-range dynamics and forecast skill over one region (Eastern Asia and the western North Pacific), and the downstream impact on medium-range dynamics and forecast skill of another region (in particular, the eastern North Pacific and North America). The driftsonde and ELectra DOppler Radar (ELDORA) are two primary platforms that have been requested for this experiment.

The Ice In Clouds Experiment (ICE-L) will begin in November 2007. The objective of the ICE-L experiment is to show that, under given conditions, direct ice nucleation measurement(s), or other specific measurable characteristics of the aerosol, can be used to predict the number of ice particles forming by nucleation mechanisms in selected clouds. The PIs also seek improved quantitative understanding of the roles of thermodynamic pathway, location within the cloud, and temporal dependency. The project, led by Andy Heymsfield (NCAR), will be based at the Rocky Mountain Municipal Airport in Broomfield Colorado. The NSF/NCAR C-130 and the Wyoming Cloud Radar will support the project during November and December 2007.

In FY2008 Hector Socas-Navarro and the ESSL/HAO instrumentation group will complete the Spectro-Polarimeter for Infrared and Optical Regions (SPINOR) instrument in partnership with NSO, mating it to the new adaptive optics system at the NSO Dunn Telescope at Sacremento Peak Observatory at Sunspot, NM. SPINOR will allow researchers to make observations combining simultaneous visible and IR spectro-polarimetry of the magnetic fields in the solar photosphere and chromosphere, offering substantial scientific advantage over the visible for studies of solar magnetism.

*Science: Strategic Goal 5* previous next


*Postal Address: P.O. Box 3000, Boulder, CO 80307-3000 • Shipping Address: 1850 Table Mesa Drive, Boulder, CO 80305 • Contact*

Director's Message
Table of Contents
About NCAR
**Strategic Goals**: Science, Facilities & Technology
Metrics
Conclusion/Lab Links
Archives and Supplemental Info

NCAR is sponsored by the National Science Foundation.

## *GOAL 5*, PRIORITY 2: DEVELOPING NEW INSTRUMENTATION

Advances in research on weather, climate, the water cycle, chemistry and dynamics of the upper troposphere/lower stratosphere, space weather and solar physics, and biogeosciences all require capabilities that stretch beyond those provided by EOL's current suite of airborne and ground-based instruments. NCAR is tasked with developing a new generation of robust, inexpensive, easily deployable, and versatile instrument systems to address the university community's need for these instruments, which facilitate their research efforts. Our extensive and talented scientific and engineering staff continually creates and test new instrumentation for studying the links between atmospheric composition and the biogeosciences, with systems for quantifying the surface-atmosphere exchange of gases and aerosols on whole-plant, whole-canopy, and regional scales using mobile laboratories and research aircraft.

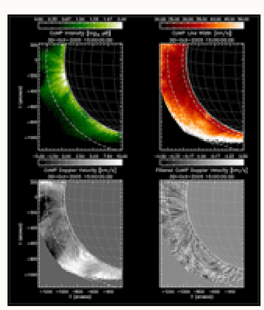
### FY2007 Accomplishments

**Click to enlarge.** Secure within its gondola, the Sunrise telescope hangs suspended from its crane-like launch vehicle at dawn. (Photo by Carlye Calvin)

NCAR has completed a sophisticated gondola that will be carried approximately 25 miles into the atmosphere by a giant balloon and will support a 1-meter solar telescope that will capture images of the Sun's outer surface at a higher resolution than ever before. The first flight, scheduled for October of this year, will test the entire system including the complex pointing control. Closer to Earth, NCAR's adaptive sensor array wireless mesh network communication system will allow deployment of numerous low-power instruments in a variety of complex environments.

In FY2007, an important milestone in the Sunrise balloon-borne solar telescope project was reached with completion of balloon gondola construction at NCAR. This design and fabrication effort was a joint undertaking of ESSL's HAO and EOL. In October 2007, the sophisticated gondola carried a 1-m-aperture telescope to stratospheric altitudes, where it acquired the highest spatial resolution solar observations ever obtained. Science flights of the full instrumentation are scheduled to commence in 2009 in Kiruna, Sweden. This project is an international collaboration with the Max-Planck-Institut fur Sonnensystemforschung (Germany), the Kiepenheuer-Institut fur Sonnenphysik, (Germany), the Instituto de Astrofisica de Canarias (Spain), the University of Utrecht (The Netherlands), the Lockheed Martin Solar & Astrophysics Laboratory (USA), and the University of Chicago.

Recently, HAO's Coronal Multi-channel Polarimeter (CoMP) instrument enabled a scientific breakthrough by imaging, for the first time, Alfvén waves in the solar corona. These waves were found in observations of the Doppler shift of coronal plasma in the coronal emission line at 1,074.7 nm. These waves are important in that they may transport energy from the turbulent photosphere and into the solar corona and it could explain why the solar corona is heated to a temperature of 1 million degrees.



**Click to enlarge.** Scientists for the first time have observed elusive oscillations in the Sun's corona, known

In FY2007, NCAR and our user community collaborated to move the Community Airborne Platform Remote-Sensing Interdisciplinary Suite

Related Lab Annual Report Sections: Goal 5, Priority 2

- EOL Activities
- ESSL Activities
- RAL Activities

(CAPRIS) development forward. CAPRIS will be a new system within NSF/LAOF to serve observational needs of the climate, atmospheric chemistry, and meteorology communities by providing an unprecedented combination of coincident observations of precipitation, winds, cloud microphysics, water vapor, ozone, and aerosol at a wide range of temporal and spatial scales. The suite will work in conjunction with existing in-situ sensors on NSF/NCAR C-130 and NSF/NCAR GV aircraft in providing these observations. EOL has relied on community involvement via seminars and town meetings at various venues to seek community input on the design and capabilities of CAPRIS. In January 2008, EOL will submit a pre-proposal for CAPRIS in response to the midsize infrastructure solicitation

as Alfvén waves, by tracking the motions of coronal plasma (charged particles and gas) around the entire edge of the Sun. In this series of images and animations, NCAR's Coronal Multi-channel Polarimeter instrument, or CoMP, captured the intensity of the light emitted from the solar corona (upper left), the line width or spectral extent over which the light is emitted (upper right), and the velocity (lower left). The oscillations of the plasma velocity are made clearer by filtering the velocity data to show only oscillations that recur periodically every five minutes. (lower right). (Image courtesy Steve Tomczyk and Scott McIntosh, NCAR.)

ESSL/ACD scientists are also involved in many of the efforts described above to develop, improve, operate, and maintain a large number of instruments designed to measure trace gases, radicals, optical properties, and aerosols in the atmosphere, including ground-based, aircraft, and satellite instruments. Additionally, ACD scientists to improve and refine HIRDLS’ correction algorithms, making them more robust, and if possible developing a physical basis for them that would assure that they would work under all conditions. (When HIRDLS was launched on the Aura spacecraft in July 2004, a thin plastic film from inside HIRDLS came loose and obstructed most of the instrument's aperture, limiting the view to the atmosphere to a small fraction of the width of the optical beam.) More information on HIRDLS effort is available in the ESSL LAR.

In a significant move, The Advanced Technology Solar Telescope (ATST) received the go-ahead from the National Science Board in FY2007. The ATST is a large-aperture solar telescope project with a 4-meter diameter primary mirror that will have a collecting area 16 times larger than the largest existing solar telescope and will be able to operate at the diffraction limit thanks to an advanced adaptive optics system. This project has been ranked by the Decadal Survey of Astronomy and Astrophysics as the most important ground-based initiative for the next decade. In FY2008, Michael Knolker and Hector Socas-Navarro of ESSL/HAO will begin to support the construction phase of this major telescope in partnership with the NSO.

Over the past several years RAL scientists and engineers have developed the NEXRAD Turbulence Detection Algorithm (NTDA), a new approach to processing data from the National Weather Service’s network of Next Generation Radars (NEXRADs). By directly measuring the in-cloud turbulence intensity, the NTDA will provide airline dispatchers, air traffic managers, and pilots an important new source of information for tactical turbulence avoidance. In 2007, NTDA won final approval from the NEXRAD Technical Advisory Committee (TAC) and the NEXRAD Software Recommendation and Evaluation Committee, and the software package has now been delivered to the NEXRAD Radar Operations Center.

### FY2008 Plans for Strategic Priority 2

Now under way, a new NCAR Program in Atmospheric Composition Remote Sensing and Prediction (ACRESP) will build on current ESSL/ACD-led satellite missions and expertise in satellite remote sensing science, Earth System modeling, and data assimilation. The first stage of the ACRESP Program will to develop the Satellite Observation Simulator and Assimilation System (SOSAS) capability in modeling and measurement of air quality. Parallel and related efforts on air quality satellite instrument Observation System Simulation Experiments, and chemical weather forecasts using existing satellite observations. Work in these areas will continue into FY2008.

The Prominence Magnetometer (ProMag), currently under construction at HAO, is an instrument specifically designed to perform high-precision spectro-polarimetry of prominences and filaments. The instrument design was supported by NCAR Opportunity Funds, and will observe in the HeI lines at 587.6 and 1,083 nm. We will install this instrument in 2008 at the prime focus of the 40-cm aperture Evans coronagraph at NSO’s Sacramento Peak Observatory.

Space limitations do not permit an extensive discussion of NCAR's other development efforts. However, the following projects are moving forward at a minimum level:

- Wind lidar
- Compact Atmospheric Multi-species Spectrometer (CAMS) for the GV
- NO/NOy for the GV
- SATCOM products for the GV
- High-precision carbon dioxide ratio instrument
- High efficiency waveguide Difference Frequency Generation (DFG) instrument
- A water reference sounding system.
- See http://www.eol.ucar.edu/development/current-development-projects for more detailed information.

Final testing and deployment of NTDA is expected to occur in Summer 2008. A pilot program with United Airlines to test the uplink of the NTDA to the cockpit is expected to be expanded.





*Postal Address: P.O. Box 3000, Boulder, CO 80307-3000 • Shipping Address: 1850 Table Mesa Drive, Boulder, CO 80305 • Contact*

## *GOAL 5*, PRIORITY 3: INSTALLING INITIAL INSTRUMENT SUITE AND BEGINNING OPERATIONS OF THE NSF/NCAR GULFSTREAM V (GV) AIRCRAFT

FY2006 heralded the debut of the nation's most advanced research aircraft, the NSF/NCAR Gulfstream V (or GV, formerly referred to as HIAPER). In FY2007, the GV began flying, performing its mission of serving the National Science Foundation's and our university community's environmental research needs for the next several decades.

### FY2007 Accomplishments

**PACific Dust EXperiment (PACDEX)** – PACDEX represents the first true deployment of the GV as originally envisioned. See Goal 1, Priority 1 for more information on this project.


**Click to enlarge.** Stith, a principal investigator on the Pacific Dust Experiment (PACDEX), was featured in a number of interviews discussing how dust and pollutants can interact with clouds. (Photo by Carlye Calvin)

**HAIS Instrumentation** - In FY2007, HIAPER Airborne Instrumentation Solicitation (or HAIS) instruments started to arrive for installation and testing on the GV. The first of these instruments (Small Ice Detector, version 2 (SID-2H), HIAPER Airborne Radiation Package (HARP), and a Vertical Cavity Surface Emitting Laser Hygrometer (VCSEL)) are operating in PACDEX and making important contributions to that project. In addition to PACDEX instrumentation, Advanced Whole Air Sampler (AWAS), Fast Ozone, Microwave Temperature Profiler (MTP), Ozone Photometer were delivered in FY2007.

**Cloud Radar** - The GV cloud radar is an airborne millimeter-wavelength radar that will serve the atmospheric science community by providing remote sensing capabilities to the GV aircraft. During FY2007, we expect to complete the detailed design of the receiver, begin the design of the data system and procure a transmitter.

**Laser Air Motion Sensor (LAMS)** - EOL scientists and engineers have been developing a new, high-accuracy, state-of-the-art wind velocity instrument for the GV over the past year. This instrument utilizes measurements of Doppler shifts in backscattered, near-IR laser radiation caused by the 3D wind field. It will improve upon the accuracy of airborne wind velocity measurements over current technology based upon differential gust probes. The accuracy for the latter, which is severely compromised by aircraft flow perturbations, becomes a particular problem on the GV. The new instrument solves this problem by remotely detecting the wind fields well in front of the airplane, resulting in anticipated flow velocity accuracies around 0.1 m/sec. In FY2007, EOL anticipates completion of the single channel demonstration phase, including airborne testing, of this new instrument on the GV.

**The Microwave Temperature Profiler (MTP)** – The Jet Propulsion Laboratory (JPL) has been tasked with building a customized MTP for theGV. Julie Haggerty, EOL/RAL, is working with JPL investigators to certify and install the sensor. The MTP measures brightness temperature at multiple frequencies and elevation angles; retrieval algorithms applied to the measurements yield temperature profiles above and below the aircraft.

### FY2008 Plans for Strategic Priority 3

EOL scientists are working with Gulfstream to develop four pylons similar to the

*Related Lab Annual Report Sections: Goal 5, Priority 3*

- EOL Activities

two installed for PACDEX. Plans are to install these pylons in January 2008. EOL also expects to add the large pods in 2008, but funds are unsecured.

Initial reports from PACDEX indicate that the plane is staying cooler than expected, so the cooling system upgrade will be postponed until FY2009. Development of optical ports is intended to be complete in FY2008, and EOL plans include testing the instrumentation and infrastructure upgrades. One test run occurred July 2007; the other is planned for February 2008. Further testing of GV instrumentation will occur in 2008 after the quantum cascade lasers (QCLs), chemical ionization mass spectrometer (CIMS), High Spectral Resolution Lidar (HSRL), three-view cloud particle imager (3V-CPI), and GPS are delivered. The Tropical Ocean Global Atmosphere (TOGA), and Time-of-Flight Aerosol Mass Spectrometer (ToF-AMS) are scheduled to be delivered in FY2009, which means an additional test period will likely be needed in late 2008 or early 2009.

EOL anticipates completion of the remaining electronic design, mechanical design, fabrication and subsystem testing of the GV Cloud Radar in FY2008. System integration will start in FY2008 and culminate in FY2009, with flight testing to be completed in April 2009.

Upon completion of the Laser Air Motion Sensor single channel demonstration and testing phase, EOL anticipates embarking on full development of a three-channel system for measurements of all three wind velocity components.

NCAR is sponsored by the National Science Foundation.

## EDUCATION & OUTREACH METRICS

- Teaching Appointments
- Advising on Graduate Research
- Member of Thesis Committee
- Post doc, Graduate & Undergraduate Staff
- K - 12
- Other Informal Education Activities





*Postal Address: P.O. Box 3000, Boulder, CO 80307-3000 • Shipping Address: 1850 Table Mesa Drive, Boulder, CO 80305 • Contact*

Director's Message
Table of Contents
About NCAR
**Strategic Goals**: Science, Facilities & Technology
Metrics
Conclusion/Lab Links
Archives and Supplemental Info

NCAR is sponsored by the National Science Foundation.

## HONORS & AWARDS

- Awards
- Fellowships




*Postal Address: P.O. Box 3000, Boulder, CO 80307-3000 • Shipping Address: 1850 Table Mesa Drive, Boulder, CO 80305 • Contact*

NCAR is sponsored by the National Science Foundation.

## COMMUNITY SERVICE

1. Workshops
2. Colloquia/Symposia
3. Field Programs
4. Seminars & Presentations
5. Editorships
6. External Scientific, Policy, or Educational Committees and Advisory Panels, Boards



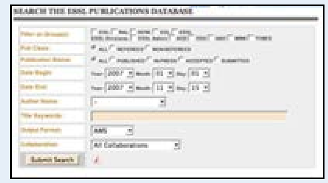

*Postal Address: P.O. Box 3000, Boulder, CO 80307-3000 • Shipping Address: 1850 Table Mesa Drive, Boulder, CO 80305 • Contact*

## NCAR FY 2007 PUBLICATIONS

**NAR Format: Refereed -- Non-Refereed | Title First Format: Refereed -- Non-Refereed**

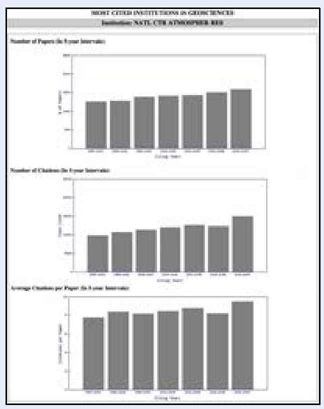
### Note regarding the FY2007 publications statistics

This year, NCAR engaged in a pilot project for the production of our publications metrics. Dynamic searches of the data are available online by clicking on the thumbnail image.



### NCAR publication & citation statistics. Click thumbnails for full-sized view.

Citation rankings for publications in the Geosciences (source: ISI Web of Knowledge, The Thompson Scientific Corporation).



NCAR citation graphs for 5-year intervals in the Geosciences (source: ISI Web of Knowledge, The Thompson Scientific Corporation).

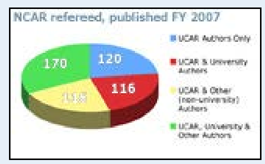



Chart showing the highly collaborative output of refereed publications (source: NCAR data)."

## NCAR Refereed Publications for Fiscal Year 2007 (alpha. by title) top

**522 Publication(s) for the time period 2006-10-01 to 2007-09-30**
**Group(s): CISL, SERE, RAL, EOL, ESSL**
**Class: Refereed**
**Status: Published; (alphabetical by title, NCAR Annual Report format)**

***Author Collaborations Summary:***
**UCAR Only: 120**
**UCAR & University: 116**
**UCAR & Other: 116**
**UCAR, University, & Other: 170**

***Legend:***
*[1] = UCAR Only Collaboration, [2] = UCAR & University Collaboration, [3] = UCAR & Other Collaboration, [4] = UCAR, University, & Other Collaboration*

Teng, H., W. M. Washington, G. A. Meehl, L. E. Buja, G. W. Strand, 2006: 21st century arctic climate change in the CCSM3 IPCC scenario simulations. *Climate Dynamics*, doi: 10.1007/s00382-005-099-z.[1]

Chen, Q., J. Laminie, A. Rousseau, R. Temam, J. Tribbia, 2007: A 2.5 model for the equations of the ocean and the atmosphere.

*Analysis and Applications*, **5**, 199-229, doi: 10.1142/S021953050700095X.[4]

Jablonowski, C., D. L. Williamson, 2006: A baroclinic instability test case for atmospheric model dynamical cores. *Quarterly Journal of the Royal Meteorological Society*, **132**, 2943-2975, doi: 10.1256/qj.06.12.[3]

Cooley, D., P. Naveau, V. Jomelli, A. Rabatel, D. Grancher, 2006: A Bayesian hierarchical extreme value model for lichenometry. *Environmetrics*, **17**, 555-574, doi: 10.1002/env.764.[3]

Williamson, D. L., J. G. Olson, 2007: A comparison of forecast errors in CAM2 and CAM3 at the ARM Southern Great Plains Site. *Journal of Climate*, **20**, 4572-4585.[1]

Wyant, M. C., C. S. Bretherton, J. T. Bacmeister, J. T. Kiehl, I. M. Held, M. Zhao, S. A. Klein, B. A. Soden, 2006: A comparison of tropical cloud properties and responses in GCMs using mid-tropospheric vertical velocity. *Climate Dynamics*, **27**, 261-279, doi: 10.1007/s00382-006-0138-4.[3]

Turner, D. P., W. D. Ritts, J. Styles, Z.-L. Yang, W. B. Cohen, B. E. Law, P. E. Thornton, 2006: A diagnostic carbon flux model to monitor the effects of disturbance and interannual variation in climate on regional NEP. *Tellus*, **58B**, 476-490.[4]

Furrer, E., D. W. Nychka, 2007: A framework to understand the asymptotic properties of Kriging and splines. *Journal of the Korean Statistical Society*, **36**, 57-76.[1]

Smith, A. K., D. V. Pancheva, N. J. Mitchell, D. R. Marsh, J. M. Russell III, M. G. Mlynczak, 2007: A link between variability of the semidiurnal tide and planetary waves in the opposite hemisphere. *Geophysical Research Letters*, **34**, L07809, doi: 10.1029/2006GL028929.[4]

Taylor, M. A., J. Edward, S. Thomas, R. Nair, 2007: A mass and energy conserving spectral element atmospheric dynamical core on the cubed-sphere grid. *Journal of Physics: Conference Series*, Boston, MA, **78**, 012074, doi: 10.1088/1742-6596/78/1/012074.[3]

Fast, J. D., B. deFoy, F. Acevedo Rosas, E. Caetano, G. Carmichael, L. Emmons, D. McKenna, M. Mena, W. Skamarock, X. Tie, R. L. Coulter, J. C. Barnard, C. Wiedinmyer, S. Madronich, 2007: A meteorological overview of the MILAGRO field campaigns. *Atmospheric Chemistry and Physics*, **7**, 2233-2257.[4]

Bryan, G. H., J. C. Knievel, M. D. Parker, 2006: A multi-model assessment of RKW Theory's relevance to squall line characteristics. *Monthly Weather Review*, **134**, 2772-2792.[2]

Sain, S. R., J. Shrikant, L. Mearns, D. Nychka, 2006: A multivariate spatial model for soil water profiles. *Journal of Agricultural, Biological, and Environmental Statistics*, **11**, 462-480, doi: 10.1198/108571106X154957.[2]

Wang, J., L. Zhang, A. Dai, T. VanHove, J. Van Baelen, 2007: A near-global, 2-hourly data set of atmospheric precipitable water from ground-based GPS measurements. *Journal of Geophysical Research*, **112**, D11107, doi: 10.1029/2006JD007529.[2]

Charlton, A. J., L. M. Polvani, J. Perlwitz, F. Sassi, E. Manzini, K. Shibata, S. Pawson, J. E. Nielson, D. Rind, 2007: A new look at stratospheric sudden warmings. Part II: Evaluation of numerical model simulations. *Journal of Climate*, **20**, 470-488, doi: 10.1175/JCLI3994.1.[4]

Hurrell, J. W., J. J. Hack, D. Shea, J. M. Caron, J. Rosinski, 2007: A new sea surface temperature and sea ice boundary data set for the Community Atmosphere Model. *Journal of Climate*, **19**, 5100-5122.[1]

Li, B., M. G. Genton, M. Sherman, 2007: A nonparametric assessment of properties of space-time covariance functions. *Journal of the American Statistical Association*, **102**, 736-744, doi: 10.1198/016214507000000202.[2]

Wang, W., K. J. Davis, C. Yi, E. G. Patton, M. P. Butler, D. M. Ricciuto, P. Bakwin, 2007: A note on the top-down and bottom-up gradient functions over a forested site. *Boundary-Layer Meteorology*, **124**, 305-314, doi: 10.1007/s10546-007-9162-0.[4]

Poulos, G. S., J. Wang, D. K. Lauritsen, H. L. Cole, 2007: A note on the use of targeted dropwindsondes in complex terrain. *Journal of Atmospheric and Oceanic Technology*, **24**, 1489-1494, doi: 10.1175/JTECH2065.1.[1]

Wang, W., A. G. Burns, T. L. Killeen, 2006: A numerical study of the response of ionospheric electron temperature to geomagnetic activity. *Journal of Geophysical Research - Space Physics*, **111**, A11301.[1]

Cotton, R. J., S. Benz, P. R. Field, O. Mohler, M. Schnaiter, 2007: A numerical test-bed for detailed ice nucleation studies in the AIDA cloud simulation chamber. *Atmospheric Chemistry and Physics*, **7**, 243-256.[3]

Helmig, D., S. J. Oltmans, D. Carlson, J.-F. Lamarque, A. Jones, C. Labuschagne, K. Anlauf, K. Hayden, 2007: A review of surface ozone in the polar regions. *Atmospheric Environment*, **41**, 5138-5161, doi: 10.1016/j.atmosenv.2006.09.053.[4]

Pan, L. L., J. C. Wei, D. E. Kinnison, R. R. Garcia, D. J. Wuebbles, G. P. Brasseur, 2007: A set of diagnostics for evaluating chemistry-climate models in the extratropical tropopause region. *Journal of Geophysical Research*, **112**, D09316, doi: 10.1029/2006JD007792.[4]

Alfieri, J. G., D. Niyogi, M. A. LeMone, F. Chen, S. Fall, 2007: A simple reclassification method for correcting uncertainty in land use/land cover datasets used with land surface models. *Pure and Applied Geophysics*, **164**, 1789-1809, doi: 10.1007/s00024-007-0241-4.[4]

Lei, J., R. G. Roble, S. Kawamura, S. Fukao, 2007: A simulation study of thermospheric neutral winds over the MU radar. *Journal of Geophysical Research*, **112**, A04303, doi: 10.1029/2006JA012038.[4]

Sain, S. R., N. Cressie, 2007: A spatial model for multivariate lattice data. *Journal of Econometrics*, **140**, 226-259, doi: 10.1016/j.jeconom.2006.09.010.[2]

Lauritzen, P. H., 2007: A stability analysis of finite-volume advection schemes permitting long time steps. *Monthly Weather Review*, **135**, 2658-2673, doi: 10.1175/MWR3425.0.[1]

Brandes, E. A., K. Ikeda, G. Zhang, M. Schoenhuber, R. M. Rasmussen, 2007: A statistical and physical description of hydrometeor distributions in Colorado snowstorms using a video disdrometer. *Journal of Applied Meteorology and Climatology*, **46**, 634-650.[1]

Hibbard, K. A., G. Meehl, P. Cox, P. Friedlingstein, 2007: A strategy for climate change stabilization experiments. *EOS, Transactions, American Geophysical Union*, **88(20)**, 217,219,221.[4]

Randel, W. J., F. Wu, 2007: A stratospheric ozone profile data set for 1979-2005: Variability, trends, and comparisons with column ozone data. *Journal of Geophysical Research*, **112**, D06313, doi: 10.1029/2006JD007339.[1]

Lites, B., R. Casini, J. Garcia, H. Socas-Navarro, 2007: A suite of community tools for spectro-polarimetric analysis. *Memorie della Societa Astronomica Italiana*, **78**, 148.[1]

Socas-Navarro, H., A. Asensio Ramos, R. Manso Sainz, 2007: A synthetic stellar polarization atlas from 400 to 1000 nm. *Astronomy and Astrophysics*, **465**, 339, doi: 10.1051/0004-6361:20066388;eprintid:arXiv:astro-ph.[3]

Farrugia, C. J., V. K. Jordanova, M. F. Thomsen, G. Lu, S. Cowley, 2006: A two-ejecta event associated with a two-step geomagnetic storm. *Journal of Geophysical Research*, **111**, A11104, doi: 10.1029/2006JA011893.[4]

Moreno-Sanchez, R., M. H. Hayden, C. Janes, G. Anderson, 2006: A web-based multimedia spatial information system to document Aedes aegypti breeding sites and dengue fever risk along the US-Mexico border. *Health and Place*, **12(4)**, 715-727.[4]

Rosenberg, D., A. Pouquet, P. D. Mininni, 2007: Adaptive mesh refinement with spectral accuracy for magnetohydrodynamics in two space dimensions. *New Journal of Physics*, **9**, 304, doi: 10.1088/1367-2630/9/8/304.[1]

Kent, E., S. Woodruff, N. Rayner, T. Arbetter, C. Folland, F. Koek, D. Parker, R. Reynolds, R. Saunders, V. Smolyanitsky, S. Worley, T. Yoshida, 2007: Advances in the use of historical marine climate data. *Bulletin of the American Meteorological Society*, **88**, 559-564, doi: 10.1175/BAMS-88-4-559.[3]

Massie, S. T., A. Heymsfield, C. Schmitt, D. Mueller, P. Seifert, 2007: Aerosol indirect effects as a function of cloud top pressure. *Journal of Geophysical Research*, **112**, D06202, doi: 10.1029/2006JD007383.[3]

Kazil, J., E. R. Lovejoy, M. C. Barth, K. O'Brien, 2006: Aerosol nucleation over oceans and the role of galactic cosmic rays. *Atmospheric Chemistry and Physics*, **6**, 4905-4924.[3]

Spackman, J. R., E. M. Weinstock, J. G. Anderson, D. F. Hurst, H.-J. Jost, S. M. Schauffler, 2007: Aircraft observations of rapid meridional transport from the tropical tropopause layer into the lowermost stratosphere: Implications for midlatitude ozone. *Journal of Geophysical Research*, **112**, D12308, doi: 10.1029/2006JD007618.[4]

Shepherd, G. G., Y. M. Cho, G. P. Liu, M. G. Shepherd, R. G. Roble, 2006: Airglow variability in the context of the global mesospheric circulation. *Journal of Atmospheric and Solar-Terrestrial Physics*, **68(17)**, 2000-2011, doi: 10.1016/j.jastp.2006.06.006.[2]

Anderson, J., 2007: An adaptive covariance inflation error correction algorithm for ensemble filters. *Tellus*, **59A**, 210-224, doi: 10.1111/j.1600-0870.2006.00216.x.[1]

Wang, W., A. G. Burns, M. Wiltberger, S. C. Solomon, T. L. Killeen, 2007: An analysis of neutral wind generated currents during geomagnetic storms. *Journal of Atmospheric and Solar-Terrestrial Physics*, **69**, 159.[1]

Kwak, Y.-S., A. D. Richmond, 2007: An analysis of the momentum forcing in the high-latitude lower thermosphere. *Journal of*

*Geophysical Research*, **112**, A01306, doi: 10.1029/2006JA011910.[1]

Liu, L., H. Le, W. Wan, M. P. Sulzer, J. Lei, M.-L. Zhang, 2007: An analysis of the scale heights in the lower topside ionosphere based on the Arecibo incoherent scatter radar measurements. *Journal of Geophysical Research - Space Physics*, **112**, A06307, doi: 10.1029/2007JA012250.[4]

Xiao, Q., Y.-H. Kuo, J. Sun, W.-C. Lee, D. M. Barker, E. Lim, 2007: An approach of reflectivity data assimilation and its assessment with the inland QPF of Typhoon Rusa (2002) at landfall. *Journal of Applied Meteorology and Climatology*, **46**, 14-22.[3]

Alexeev, V. A., D. J. Nicolsky, V. E. Romanovsky, D. M. Lawrence, 2007: An evaluation of deep soil configurations in the CLM3 for improved representation of permafrost. *Geophysical Research Letters*, **34**, L09502, doi: doi:/10.0129/2007GL029536.[3]

Khare, S. P., J. L. Anderson, 2006: An examination of ensemble filter based adaptive observation methodologies. *Tellus*, **58**, 179-195, doi: 10.1111/j.1600-0870.2006.00200.x.[3]

Cope, J., H. M. Tufo, M. Woitaszek, 2006: An extensible service development toolkit to support Earth science grids. *Proc. 2nd IEEE International Conference on e-Science and Grid Computing*, Amsterdam, Institute of Electrical and Electronics Engineers, CdRom.[2]

Tremblay, L. B., M. M. Holland, I. V. Gorodetskaya, G. A. Schmidt, 2007: An ice-free Arctic? Opportunities for computational science. *Computing in Science and Engineering*, **9**, 65-74, doi: 10.1109/MCSE.2007.45.[4]

Thornton, P. E., N. E. Zimmermann, 2007: An improved canopy integration scheme for a land surface model with prognostic canopy structure. *Journal of Climate*, **20**, 3902-3923.[3]

Huck, P. E., S. Tilmes, G. E. Bodeker, W. J. Randel, A. J. McDonald, H. Nakajima, 2007: An improved measure of ozone depletion in the Antarctic stratosphere. *Journal of Geophysical Research*, **112**, D11104, doi: 10.1029/2006JD007860.[4]

Sharman, R., C. Tebaldi, G. Wiener, J. Wolff, 2006: An integrated approach to mid- and upper-level turbulence forecasting. *Weather and Forecasting*, **21**, 268-287, doi: 10.1175/WAF924.1.[1]

Beare, R. J., M. K. MacVean, A. A. M. Holtslag, J. Cuxart, I. Esau, J. C. Golaz, M. A. Jimenez, M. Khairoutdinov, B. Kosovic, D. Lewellen, T. S. Lund, J. K. Lundquist, A. McCabe, A. F. Moene, Y. Noh, S. Raasch, P. P. Sullivan, 2006: An intercomparison of large-eddy simulations of the stable boundary layer. *Boundary-Layer Meteorology*, **118**, 247-272, doi: 10.1007/s10546-004-2820-6.[4]

Tebaldi, C., K. Hayhoe, J. M. Arblaster, G. A. Meehl, 2006: An intercomparison of model-simulated historical and future changes in extreme events. *Climatic Change*, **79**, 185-211.[3]

Tsuda, T. T., S. Nozawa, A. Brekke, Y. Ogawa, T. Motoba, R. Roble, R. Fujii, 2007: An ion drag contribution to the lower thermospheric wind in the summer polar region. *Journal of Geophysical Research - Space Physics*, **112**, 6319, doi: 10.1029/2006JA011785.[4]

Harriss, R., 2007: An ongoing dialogue on climate change: The Boulder manifesto. *Creating a Climate for Change: Communicating Climate Change and Facilitating Social Change*, S. C. Moser and L. Dilling, Ed., Cambridge University Press, 485-486.[1]

Dibb, J. E., M. Albert, C. Anastasio, E. Atlas, A. J. Beyersdorf, N. J. Blake, D. R. Blake, F. Bocquet, J. F. Burkhart, G. Chen, L. Cohen, T. J. Conway, Z. Courville, M. M. Frey, D. K. Friel, E. S. Galbavy, S. Hall, M. G. Hastings, D. Helmig, L. G. Huey, M. A. Hutterli, J. C. Jarvis, B. L. Lefer, S. Meinardi, W. Neff, S. J. Oltmans, F. S. Rowland, S. J. Sjostedt, E. J. Steig, A. L. Swanson, D. Tanner, 2007: An overview of air-snow exchange at Summit, Greenland: Recent experiments and findings. *Atmospheric Environment*, **41**, 4995-5006, doi: 10.1016/j.atmosenv.2006.12.006.[4]

Ridley, B. A., T. Zeng, Y. Wang, E. V. Browell, P. G. Hess, J. J. Orlando, K. Chance, R. Richter, 2007: An ozone depletion event in the sub-arctic layer over Hudson Bay, Canada. *Journal of Atmospheric Chemistry*, **57**, 255-280, doi: 10.1007/s10874-007-9072-z.[4]

McTaggert-Cowan, R., L. F. Bosart, C. A. Davis, E. H. Atallah, J. R. Gyakum, K. A. Emanuel, 2006: Analysis of Hurricane Catarina (2004). *Monthly Weather Review*, **134**, 3029-3053.[4]

Roberts, J. M., M. Marchewka, S. B. Bertman, P. Goldan, W. Kuster, J. De Gouw, C. Warneke, E. Williams, B. Lerner, P. Murphy, E. Apel, F. C. Fehsenfeld, 2006: Analysis of the isoprene chemistry observed during the New England Air Quality Study (NEAQS) 2002 intensive experiment. *Journal of Geophysical Research*, **111**, D23S12, doi: 10.1029/2006JD007570.[2]

Stephens, B. B., P. S. Bakwin, P. P. Tans, R. M. Teclaw, D. D. Baumann, 2007: Application of a differential fuel-cell analyzer for measuring atmospheric oxygen variations. *Journal of Atmospheric and Oceanic Technology*, **24**, 82-94, doi:

10.1175/JTECH1959.1.[3]

Glantz, M. H., 2007: Aral Sea basin: A sea dies, a sea also rises. *Ambio*, **36(4)**, 324-327, doi: 10.1579/0044-7447(2007)36[323:ASBASD]2.0.CO;2.[1]

Stroeve, J., M. M. Holland, W. Meier, T. Scambos, M. C. Serreze, 2007: Arctic Sea ice decline: Faster than forecast. *Geophysical Research Letters*, **34**, L09501, doi: 10.1029/2007GL029703.[4]

Feldstein, S., C. Franzke, 2006: Are the North Atlantic Oscillation and the Northern Annular Mode distinguishable? *Journal of the Atmospheric Sciences*, **63**, 2915-2930, doi: 10.1175/JAS3798.1.[2]

Romero-Lankao, P., 2007: Are we missing the point? Particulars of urbanization, sustainability and carbon emissions in Latin American cities. *Environment and Urbanization*, **19(1)**, 157-175.[1]

Cucurull, L., Y.-H. Kuo, D. M. Barker, S. R. H. Rizvi, 2006: Assessing the impact of COSMIC GPS radio occultation data on weather analysis and short-term forecasts over the Antarctic. *Monthly Weather Review*, **134**, 3283-3296.[1]

Fasullo, J., 2006: Assessing tropical cyclone trends in the context of potential sampling biases. *Geophysical Research Letters*, **33**, L24808, doi: 10.1029/2006GL027852.[1]

Eyring, V., N. Butchart, D. W. Waugh, H. Akiyoshi, J. Austin, S. Bekki, G. E. Bodeker, B. A. Boville, C. Bruehl, M. P. Chipperfield, E. Cordero, M. Dameris, M. Deushi, V. E. Fioletov, S. M. Frith, R. R. Garcia, A. Gettelman, M. A. Giorgetta, V. Grewe, L. Jourdain, D. E. Kinnison, E. Mancini, E. Manzini, M. Marchand, D. R. Marsh, T. Nagashima, P. A. Newman, J. E. Nielsen, S. Pawson, G. Pitari, D. A. Plummer, E. Rozanov, M. Schraner, T. G. Shepherd, K. Shibata, R. S. Stolarski, H. Struthers, W. Tian, M. Yoshiki, 2006: Assessment of temperature, trace species, and ozone in chemistry-climate model simulations of the recent past. *Journal of Geophysical Research*, **111**, D22308, doi: 10.1029/2006JD007327.[4]

Jomelli, V., D. Grancher, P. Naveau, D. Cooley, D. Brunstein, 2007: Assessment study of lichenometric methods for dating surface. *Geomorphology*, **86**, 131-143, doi: 10.1016/j.geomorph.2006.08.010.[4]

Chen, Y., C. Snyder, 2007: Assimilating vortex position with an ensemble Kalman filter. *Monthly Weather Review*, **135**, 1828-1845.[3]

Cunha, M. S., T. S. Metcalfe, 2007: Asteroseismic signatures of small convective cores. *The Astrophysical Journal*, **666**, 413-422, doi: 10.1086/520045.[2]

Metcalfe, T. S., W. A. Dziembowski, P. G. Judge, M. Snow, 2007: Asteroseismic signatures of stellar magnetic activity cycles. *Monthly Notices of the Royal Astronomical Society*, 379, L16-L20, doi: 10.1111/j.1745-3933.2007.00325.x.[4]

Hurrell, J. W., M. Visbeck, A. Busalacchi, R. A. Clarke, T. L. Delworth, R. R. Dickson, W. E. Johns, K. P. Koltermann, Y. Kushnir, D. Marshall, C. Mauritzen, M. S. McCartney, A. Piola, C. Reason, G. Reverdin, F. Schott, R. Sutton, I. Wainer, D. Wright, 2006: Atlantic climate variability and predictability: A CLIVAR perspective. *Journal of Climate*, **19**, 5100-2121.[4]

Patra, P. K., M. D. Kumar, N. Mahowald, V. S. Sarma, 2007: Atmospheric deposition and surface stratification as controls of contrasting chlorophyll abundance in the North Indian Ocean. *Journal of Geophysical Research*, **112**, C05029, doi: 10.1029/2006JC003885.[4]

Tie, X., G. Li, Z. Ying, A. Guenther, S. Madronich, 2006: Biogenic emissions of isoprenoids and NO in China and comparison to anthropogenic emissions. *Science of the Total Environment*, Elsevier Ltd., **371**, 238-251, doi: 10.1016/j.scitotenv.2006.06.025.[2]

Jablonowski, C., M. Herzog, J. E. Penner, R. C. Oehmke, Q. F. Stout, B. van Leer, K. G. Powell, 2006: Block-structured adaptive grids on the sphere: Advection experiments. *Monthly Weather Review*, **134**, 3691-3713, doi: 10.1175/MWR3223.1.[2]

Baum, B., P. Yang, S. Nasiri, A. K. Heidinger, A. J. Heymsfield, J. Li, 2007: Bulk scattering properties for the remote sensing of ice clouds. Part III: High-resolution spectral models from 100 to 3250 cm-1. *Journal of Applied Meteorology and Climatology*, **46**, 423-434, doi: 10.1175/JAM2473.1.[4]

Qian, L., R. G. Roble, S. C. Solomon, T. J. Kane, 2006: Calculated and observed climate change in the thermosphere, and a prediction for solar cycle 24. *Geophysical Research Letters*, **33**, 23705, doi: 10.1029/2006GL027185.[2]

Metcalfe, T. S., T. J. Henry, M. Knoelker, D. R. Soderblom, 2006: Calibrating the solar dynamo: magnetic activity cycles of southern Sun-like stars. *SOHO/18/GONG2006/HELAS I Conference*, Sheffield, ESA, 18, 111.[4]

Doney, S. C., D. S. Schimel, 2007: Carbon and climate system coupling on timescales from the Precambrian to the Anthropocene. *Annual Review of Environment and Resources*, **32**, 14.1-14.36, doi: 10.1146/annurev.energy.32.041706.124700.[3]

Hu, A., G. A. Meehl, W. Han, 2007: Causes of a fresher, colder northern North Atlantic in late 20th century in a coupled model. *Progress in Oceanography*, **73**, 384-405.[3]

Mahowald, N. M., D. R. Muhs, S. Levis, P. J. Rasch, M. Yoshioka, C. S. Zender, C. Luo, 2006: Change in atmospheric mineral aerosols in response to climate: Last glacial period, preindustrial, modern, and doubled carbon dioxide climates. *Journal of Geophysical Research*, **111**, D10202, doi: 10.1029/2005JD006653.[4]

Bryan, F. O., G. Danabasoglu, P. R. Gent, K. Lindsay, 2006: Changes in ocean ventilation during the 21st century in the CCSM3. *Ocean Modelling*, **15**, 141-156.[1]

Barstad, I., W. W. Grabowski, P. K. Smolarkiewitz, 2007: Characteristics of large-scale orographic precipitation: evaluation of linear model in idealized problems. *Journal of Hydrology*, **340**, 78-90.[3]

Wilson, D. K., E. L. Andreas, C. L. Pettit, E. G. Patton, P. P. Sullivan, J. W. Weatherly, 2007: Characterization of uncertainty in outdoor sound propagation predictions. *Journal of the Acoustical Society of America Express Letters*, **121(5)**, EL177-EL183, doi: 10.1121/1.2716159.[4]

Tie, X., S. Madronich, G. Li, Z. Ying, R. Zhang, A. R. Garcia, J. Lee-Taylor, Y. Liu, 2007: Characterizations of chemical oxidants in Mexico City: A regional chemical dynamical model (WRF-Chem) study. *Atmospheric Environment*, **41**, 1989-2008, doi: 10.1016/j.atmosenv.2006.10.053.[2]

Pan, L. L., K. P. Bowman, M. Shapiro, W. J. Randel, R. S. Gao, T. Campos, C. Davis, S. Schauffler, B. A. Ridley, J. C. Wei, C. Barnet, 2007: Chemical behavior of the tropopause observed during the Stratosphere-Troposphere Analysis of Regional Transport experiment. *Journal of Geophysical Research*, American Geophysical Union, **112**, D18110, doi: 10.1029/2007JD008645.[4]

Madronich, S., 2006: Chemical evolution of gaseous air pollutants down-wind of tropical megacities: Mexico City case study. *Atmospheric Environment*, Elsevier Ltd., **40**, 6012-6018, doi: 10.1016/j.atmosenv.2005.08.047.[1]

Tilmes, S., R. Mueller, A. Engel, M. Rex, J. M. Russell III, 2006: Chemical ozone loss in the Arctic and Antarctic stratosphere between 1992 and 2005. *Geophysical Research Letters*, **33**, L20812, doi: 10.1029/2006GL026925.[4]

Tilmes, S., R. Mueller, R. J. Salawitch, U. Schmidt, C. R. Webster, H. Oelhaf, J. M. Russell III, C. C. Camy-Peyret, 2007: Chemical ozone loss in the Arctic winter 1991-1992. *Atmospheric Chemistry and Physics Discussions*, **7**, 10097-10129.[4]

Seifert, P., A. Ansmann, D.-J. Muller, U. Wandinger, D. Althausen, A. J. Heymsfield, S. T. Massie, C. Schmitt, 2007: Cirrus optical properties observed with lidar, radiosonde, and satellite over the tropical Indian Ocean during the aerosol-polluted northeast and clean maritime southwest monsoon. *Journal of Geophysical Research*, **112**, D17205, doi: 10.1029/2006JD008352.[3]

Moser, S. C., 2006: Climate change in the northeast. *Climate Change in the Northeast*, Union of Concerned Scientists, Ed., Northeast Climate Impacts Assessment, 52 pp.[4]

Weese, S. R., F. O. Bryan, 2006: Climate impacts of systematic errors in the simulation of the path of the North Atlantic Current. *Geophysical Research Letters*, **33**, L19708, doi: 10.1029/2006GL027669.[1]

Baer, F., H. Wang, J. J. Tribbia, A. Fournier, 2006: Climate modeling with spectral elements. *Monthly Weather Review*, **134**, 3610-3624, doi: 10.1175/MWR3360.1.[2]

Mahowald, N. M., M. Yoshioka, W. D. Collins, A. J. Conley, D. W. Fillmore, D. B. Coleman, 2006: Climate response and radiative forcing from mineral aerosols during the last glacial maximum pre-industrial, current and doubled-carbon dioxide climates. *Geophysical Research Letters*, **33**, L20705, doi: 10.1029/2006GL026126.[1]

Gritsun, A., G. Branstator, 2007: Climate response using a three-dimensional operator based on the fluctuation-dissipation theorem. *Journal of the Atmospheric Sciences*, **64**, 2258-2275.[3]

Zhu, P., J. J. Hack, J. T. Kiehl, C. S. Bretherton, 2007: Climate sensitivity of tropical and subtropical marine low cloud amount to ENSO and global warming due to doubled CO2. *Journal of Geophysical Research*, **112**, D17108, doi: 10.1029/2006JD008174.[2]

Miller, K. A., 2007: Climate variability and tropical tuna: Management challenges for highly migratory fish stocks. *Marine Policy*, **31(1)**, 56-70, doi: 10.1016/j.marpol.2006.05.006.[1]

Forster, P., R. Somerville, N. Bindoff, J. Christensen, K. Denman, G. Hegerl, B. Hewitson, E. Jansen, P. Jones, P. Lemke, G. A. Meehl, J. Overpeck, V. Ramaswamy, D. Randall, T. Stocker, K. Trenberth, H. Le Treut, J. Willebrand, R. Wood, F. Zwiers, 2007: Climate with care. *New Scientist*, 193 (2596), 27, doi: 10.1016/S0262-4079(07)60732-5.[4]

Lal, D., W. G. Large, S. G. Walker, 2007: Climatic forcing before, during, and after the 8.2 Kyr B. P. global cooling event. *Journal of Earth System Sciences*, **116**, 171-177.[3]

Gettelman, A., W. D. Collins, E. J. Fetzer, A. Eldering, F. W. Irion, P. B. Duffy, G. Gala, 2006: Climatology of upper tropospheric relative humidity from the atmospheric infrared sounder and implications for climate. *Journal of Climate*, **19**, 6104-6121, doi: 10.1175/JCLI3956.1.[3]

Stroud, C. A., A. Nenes, J. L. Jimenez, P. F. DeCarlo, J. A. Huffman, R. Bruintjes, E. Nemitz, A. E. Delia, D. W. Toohey, A. B. Guenther, S. Nandi, 2007: Cloud activating properties of aerosol observed during CELTIC. *Journal of the Atmospheric Sciences*, American Meteorological Society, **64 (2)**, 441-459, doi: 10.1175/JAS3843.1.[4]

Barth, M. C., S.-W. Kim, C. Wang, K. E. Pickering, L. E. Ott, G. Stenchikov, M. Leriche, S. Cautenet, J.-P. Pinty, C. Barthe, C. Mari, J. H. Helsdon, R. D. Farley, A. M. Fridlind, A. S. Ackerman, V. Spiridonov, B. Telenta, 2007: Cloud-scale model intercomparison of chemical constituent transport in deep convection. *Atmospheric Chemistry and Physics*, **7**, 4709-4731.[4]

Wigley, T. M. L., 2007: CO2 emissions: A piece of the pie. *Science*, **316**, 829-830.[1]

Sun, J., S. P. Burns, A. C. Delaney, S. P. Oncley, A. A. Turnipseed, B. B. Stephens, D. H. Lenschow, M. A. LeMone, R. K. Monson, D. E. Anderson, 2007: CO2 Transport over Complex Terrain. *Agricultural and Forest Meteorology*, **145**, 1-21, doi: 10.1016/j.agrformet.2007.02.007.[2]

Pinto, J. O., D. B. Parsons, W. O. J. Brown, S. Cohn, N. Chamberlain, B. Morley, 2006: Coevolution of down-valley flow and the nocturnal boundary layer in complex terrain. *Journal of Applied Meteorology and Climatology*, **45(10)**, 1429-1449, doi: 10.1175/JAM2412.1.[1]

Lothon, M., D. H. Lenschow, S. Mayor, 2006: Coherence and scale of vertical velocity in the convective boundary layer from a Doppler lidar. *Boundary-Layer Meteorology*, **121**, 521-536.[2]

Moncrieff, M. W., M. Shapiro, J. Slingo, F. Molteni, 2007: Collaborative research at the intersection of weather and climate. *WMO Bulletin*, **56**, 206-211.[4]

McDougall, T. J., P. R. Gent, S. Drijfhout, 2007: Comment on "Dynamical model of mesoscales in z-coordinates" and "The effect of mesoscales on the tracer equation in z-coordinates OGCMs". *Ocean Modelling*, **17**, 163-171.[3]

Moser, S. C., 2007: Communicating climate change motivating citizens action: An opportunity for democratic renewal? *Climate Change Politics in North America*, H. Selin and S. D. Vandeveer, Ed., Canada Institute, 109-118.[1]

Moser, S. C., 2007: Communication strategies to mobilize the climate movement. *Ignition: What You Can Do to Fight Global Warming and Spark a Movement*, J. Isham and S. Waage, Ed., Island Press, 73-93.[1]

Morrison, H., W. W. Grabowski, 2007: Comparison of bulk and bin warm rain microphysics models using a kinematic framework. *Journal of the Atmospheric Sciences*, **64**, 2839-2861, doi: 10.1175/JAS3980.[1]

Lei, J., S. Syndergaard, A. G. Burns, S. C. Solomon, W. Wang, Z. L. Zeng, R. G. Roble, Q. Wu, Y.-H. Kuo, J. M. Holt, S.-R. Zhang, D. L. Hysell, F. S. Rodrigues, C. H. Lin, 2007: Comparison of COSMIC ionospheric measurements with ground-based observations and model predictions: Preliminary results. *Journal of Geophysical Research - Space Physics*, **112**, A07309, doi: 10.1029/2006JA012240.[4]

Committee on Estimating and Communicating Uncertainty in Weather and Climate Forecasts, ., R. J. Ban, J. T. Andrew, B. G. Brown, D. Changnon, K. Georgakakos, J. Hansen, R. N. Keener, Jr., U. Lall, C. F. Mass, R. E. Morss, R. T. Ryan, E. U. Weber, 2006: Completing the forecast: Characterizing and communicating uncertainty for better decisions using weather and climate forecasts. *Completing the Forecast: Characterizing and Communicating Uncertainty for Better Decisions Using Weather and Climate Forecasts*, National Research Council, Ed., National Academies Press, 124 pp.[4]

Rast, M. P., J. Mendoza, J. Clyne, 2007: Compressible thermal starting plume. *Journal of Visualization*, **10**, 247.[2]

Bower, K., T. Choularton, J. Latham, J. Sahraei, S. Salter, 2006: Computational assessment of a proposed technique for global warming mitigation via albedo-enhancement of marine stratocumulus clouds. *Atmospheric Research*, **82**, 328-336.[2]

Heald, C. L., D. J. Jacob, S. Turquety, R. C. Hudman, R. J. Weber, A. P. Sullivan, R. E. Peltier, E. L. Atlas, J. A. de Gouw, C. Warneke, J. S. Holloway, J. A. Neuman, F. M. Flocke, J. H. Seinfeld, 2006: Concentrations and sources of organic carbon aerosols in the free troposphere over North America. *Journal of Geophysical Research*, **111**, D23S47, doi: 10.1029/2006JD007705.[4]

Frumhoff, P. C., J. J. McCarthy, J. M. Melillo, S. C. Moser, D. J. Wiebbles, 2007: Confronting climate change in the U.S. northeast: science, impacts, and solutions. *Confronting Climate Change in the U.S. Northeast: Science, Impacts, and Solutions*, Northeast Climate Impacts Assessment, 160 pp.[4]

Knutti, R., G. A. Meehl, M. R. Allen, D. A. Stainforth, 2006: Constraining climate sensitivity from the seasonal cycle in surface temperature. *Journal of Climate*, **19**, 4224-4233.[2]

Kleypas, J. A., 2007: Constraints on predicting coral reef response to climate change. Chapter 12. *Geological Approaches to Coral Reef Ecology*, R. Aronson, Ed., New York, Springer-Verlag, 386-424.[1]

Iida, K., M. Stolzenburg, P. McMurry, M. J. Dunn, J. N. Smith, F. Eisele, P. Keady, 2006: Contribution of ion-induced nucleation to new particle formation: Methodology and its application to atmospheric observations in Boulder, Colorado. *Journal of Geophysical Research*, **111**, D23201, doi: 10.1029/2006JD007167.[4]

Konopka, P., G. Guenther, R. Mueller, F. H. S. dos Santos, C. Schiller, F. Ravegnani, A. Ulanovsky, H. Schlager, C. M. Volk, S. Viciani, L. L. Pan, D.-S. McKenna, M. Riese, 2007: Contribution of mixing to upward transport across the tropical tropopause layer (TTL). *Atmospheric Chemistry and Physics*, **7**, 3285-3308.[4]

Latham, J., 2007: Cooling may be possible but we need safety data. *Nature*.[1]

Kleypas, J. A., J.-P. Gattuso, 2006: Coral reef. *The Encyclopedia of Earth*, C. J. Cleveland, Ed., National Council of Science and Environment.[2]

Kleypas, J. A., C. Langdon, 2006: Coral reefs and changing seawater carbonate chemistry. Chapter 5. *Coral Reefs and Climate Change: Science and Management, Coastal and Estuarine Studies*, J. Phinney, O. Hoegh-Guidberg, J. Kleypas, W. Skrving, and A. Strong, Eds., American Geophysical Union, 61, 73-110.[3]

Phinney, J. T., O. Hoegh-Guldberg, J. A. Kleypas, W. Skrving, A. Strong, 2006: Coral reefs and climate change: science and management. *Coral Reefs and Climate Change: Science and Management, Coastal and Estuarine Studies*, American Geophysical Union, 61, 244 pp.[4]

Janse, A. M., B. C. Low, 2007: Coronal hydromagnetic implosions. *Astronomy and Astrophysics*, **472**, 957-965, doi: 10.1051/0004-6361:20077532.[2]

Gibson, S. E., Y. Fan, 2007: Coronal prominence structure and dynamics: A magnetic flux rope interpretation. *Journal of Geophysical Research*, **111**, A12103, doi: 10.1029/2006JA11871.[1]

Gochis, D., L. Brito-Castillo, W. J. Shuttleworth, 2007: Correlations between sea-surface temperatures and warm season streamflow in northwest Mexico. *International Journal of Climatology*, **27**, 883-901.[4]

van Loon, H., G. A. Meehl, D. J. Shea, 2007: Coupled air-sea response to solar forcing in the Pacific region during northern winter. *Journal of Geophysical Research*, **112**, D02108, doi: 10.1029/2006JD007378.[1]

Denman, K. L., G. P. Brasseur, A. Chidthaisong, P. Ciais, P. M. Cox, R. E. Dickinson, D. Hauglustaine, C. Heinze, E. Holland, D. Jacob, U. Lohmann, S. Ramachandran, P. L. Da Silva Dias, S. C. Wofsy, X. Zhang, 2007: Couplings between changes in the climate system and biogeochemistry. Chapter 7. *Climate Change 2007 - The Physical Science Basis: Working Group I contribution to the Fourth Assessment Report of the IPCC*, Solomon, S., D. Qin, M/ Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor, and H. L. Miller, Eds., Cambridge University Press, 499-588.[4]

Furrer, R., M. Genton, D. Nychka, 2006: Covariance tapering for interpolation of large spatial datasets. *Journal of Computational Graphical Statistics*, **15**, 502-523.[2]

Moser, S. C., L. Dilling, 2007: Creating a climate for change: Communicating climate change and facilitating social change. *Creating a Climate for Change: Communicating Climate Change and Facilitating Social Change*, S. C. Moser and L. Dilling, Ed., Cambridge University Press, 549 pp.[2]

Romero-Lankao, P., 2007: Decentralizacion y retiro del estado: Mecanismos para gestionar sustenablemente del agua!. *Gestion y Politica Publica*, **VXI(1)**, 29-59.[1]

Kwak, Y. S., A. D. Richmond, R. G. Roble, 2007: Dependence of the high-latitude lower thermospheric momentum forcing on the interplanetary magnetic field. *Journal of Geophysical Research - Space Physics*, **112**, 6316, doi: 10.1029/2006JA012208.[1]

Rogers, D. P., Y. Adebayo, S. Clarke, S. J. Connor, R. DeGuzman, P. Dexter, L. Dubus, J. Guddal, L. Jalkanen, A. I. Korshunov, J. K. Lazo, H. Puempel, M. I. Smetanin, B. Stewart, T. Xu, V. V. Tsirkunov, S. I. Ulatov, P.-Y. Whung, D. A. Wilhite, 2007: Deriving societal and economic benefits from meteorological and hydrological services. *WMO Bulletin*, **56(1)**, 15-22.[4]

Chen, F., K. W. Manning, M. A. LeMone, S. B. Trier, J. G. Alfieri, R. Roberts, M. Tewari, D. Niyogi, T. W. Horst, S. P. Oncley, J. B. Basara, P. D. Blanken, 2007: Description and evaluation of the characteristics of the NCAR high-resolution land data assimilation system. *Journal of Applied Meteorology and Climatology*, **46**, 694-713, doi: 10.1175/JAM2463.1.[2]

Gomez, D. O., P. D. Mininni, 2006: Description of Maunder-like events from a stochastic Alpha-Omega model. *Advances in Space Research*, **38**, 858-861, doi: 10.1016/j.asr.2005.07.032.[3]

Wang, Y., M. Notaro, Z. Liu, R. Gallimore, S. Levis, J. E. Kutzbach, 2007: Detecting vegetation-precipitation feedbacks in mid-Holocene North Africa from two climate models. *Climate of the Past Discussions*, **3**, 961-975.[4]

Hoerling, M. P., J. W. Hurrell, J. Eischeid, A. S. Phillips, 2006: Detection and attribution of 20th Century Northern and Southern African monsoon change. *Journal of Climate*, **19**, 3989-4008.[3]

Dzepina, K., J. Arey, L. C. Marr, D. R. Worsnop, D. Salcedo, Q. Zhang, T. B. Onasch, L. T. Molina, M. Molina, J. L. Jimenez, 2007: Detection of particle-phase polycyclic aromatic hydrocarbons in Mexico City using an aerosol mass spectrometer. *International Journal of Mass Spectrometry*, Elsevier Ltd., **263**, 152-170, doi: 10.1016/j.ijms.2007.01.010.[4]

Osborne, T. M., D. M. Lawrence, A. J. Challinor, J. M. Slingo, T. R. Wheeler, 2007: Development and assessment of a coupled crop-climate model. *Global Change Biology*, **13**, 169-183.[3]

Tilmes, S., R. Mueller, J.-U. Grooss, H. Nakajima, Y. Sasano, 2006: Development of tracer relations and chemical ozone loss during the setup phase of the polar vortex. *Journal of Geophysical Research*, **111**, D24S90, doi: 10.1029/2005JD006726.[3]

Zhu, P., J. J. Hack, J. T. Kiehl, 2007: Diagnosing cloud feedbacks in General Circulation Models. *Journal of Climate*, American Meteorological Society, **20**, 2602-2622, doi: 10.1175/JCLI4140.1.[1]

Bertram, T. H., A. E. Perring, P. J. Wooldridge, J. D. Crounse, A. J. Kwan, P. O. Wennberg, E. Scheuer, J. Dibb, M. Avery, G. Sachse, S. A. Vay, J. H. Crawford, C. S. McNaughton, A. Clarke, K. E. Pickering, H. Fuelberg, G. Huey, D. R. Blake, H. B. Singh, S. R. Hall, R. E. Shetter, A. Fried, B. G. Heikes, R. C. Cohen, 2007: Direct measurements of the convective recycling of the upper troposphere. *Science*, **315**, 816 - 820, doi: 10.1126/science.1134548.[4]

Wedi, N. P., P. K. Smolarkiewicz, 2006: Direct numerical simulation of the Plumb-McEwan laboratory analogue of the QBO. *Journal of the Atmospheric Sciences*, **63**, 3226-3252.[3]

Shell, K. M., R. C. J. Somerville, 2007: Direct radiative effects of mineral dust and volcanic aerosols in a simple aerosol climate model. *Journal of Geophysical Research*, **112**, D03205, doi: 10.1029/2006JD007197.[2]

Kelman, I., 2007: Disaster diplomacy in Aceh. *Humanitarian Exchange*, **37**, 37-90.[1]

Komm, R., R. Howe, F. Hill, M. Miesch, D. Haber, B. Hindman, 2007: Divergence and vorticity of solar subsurface flows derived from ring-diagram analysis of MDI and GONG data. *The Astrophysical Journal*, **667**, 571-584, doi: 10.1086/520765.[4]

Barlow, M., H. Cullen, B. Lyon, O. Wilhelmi, 2006: Drought disaster in Asia. Chapter 1. *Natural Disaster Hotspots Case Studies*, Arnold et al, Ed., The World Bank, 1-19.[4]

Bryant, R., G. Bigg, N. Mahowald, F. Eckardt, S. Ross, 2007: Dust emission response to climate in southern Africa. *Journal of Climate*, **112**, D09207, doi: 10.1029/2005JD007025.[4]

Lin, Y.-L., N. Witcraft, Y.-H. Kuo, 2006: Dynamics of track deflection associated with the passage of a tropical cyclone over a mesoscale mountain. *Monthly Weather Review*, **134**, 3509-3538.[4]

Ponty, Y., P. D. Mininni, J.-F. Pinton, H. Politano, A. Pouquet, 2007: Dynamo action at low magnetic Prandtl numbers: Mean flow versus fully turbulent motions. *New Journal of Physics*, **9**, 297, doi: 10.1088/1367-2630/9/8/296.[3]

England, S. L., T. J. Immel, E. Sagawa, S. B. Henderson, M. E. Hagan, S. B. Mende, H. U. Frey, C. M. Swenson, L. J. Paxton, 2006: Effect of atmospheric tides on the morphology of the quiet time, postsunset equatorial ionospheric anomaly. *Journal of Geophysical Research*, **111**, A10S19, doi: 10.1029/2006JA011795.[2]

Crowley, G., T. J. Immel, C. L. Hackert, J. Craven, R. G. Roble, 2006: Effect of IMF BY on thermospheric composition at high and middle latitudes: 1. Numerical experiments. *Journal of Geophysical Research*, **111**, 10311, doi: 10.1029/2005JA011371.[4]

Immel, T. J., G. Crowley, C. L. Hackert, J. D. Craven, R. G. Roble, 2006: Effect of IMF BY on thermospheric composition at high and middle latitudes: 2. Data comparisons. *Journal of Geophysical Research*, **111**, 10312, doi: 10.1029/2005JA011372.[4]

Gruzdev, A. N., G. P. Brasseur, 2007: Effect of the 11-year cycle of solar activity on characteristics of the total ozone annual variation. *Izvestiya, Atmospheric and Oceanic Physics*, **43**, 344-356, doi: 10.1134/S0001433807030097.[3]

Green, C. A., A. G. Kosovichev, M. S. Miesch, 2006: Effect of the subsurface shear layer on solar supergranulation. *SOHO/18/GONG2006/HELAS I Conference*, ESA, 18, 13.[2]

Wang, L.-P., O. Ayala, W. W. Grabowski, 2007: Effects of aerodynamic interactions on the motion of heavy particles in a bidisperse suspension. *Journal of Turbulence*, 8, 1-28, doi: 10.1080/14685240701233426.[2]

Trenberth, K. E., A. Dai, 2007: Effects of Mount Pinatubo volcanic eruption on the hydrological cycle as an analog of geoengineering. *Geophysical Research Letters*, **34**, L15702, doi: 10.1029/2007GL030524.[1]

Tian, X., A. Dai, D. Yang, Z. Xie, 2007: Effects of precipitation-bias corrections on surface hydrology over northern latitudes. *Journal of Geophysical Research*, **112**, D14101, doi: 10.029/2007JD008420.[2]

Wang, L.-P., Y. Xue, O. Ayala, W. W. Grabowski, 2006: Effects of stochastic coalescence and air turbulence on the size distribution of cloud droplets. *Atmospheric Research*, **82**, 416-432, doi: 10.1016/j.atmosres.2005.12.011..[2]

Danabasoglu, G., J. Marshall, 2007: Effects of vertical variations of thickness diffusivity in an ocean general circulation model. *Ocean Modelling*, **18**, 122-141.[2]

Lei, J., R. G. Roble, W. Wang, B. A. Emery, S.-R. Zhang, 2007: Electron temperature climatology at Millstone Hill and Arecibo. *Journal of Geophysical Research*, **112**, A02302, doi: 10.1029/2006JA012041.[4]

Centeno, R., H. Socas-Navarro, B. Lites, M. Kubo, Z. Frank, R. Shine, T. Tarbell, A. Title, K. Ichimoto, S. Tsuneta, Y. Katsukawa, Y. Suematsu, T. Shimizu, S. Nagata, 2007: Emergence of small-scale magnetic loops in the quiet-sun internetwork. *The Astrophysical Journal*, **666**, L137-L140, doi: 10.1086/521726; eprintid: arXiv:0708.0844.[3]

Middleton, D. E., D. E. Bernholdt, D. Brown, M. Chen, A. L. Chervenak, L. Cinquini, R. Drach, P. Fox, P. Jones, C. Kesselman, I. T. Foster, V. Nefedova, A. Shoshani, A. Sim, W. G. Strand, D. Williams, 2006: Enabling worldwide access to climate simulation data: The Earth System Grid (ESG). *Journal of Physics: Conference Series*, **46**, 510-514, doi: 10.1088/1742-6596/46/1/070.[4]

Wiltberger, M., D. Baker, 2006: End-to-end modeling of the solar terrestrial system. *Space Science Reviews*, **124**, 217, doi: 10.1007/s11214-006-9106-x.[3]

Kavanagh, A. J., G. Lu, E. F. Donovan, G. D. Reeves, F. Honary, J. Manninen, T. J. Immel, 2007: Energetic electron precipitation during sawtooth injections. *Annales Geophysicae*, **25**, 1199-1214.[4]

Turner, N. E., D. Knipp, B. Emery, 2006: Energetics of magnetic storms driven by corotating interaction regions: A study of geoeffectiveness. *Recurrent Magnetic Storms: Corotating Solar Wind Streams, Geophysical Monograph*, American Geophysical Union, 167, 113-124.[4]

Alexakis, A., C. R. Doering, 2006: Energy and enstrophy dissipation in steady state 2d turbulence. *Physics Letters A*, **359**, 652-657.[2]

Mininni, P., A. Alexakis, A. Pouquet, 2007: Energy transfer in Hall-MHD turbulence, cascades, backscatter and dynamo action. *Journal of Plasma Physics*, **73**, 377-401, doi: 10.1017/S0022377806004624.[1]

Young, L.-H., D. R. Benson, W. M. Montanaro, S.-H. Lee, L. L. Pan, D. C. Rogers, J. Jensen, J. L. Stith, C. A. Davis, T. L. Campos, K. P. Bowman, W. A. Cooper, L. R. Lait, 2007: Enhanced new particle formation observed in the northern midlatitude tropopause region. *Journal of Geophysical Research*, **112**, D10218, doi: 10.1029/2006JD008109.[4]

McPhaden, M. J., S. E. Zebiak, M. H. Glantz, 2006: ENSO as an integrating concept in earth science. *Science*, **314**, 1740-1745, doi: 10.1126/science.1132588.[3]

Katz, R. W., 2007: Environmental sciences. *Statistical Analysis of Extreme Values with Applications to Insurance, Finance, Hydrology, and Other Fields*, R.-D. Reiss and M. Thomas, Ed., Birkhauser, 353-367.[1]

Methven, J., S. R. Arnold, A. Stohl, M. J. Evans, m. Avery, K. Law, A. C. Lewis, P. S. Monks, D. D. Parrish, C. E. Reeves, H. Schlager, E. Atlas, D. R. Blake, H. Coe, J. Crosier, F. M. Flocke, J. S. Holloway, J. R. Hopkins, J. McQuaid, R. Purvis, B. Rappenglueck, H. B. Singh, N. M. Watson, L. K. Whalley, P. I. Williams, 2006: Establishing Lagrangian connections between observations within air masses crossing the Atlantic during the International Consortium for Atmospheric Research on Transport and Transformation experiment. *Journal of Geophysical Research*, **111**, D23S62, doi: 10.1029/2006JD007540.[4]

Trenberth, K. E., L. Smith, T. Qian, A. Dai, J. Fasullo, 2007: Estimates of the global water budget and its annual cycle using observational and model data. *Journal of Hydrometeorology*, **8**, 758-769.[2]

Molotch, N. P., P. D. Blanken, M. W. Williams, A. A. Turnipseed, R. K. Monson, S. A. Margulis, 2007: Estimating sublimation of intercepted and sub-canopy snow using eddy covariance systems. *Hydrological Processes*, **21 (12)**, 1567-1575, doi: 10.1002/hyp.6719.[2]

vanZadelhoff, G.-J., A. J. Heymsfield, D.-J. P. Donovan, M. J. McGill, 2007: Evaluating lidar-radar microphysics retrieval using in situ measurements. *Journal of Geophysical Research*, **112**, D09213, doi: 10.1029/2006JD007202.[3]

Arellano Jr., A. F., K. Raeder, J. L. Anderson, P. G. Hess, L. K. Emmons, D. P. Edwards, G. G. Pfister, T. L. Campos, G. W. Sachse, 2007: Evaluating model performance of an ensemble-based chemical data assimilation system during INTEX-B field mission. *Atmospheric Chemistry and Physics Discussions*, **7**, 9717-9767.[4]

Ginoux, P., L. W. Horowitz, V. Ramaswamy, I. V. Geogdzhayev, B. N. Holben, G. Stenchikov, X. Tie, 2006: Evaluation of aerosol distribution and optical depth in the Geophysical Fluid Dynamics Laboratory coupled model CM2.1 for present climate. *Journal of Geophysical Research*, **111**, D22210, doi: 10.1029/2005JD006707.[4]

Protat, A., D. Bouniol, A. J. Heymsfield, A. Bansemer, P. Brown, 2007: Evaluation of ice water content retrievals from cloud radar reflectivity and temperature using a large airborne in situ microphysical database. *Journal of Applied Meteorology and Climatology*, **46**, 557-572, doi: 10.1175/JAM2488.1.[3]

Hong, Y., D. J. Gochis, J.-T. Cheng, K.-L. Hsu, S. Soroshian, 2007: Evaluation of PERSIANN-CCS rainfall measurement using the NAME event rain gauge network. *Journal of Hydrometeorology*, **8**, 469-482.[4]

Trenberth, K. E., A. Dai, 2006: Evaluation of the atmospheric water cycle in ERA-40 using observationally-constrained land model results. *GEWEX News*, 16(2), 8-10, 20.[1]

Bousserez, N., J. L. Attie, V. H. Peuch, M. Michou, G. Pfister, D. Edwards, L. Emmons, C. Mari, B. Barret, S. R. Arnold, A. Heckel, A. Richter, H. Schlager, A. Lewis, M. Avery, G. Sachse, E. V. Browell, J. W. Hair, 2007: Evaluation of the MOCAGE chemistry transport model during the ICARTT/ITOP experiment. *Journal of Geophysical Research*, **112**, D10S42, doi: 10.1029/2006JD007595.[4]

Tardif, R., R. M. Rasmussen, 2007: Event-based climatology and typology of fog in the New York City region. *Journal of Applied Meteorology and Climatology*, **46(8)**, 1141-1168.[2]

Prenni, A. J., P. J. DeMott, C. Twohy, M. R. Poellot, S. M. Kreidenweis, D. C. Rogers, S. D. Brooks, M. S. Richardson, A. J. Heymsfield, 2007: Examinations of ice formation processes in Florida cumuli using ice nuclei measurements of anvil ice crystal particle residues. *Journal of Geophysical Research*, **112**, D10221, doi: 10.1029/2006JD007549.[2]

Moeng, C.-H., J. Dudhia, J. Klemp, P. Sullivan, 2007: Examining the two-way grid nesting for large-eddy simulation of the PBL using the WRF model. *Monthly Weather Review*, **135**, 2295-2311, doi: 10.1175/MWR3406.1.[1]

Lu, J., G. Vecchi, T. Reichler, 2007: Expansion of the Hadley cell under global warming. *Geophysical Research Letters*, **34**, L06805, doi: 10.1029/2006GL028443.[4]

Anderson, J., 2007: Exploring the need for localization in ensemble data assimilation using a hierarchical ensemble filter. *Physica D*, **230**, 99-111, doi: 10.1016/j.physd.2006.02.011.[1]

Patra, P. K., J. K. Moore, N. Mahowald, M. Uematsu, S. C. Doney, T. Nakazawa, 2007: Exploring the sensitivity of interannual basin-scale air-sea CO2 fluxes to variability in atmospheric dust deposition using ocean carbon cycle models and atmospheric CO2 inversions. *Journal of Geophysical Research*, **112**, G02012, doi: 10.1029/2006JG000236.[4]

Barnes, L. R., E. C. Gruntfest, M. H. Hayden, D. M. Schultz, C. Benight, 2007: False alarms and close calls: A conceptual model of warning accuracy. *Weather and Forecasting*, **22(5)**, 1140-1147.[2]

Miller, K. A., 2007: Fish stew: Uncertainty, conflicting interests and climate regime shifts. *Advances in Fisheries Economics*, T. Bjorndal, D. Gordon, R. Arnason, and U. R. Somalia, Eds., Blackwell Publishing, 207-221, doi: ISBN 13:978-1-4051-4161-1.[1]

Ortega, J., D. Helmig, A. Guenther, P. Harley, S. Pressley, C. Vogel, 2007: Flux estimates and OH reaction potential of reactive biogenic volatile organic compounds (BVOCs) from a mixed northern hardwood forest. *Atmospheric Environment*, Elsevier Ltd., **41**, 5479-5495, doi: 10.1016/j.atmosenv.2006.12.033.[2]

Borrero, J. M., L. R. Bellot Rubio, D. A. N. Mueller, 2007: Flux tubes as the origin of net circular polarization in sunspot penumbrae. *The Astrophysical Journal*, **666**, L133-L136, doi: 10.1086/521923..[4]

Crowley, S., J.-F. Pinton, A. Pouquet, 2007: Focus on magnetohydrodynamics and the dynamo problem. *New Journal of Physics*, **9**, 304, doi: 10.1088/1367-2630/9/8/E04.[4]

Santer, B. D., T. M. L. Wigley, P. J. Gleckler, C. Bonfils, M. Wehner, K. M. AchutaRao, T. P. Barnett, J. S. Boyle, W. Brueggemann, M. Fiorino, N. Gillett, J. E. Hansen, P. D. Jones, S. A. Klein, G. A. Meehl, S. C. B. Raper, R. W. Reynolds, K. E. Taylor, W. M. Washington, 2006: Forced and unforced ocean temperature changes in the Atlantic and Pacific tropical cyclogenesis regions. *Proceedings of the National Academy of Sciences (PNAS)*, **103**, 13905-13910.[4]

Joy, K. I., M. Miller, H. Childs, E. W. Bethel, J. Clyne, G. Ostrouchov, 2007: Frameworks for visualization at the extreme scale. *Journal of Physics: Conference Series*, Boston, MA, **78**, 012035, doi: 10.1088/1742-6596/78/1/012035.[4]

IPCC, (including E. A. Holland)., 2007: Frequently Asked Questions-A publication to accompany, In, Climate Change 2007, The Physical Science Basis. *Climate Change 2007 - The Physical Science Basis: Working Group I contribution to the Fourth Assessment Report of the IPCC*, X. Dahe, M. Manning, S. Solomon et al., Eds..[1]

Kundzewicz, Z. W., L. J. Mata, N. W. Arnell, P. Doll, P. Kabat, B. Jiminez, K. A. Miller, T. Oki, Z. Sen, I. A. Shiklomanov, 2007: Freshwater resources and their management. Chapter 3. *Climate Change 2007 - Impacts, Adaptation and Vulnerability: Working Group II contribution to the Fourth Assessment Report of the IPCC*, M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. van der Linden, and C. E. Hanson, Eds., Cambridge University Press, 173-210.[4]

Holland, M. M., C. M. Bitz, B. Tremblay, 2006: Future abrupt reductions in the summer Arctic sea ice. *Geophysical Research Letters*, **33**, L23503, doi: 10.1029/2006GL028024.[4]

Meehl, G. A., H. Teng, G. W. Branstator, 2006: Future changes of El Nino in two global coupled climate models. *Climate Dynamics*, **26**, 549-566, doi: 10.1007/s00382-005-0098-0.[1]

Simmons, A., K. E. Trenberth, S. Uppala, 2006: Future needs in atmospheric reanalysis. *EOS, Transactions, American Geophysical Union*, **87**, 583, 587.[3]

Furrer, E. M., R. W. Katz, 2007: Generalized linear modeling approach to stochastic weather generators. *Climate Research*, **34**, 129-144, doi: 10.3354/cr034129.[1]

Alexander, M. J., J. H. Richter, B. R. Sutherland, 2006: Generation and trapping of gravity waves from convection with comparison to parameterization. *Journal of the Atmospheric Sciences*, **63**, 2963-2977.[4]

Fang, X., M. W. Liemohn, J. U. Kozyra, D. S. Evans, A. D. DeJong, B. A. Emery, 2007: Global 30-240 keV proton precipitation in the 17-18 April 2002 geomagnetic storms: 1. Patterns. *Journal of Geophysical Research*, **112**, 5301, doi: 10.1029/2006JA011867.[4]

Kleypas, J. A., C. M. Eakin, 2007: Global and regional threats to coral reefs: Results of a survey of coral reef researchers. *Bulletin of Marine Science*, **80**, 419-436.[3]

Hunke, E. C., M. M. Holland, 2007: Global atmospheric forcing data for Arctic ice-ocean modeling. *Journal of Geophysical Research*, **12**, C04S14, doi: 10.1029/2006JC003640.[3]

Gilman, P. A., P. S. Cally, 2007: Global MHD instabilities of the tachocline. *The Solar Tachocline*, Hughes, David; Rosner, Robert; and Weiss, Nigel, Eds., Cambridge University Press, 1st, 243.[2]

Dikpati, M., P. A. Gilman, 2007: Global solar dynamo models: Simulations and predictions of cyclic photospheric fields and long-term non-reversing interior fields. *New Journal of Physics*, 9, 297, doi: 10.1088/1367-2630/9/8/297.[1]

Crowley, G., C. L. Hackert, R. R. Meier, D. J. Strickland, L. J. Paxton, X. Pi, A. Mannucci, A. B. Christensen, D. Morrison, G. S. Bust, R. G. Roble, N. Curtis, G. Wene, 2006: Global thermosphere-ionosphere response to onset of 20 November 2003 magnetic storm. *Journal of Geophysical Research*, **111**, A10S18, doi: 10.1029/2005JA011518.[4]

Parson, E. A., V. R. Burkett, K. Fisher-Vanden, D. W. Keith, L. O. Mearns, H. M. Pitcher, C. E. Rosenzweig, M. D. Webster, 2007: Global-change scenarios: Their development and use. *Global Change Scenarios: Their Development and Use*, The Climate Change Science Program and the Subcommittee on Global Change Research, 117 pp.[4]

Lane, T. P., R. D. Sharman, 2006: Gravity wave breaking, secondary wave generation, and mixing above deep convection in a three-dimensional cloud model. *Geophysical Research Letters*, **33**, L23813, doi: 10.1029/2006GL027988.[2]

Shiokawa, K., G. Lu, Y. Otsuka, T. Ogawa, M. Yamamoto, N. Nishitani, N. Sato, 2007: Ground observation and AMIE-TIEGCM modeling of a storm-time traveling ionospheric disturbance. *Journal of Geophysical Research - Space Physics*, **112(A5)**, A05308, doi: 10.1029/2006JA011772.[3]

Tanamachi, R. L., H. B. Bluestein, W.-C. Lee, M. Bell, A. Pazmany, 2007: Ground-Based Velocity Track Display (GBVTD) analysis of W-Band Doppler radar data in a tornado near Stockton, Kansas on 15 May 1999. *Monthly Weather Review*, **135**, 783-800, doi: 10.1175/MWR3325.1.[4]

Wakimoto, R. M., H. V. Murphey, C. A. Davis, N. T. Atkins, 2006: High winds generated by bow echoes. Part II: The relationship between the mesovortices and damaging straight-line winds. *Monthly Weather Review*, **134**, 2813-2829.[3]

Levy, M. N., R. D. Nair, H. M. Tufo, 2007: High-order Galerkin methods for scalable global atmospheric models. *Computers and Geosciences*, **33**, 1022-1035, doi: 10.1016/j.cageo.2006.12.004.[2]

Richter, D., P. Weibring, A. Fried, O. Tadanaga, Y. Nishida, M. Asobe, H. Suzuki, 2007: High-power, tunable difference frequency generation source for absorption spectroscopy based on a ridge waveguide periodically poled lithium niobate crystal.

*Optics Express*, **15**, 564-571.[3]

Houze, Jr., R. A., S. S. Chen, B. F. Smull, W.-C. Lee, M. M. Bell, 2007: Hurricane intensity change and eyewall replacement. *Science*, **315**, 1235-1239, doi: 10.1126/science.1135650.[2]

Kelman, I., 2007: Hurricane Katrina disaster diplomacy. *Disasters*, **31(3)**, 288-309.[1]

Qian, T., A. Dai, K. E. Trenberth, 2007: Hydroclimatic trends in the Mississippi River Basin from 1948-2004. *Journal of Climate*, **20**, 4599-4614.[1]

Mininni, P. D., D. C. Montgomery, L. Turner, 2007: Hydrodynamic and magnetohydrodynamic computations inside a rotating sphere. *New Journal of Physics*, **9**, 303, doi: 10.1088/1367-2630/9/8/303.[2]

Snow, J. A., B. G. Heikes, H. Shen, D. W. O'Sullivan, A. Fried, J. Walega, 2007: Hydrogen peroxide, methyl hydroperoxide, and formaldehdye over North America and the North Atlantic. *Journal of Geophysical Research*, **112**, D12S07, doi: 10.1029/2006JD007746.[2]

France, J. L., M. D. King, J. Lee-Taylor, 2007: Hydroxyl (OH) radical production rates in snowpacks from photolysis of hydrogen peroxide (H2O2) and nitrate (NO3). *Atmospheric Environment*, **41**, 5502-5509, doi: 10.1016/j.atmosenv.2007.03.056.[2]

Santer, B. D., C. Mears, F. J. Wentz, K. E. Taylor, P. J. Gleckler, T. M. L. Wigley, T. P. Barnett, J. S. Boyle, W. Brueggemann, N. P. Gillett, S. A. Klein, G. A. Meehl, T. Nozawa, D. W. Pierce, P. A. Stott, W. M. Washington, M. F. Wehner, 2007: Identification of human-induced changes in atmospheric moisture content. *Proceedings of the National Academy of Sciences (PNAS)*, **104**, 15248-15253, doi: 10.1073/pnas.0702872104.[4]

Najjar, R. G., X. Jin, F. Louanchi, O. Aumont, K. Caldeira, S. C. Doney, J. C. Dutay, M. Follows, N. Gruber, F. Joos, K. Lindsay, E. Maier-Reimer, R. J. Matear, K. Matsumoto, P. Monfray, A. Mouchet, J. C. Orr, G. K. Plattner, J. L. Sarmiento, R. Schlitzer, R. D. Slater, M. F. Weirig, Y. Yamanaka, A. Yool, 2007: Impact of circulation on export production, dissolved organic matter, and dissolved oxygen in the ocean: Results from Phase II of the Ocean Carbon-cycle Model Intercomparison Project (OCMIP-2). *Global Biogeochemical Cycles*, **21**, GB3007, doi: 10.1029/2006GB002857.[4]

Rasmussen, R., A. Dai, K. E. Trenberth, 2007: Impact of climate change on precipitation. Chapter 16. *Large-scale Disasters: Prediction, Control and Mitigation*, Mohamed Gad-el-Hak, Ed., Cambridge University Press, 453-472.[1]

Lothon, M., F. Couvreux, S. Donier, F. Guichard, P. Lacarrere, D. H. Lenschow, J. Noilhan, F. Said, 2007: Impact of coherent eddies on airborne measurements of vertical turbulent fluxes. *Boundary-Layer Meteorology*, **124**, 425-447, doi: 10.1007/s10546-007-9182-9.[3]

Yoshioka, M., N. M. Mahowald, A. J. Conley, W. D. Collins, D. W. Fillmore, C. S. Zender, D. B. Coleman, 2007: Impact of desert dust radiative forcing on Sahel precipitation: Relative importance of dust compared to sea surface temperature variations, vegetation changes and greenhouse gas warming. *Journal of Climate*, **20**, 1445-1467, doi: 10.1175/JCL14056.1.[2]

Liu, G., R. Zhang, J.-U. Fan, X. Tie, 2007: Impacts of biogenic emissions on photochemical ozone production in Houston, Texas. *Journal of Geophysical Research*, **112**, D10309, doi: 10.1029/2006JD007924.[2]

Liu, H., J. L. Anderson, Y.-H. Kuo, K. Raeder, 2007: Importance of forecast error multivariate correlations in idealized assimilations of GPS radio occultation data with the ensemble adjustment filter. *Monthly Weather Review*, **135**, 173-185, doi: 10.1175/MWR3270.1.[1]

Ammann, C. M., E. R. Wahl, 2007: Importance of the geophysical context for statistical evaluation of climate reconstruction procedures. *Climatic Change*, doi: doi:10.1007/s10584-007-9726-x.[2]

Matsunaga, S. N., A. B. Guenther, Y. Izawa, C. Wiedinmyer, J. P. Greenberg, K. Kawamura, 2007: Importance of wet precipitation as a removal and transport process for atmospheric water soluble carbonyls. *Atmospheric Environment*, **41**, 790-796, doi: 10.1016/j.atmosenv.2006.08.054.[2]

Nicolsky, D. J., V. E. Romanovsky, V. A. Alexeev, D. M. Lawrence, 2007: Improved modeling of permafrost dynamics in a GCM land-surface scheme. *Geophysical Research Letters*, **34**, L08501, doi: doi:/10.1029/2007GL029525.[3]

Hacker, J. P., J. L. Anderson, M. Pagowski, 2007: Improved vertical covariance estimates for ensemble-filter assimilation of near-surface observations. *Monthly Weather Review*, **135**, 1021-1036.[3]

Mena-Carrasco, M., Y. Tang, G. R. Carmichael, T. Chai, N. Thongbongchoo, J. E. Campbell, S. Kulkarni, L. Horowitz, J. Vukovich, M. Avery, W. Brune, J. E. Dibb, L. Emmons, F. Flocke, G. W. Sachse, D. Tan, R. Shetter, R. W. Talbot, D. G. Streets, G. Frost, D. Blake, 2007: Improving regional ozone modeling through systematic evaluation of errors using the aircraft observations during the International Consortium for Atmospheric Research on Transport and Transformation. *Journal of Geophysical Research*, **112**, D12S19, doi: 10.1029/2006JD007762.[4]

Moser, S. C., 2007: In the long shadows of inaction: The quiet building of a climate protection movement in the United States. *Global Environmental Politics*, **7(2)**, 124-144.[1]

Lawrence, D. M., A. G. Slater, 2007: Incorporating organic soil into a global climate model. *Climate Dynamics*, doi: doi:/10.1007/s00382-007-0278-1.[3]

LeMone, M. A., F. Chen, J. G. Alfieri, M. Tewari, B. Geerts, Q. Miao, R. L. Grossman, R. L. Coulter, 2007: Influence of land cover and soil moisture on the horizontal distribution of sensible and latent heat fluxes in southeast Kansas during IHOP_2002 and CASES-97. *Journal of Hydrometeorology*, **8**, 68-87, doi: 10.1175/JHM554.1.[4]

Tang, Y., G. R. Carmichael, N. Thongboonchoo, T. Chai, L. W. Horowitz, R. B. Pierce, J. A. Al-Saadi, G. Pfister, J. M. Vukovich, M. A. Avery, G. W. Sachse, T. B. Ryerson, J. S. Holloway, E. L. Atlas, F. M. Flocke, R. J. Weber, L. G. Huey, J. E. Dibb, D. G. Streets, W. H. Brune, 2007: Influence of lateral and top boundary conditions on regional air qualify prediction: A multiscale study coupling regional and global chemical transport models. *Journal of Geophysical Research*, **112**, D10S18, doi: 10.1029/2006JD007515.[4]

Refaat, T. F., S. Ismail, T. L. Mack, M. Nurul Abedin, S. D. Mayor, S. M. Spuler, U. N. Singh, 2007: Infrared phototransistor validation for atmospheric remote sensing application using the Raman-shifted eye-safe aerosol lidar. *Optical Engineering*, **46(08)**, 86001, doi: 10.1117/12.774553.[4]

Kasahara, A., 2007: Initial-value approach to study the inertio-gravity waves without the 'traditional approximation'. *Journal of Computational Physics*, **225**, 2175-2197, doi: 10.1016/j.jcp.2007.03.006.[1]

Chanin, M.-L., G. P. Brasseur, 2007: Interaction entre la chimie atmospherique et le climat. *Comprendre le changement climatique*, Odile Jacob Publishing, 201-214.[3]

Clyne, J., P. Mininni, A. Norton, M. Rast, 2007: Interactive desktop analysis of high resolution simulations: Applications to turbulent plume dynamics and current sheet formation. *New Journal of Physics*, **9**, 301, doi: 10.1088/1367-2630/9/8/301.[2]

Behrendt, A., V. Wufmeyer, P. D. Girolamo, C. Kiemle, H.-S. Bauer, T. Schaberl, D. Summa, D. N. Whiteman, B. B. Demoz, E. V. Browell, S. Ismail, R. Ferrare, S. Kooi, G. Ehret, J. Wang, 2007: Intercomparison of water vapor data measured with lidar during IHOP_2002, Part 1: Airborne to ground-based lidar systems and comparisons with chilled-mirror hygrometer radiosondes. *Journal of Atmospheric and Oceanic Technology*, **24**, 37700, doi: 10.1175/JTECH1924.1.[4]

Han, W., G. A. Meehl, A. Hu, 2006: Interpretation of tropical thermocline cooling in the Indian and Pacific oceans during recent decades. *Geophysical Research Letters*, **33**, L23615, doi: 10.1029/2006GL027892.[2]

Zhan, R., J. Li, A. Gettelman, 2006: Intraseasonal variations of upper tropospheric water vapor in Asian monsoon region. *Atmospheric Chemistry and Physics Discussions*, 6, 8069-8095.[2]

Dilling, L., S. C. Moser, 2007: Introduction. *Creating a Climate for Change: Communicating Climate Change and Facilitating Social Change*, S. C. Moser and L. Dilling, Ed., Cambridge University Press, 1-27.[2]

Turquety, S., J. A. Logan, D. J. Jacob, R. C. Hudman, F. Y. Leung, C. L. Heald, R. M. Yantosca, S. Wu, L. K. Emmons, D. P. Edwards, G. W. Sachse, 2007: Inventory of boreal fire emissions for North America in 2004: Importance of peat burning and pyroconvective injection. *Journal of Geophysical Research*, **112**, D12S03, doi: 10.1029/2006JD007281.[4]

Mininni, P. D., 2007: Inverse cascades and alpha effect at a low magnetic Prandtl number. *Physical Review E*, **76**, 026316, doi: 10.1103/PhysRevE.76.026316.[1]

Mikaloff-Fletcher, S. E., N. Gruber, A. R. Jacobson, M. Gloor, S. C. Doney, S. Dutkiewicz, M. Gerber, M. Follows, F. Joos, K. Lindsay, D. Menemenlis, A. Mouchet, S. A. Muller, J. L. Sarmiento, 2007: Inverse estimates of the oceanic sources and sinks of natural CO2 and the implied oceanic carbon transport. *Global Biogeochemical Cycles*, **21**, GB1010, doi: 10.1029/2006GB002751.[4]

Dennis, J. M., 2007: Inverse space-filling curve partitioning of a global ocean model. *Proc. 21st IEEE International Parallel and Distributed Processing Symposium*, Long Beach, CA, Institute of Electrical and Electronics Engineers, CdRom.[1]

Cassou, C., C. Deser, M. A. Alexander, 2007: Investigating the impact of reemerging sea surface temperature anomalies on the winter atmospheric circulation over the North Atlantic. *Journal of Climate*, **20**, 3510-3526.[3]

Richmond, A. D., 2007: Ionosphere. *Encyclopedia of Geomagnetism and Paleomagnetism*, D. Gubbins and E. Herrero-Bervera, Ed., Springer-Dordrecht, 69, 452-454.[1]

Kelman, I., M. Davies, T. Mitchell, I. Orr, B. Conrich, 2006: Island disaster para-diplomacy in the Commonwealth. *The Round Table: Commonwealth Journal of International Affairs*, **95(386)**, 561-574.[3]

Kelman, I., 2006: Island security and disaster diplomacy in the context of climate change. *Cahiers de la Securite*, **63**, 61-94.[1]

Otto-Bliesner, B. L., C. D. Hewitt, T. M. Marchitto, E. Brady, A. Abe-Ouchi, M. Crucifix, S. Murakami, S. L. Weber, 2007: Last glacial maximum ocean thermohaline circulation: PMIP2 model intercomparisons and data constraints. *Geophysical Research Letters*, **34**, L12706, doi: 10.1029/2007GL029475.[3]

Kiemle, C., G. Ehret, A. Fix, M. Wirth, G. Poberaj, R. M. Hardesty, W. Brewer, C. Senff, M. LeMone, 2007: Latent Heat Flux Profiles from Collocated Airborne Water Vapor and Wind Lidars during IHOP. *Journal of Atmospheric and Oceanic Technology*, **24**, 627-639.[3]

Rotunno, R., R. A. Houze, 2007: Lessons on orographic precipitation from the Mesoscale Alpine Programme. *Quarterly Journal of the Royal Meteorological Society*, **133**, 811-830, doi: 10.1002/qj.67.[2]

Gattuso, J. P., B. Gentili, C. M. Duarte, J. A. Kleypas, J. J. Middelburg, D. Antoine, 2006: Light availability in the coastal ocean: Impact on the distribution of benthic photosynthetic organisms and their contribution to primary production. *Biogeosciences*, **3**, 489-513.[2]

Galbavy, E. S., C. Anastasio, B. L. Lefer, S. R. Hall, 2007: Light penetration in the snowpack at Summit, Greenland: Part 1 Nitrite and hydrogen peroxide photolysis. *Atmospheric Environment*, **41**, 5077-5090, doi: 10.1016/j.atmosenv.2006.04.072.[2]

Galbavy, E. S., C. Anastasio, B. L. Lefer, S. R. Hall, 2007: Light penetration in the snowpack at Summit, Greenland: Part 2 Nitrate photolysis. *Atmospheric Environment*, **41**, 5091-5100, doi: 10.1016/j.atmosenv.2006.01.066.[2]

Barthe, C., J. P. Pinty, C. Mari, 2007: Lightning-produced Nox in an explicit electrical scheme tested in a stratosphere-troposphere experiment: Radiation, aerosols, and ozone case study. *Journal of Geophysical Research*, **112**, D04302, doi: 10.1029/2006JD007402.[3]

Berner, J., G. Branstator, 2007: Linear and nonlinear signatures in the planetary wave dynamics of an AGCM: Probability density functions. *Journal of the Atmospheric Sciences*, **46**, 117-136.[3]

Borrero, J. M., S. Tomczyk, A. Norton, T. Darnell, J. Schou, P. Scherrer, R. Bush, Y. Liu, 2007: Magnetic field vector retrieval with the Helioseismic and Magnetic Imager. *Solar Physics*, **240**, 177-196, doi: 10.1007/s11207-006-0219x.[4]

Mininni, P. D., D. C. Montgomery, 2006: Magnetohydrodynamic activity inside a sphere. *Physics of Fluids*, **18**, 116602, doi: 10.1063/1.2393438.[2]

Alexakis, A., 2007: Marginally unstable Holmboe modes. *Physics of Fluids*, **19**, 054105, doi: 10.1063/1.2730545.[1]

Tomczyk, S., 2007: Measurement errors in coronal magnetic field parameters. *COronal Solar Magnetism Observatory (COSMO) Web Site*, COSMO TN #1, 9pp..[1]

Kim, S., L. G. Huey, R. E. Stickel, D. J. Tanner, J. H. Crawford, J. R. Olson, G. Chen, W. H. Brune, X. Ren, R. Lesher, P. J. Wooldridge, T. H. Bertram, A. Perring, R. C. Cohen, B. L. Lefer, R. E. Shetter, M. Avery, G. Diskin, I. Sokolik, 2007: Measurement of HO2NO2 in the free troposphere during the Intercontinental Chemical Transport Experiment- North America 2004. *Journal of Geophysical Research*, **112**, D12S01, doi: 10.1029/2006JD007676.[4]

Emmons, L. K., G. G. Pfister, D. P. Edwards, J. C. Gille, G. Sachse, D. Blake, S. Wofsy, C. Gerbig, D. Matross, P. Nedelec, 2007: Measurements of Pollution in the Troposphere (MOPITT) validation exercises during summer 2004 field campaigns over North America. *Journal of Geophysical Research*, **112**, D12S02, doi: 10.1029/2006JD007833.[4]

Doney, S. C., S. Yeager, G. Danabasoglu, W. G. Large, J. C. McWilliams, 2007: Mechanisms governing interannual variability of upper ocean temperature in a global ocean hindcast simulation. *Journal of Physical Oceanography*, **37**, 1918-1938.[4]

Friedli, H. R., L. F. Radke, N. J. Payne, D. J. McRae, T. J. Lynham, T. W. Blake, 2007: Mercury in vegetation and organic soil at an upland boreal forest site in Prince Albert National Park, Saskatchewan, Canada. *Journal of Geophysical Research*, **112**, G01004, doi: 10.1029/2005JG000061.[3]

Biello, J. A., A. J. Majda, M. W. Moncrieff, 2007: Meriodional momentum flux and super-rotation in the multi-scale IPESD MJO model. *Journal of the Atmospheric Sciences*, **64**, 1636-1651.[2]

Xu, J., H.-L. Liu, W. Yuan, A. K. Smith, R. G. Roble, C. J. Mertens, J. M. Russell III, M. G. Mlynczak, 2007: Mesopause structure from Thermosphere, Ionosphere, Mesosphere, Energetics, and Dynamics (TIMED)/Sounding of the Atmosphere using Broadband Emission Radiometry (SABER) observations. *Journal of Geophysical Research*, **112**, D09102, doi: 10.1029/2006JD007711.[4]

Conzemius, R. J., R. W. Moore, M. T. Montgomery, C. A. Davis, 2007: Mesoscale convective vortex formation in a weakly sheared moist neutral environment. *Journal of the Atmospheric Sciences*, **64**, 1443-1466, doi: 10.1175/JAS3898.1.[4]

Davis, C. A., S. B. Trier, 2007: Mesoscale convective vortices observed during BAMEX. Part I: Kinematic and thermodynamic structure. *Monthly Weather Review*, **135**, 2029-2049, doi: 10.1175/MWR3398.1.[1]

Trier, S. B., C. A. Davis, 2007: Mesoscale convective vortices observed during BAMEX. Part II: Influences on secondary deep convection. *Monthly Weather Review*, **135**, 2051-2075, doi: 10.1175/MWR3399.1.[1]

Zhang, F., N. Bei, R. Rotunno, C. Snyder, C. C. Epifanio, 2007: Mesoscale predictability of moist baroclinic waves: Convection-permitting experiments and multistage error growth dynamics. *Journal of the Atmospheric Sciences*, **64**, 3579-3594.[4]

Jackman, C. H., R. G. Roble, E. L. Fleming, 2007: Mesospheric dynamical changes induced by the solar proton events in October-November 2003. *Geophysical Research Letters*, **34**, 4812, doi: 10.1029/2006GL028328.[3]

Riggin, D. M., H. L. Liu, R. S. Lieberman, R. G. Roble, J. M. Russell III, C. J. Mertens, M. G. Mlynczak, D. Pancheva, S. J. Franke, Y. Murayama, A. H. Manson, C. E. Meek, R. A. Vincent, 2006: Mesospheric surf zone and temperature inversion layers in early November 1994. *Journal of Atmospheric and Terrestrial Physics*, **68**, 1752-1763.[4]

Donkelaar, A. V., R. V. Martin, R. J. Park, C. L. Heald, T.-M. Fu, H. Liao, A. Guenther, 2007: Model evidence for a significant source of secondary organic aerosol from isoprene. *Atmospheric Environment*, **41**, 1267-1274, doi: 10.1016/j.atmosenv.2006.09.051.[4]

Seager, R., M. Ting, I. Held, T. Kushnir, J. Lu, G. Vecchi, H.-P. Huang, N. Harnik, A. Leetmaa, N.-C. Lau, C. Li, J. Velez, N. Naik, 2007: Model projections of an imminent transition to a more arid climate in southwestern North America. *Science*, **316**, 1181-1184, doi: 10.1126/science/1139601.[4]

Hsu, H., L.-Y. Oey, W. Johnson, C. Dorman, R. Hodur, 2007: Model wind over the Central and Southern California coastal ocean. *Monthly Weather Review*, **135**, 1931-1944, doi: 10.1175/MWR3389.1.[4]

Maruyama, N., S. Sazykin, R. W. Spiro, D. Anderson, A. Anghel, R. A. Wolf, F. Toffoletto, T. J. Fuller-Rowell, M. Codrescu, A. D. Richmond, G. H. Millward, 2007: Modeling storm-time electrodynamics of the low latitude ionosphere-thermosphere system: Can long-lasting disturbance electric fields be accounted for? *Journal of Atmospheric and Terrestrial Physics*, **69**, 1182-1199, doi: 10.1016/j.jastp.2006.08.020.[4]

Hurtaud, Y., C. Peymirat, A. D. Richmond, 2007: Modelling seasonal and diurnal effects on the magnetospheric and ionospheric plasma dynamics. *Journal of Geophysical Research*, **112**, A09217, doi: 10.1029/2007JA012257.[3]

Bloomfield, D. S., S. K. Solanki, A. Lagg, J. M. Borrero, P. S. Cally, 2007: Modified p-modes in penumbral filaments? *Astronomy and Astrophysics*, **469**, 1155-1161, doi: 10.1051/0004-6361:20077330.[4]

Song, I.-S., H.-Y. Chun, R. R. Garcia, B. A. Boville, 2006: Momentum flux spectrum of convectively forced internal gravity waves and its application to gravity wave drag parameterization, Part II: Impacts in a GCM (WACCM). *Journal of the Atmospheric Sciences*, **64**, 2286-2308, doi: 10.1175/JAS3954.1.[2]

Trenberth, K. E., B. Moore, T. R. Karl, C. Nobre, 2006: Monitoring and prediction of the Earth's climate: A future perspective. *Journal of Climate (CLIVAR special issue)*, **19**, 5001-5008, doi: 10.1175/JCLI3897.1.[4]

Chervenak, A., J. M. Schopf, M.-H. Su, S. Bharathi, L. Cinquini, M. D'Arcy, N. Miller, D. Bernholdt, 2006: Monitoring the Earth system grid with MDS4. *Proc. 2nd IEEE International Conference on e-Science and Grid Computing*, Amsterdam, Institute of Electrical and Electronics Engineers, 68-69, doi: 10.1109/E-SCIENCE.2006.261153.[4]

Ray, A. J., G. M. Garfin, L. Brito-Castillo, M. Cortez-Vasquez, H. F. Diaz, J. Garatuza-Payan, D. J. Gochis, R. Lobato-Sanchez, R. Varady, C. J. Watts, 2007: Monsoon region climate applications: Integrating climate science with regional planning and policy. *Bulletin of the American Meteorological Society*, **88**, 933-935.[4]

Moser, S. C., 2007: More bad news: The risk of neglecting emotion responses to climate change information. *Creating a Climate for Change: Communicating Climate Change and Facilitating Social Change*, S. C. Moser and L. Dilling, Ed., Cambridge University Press, 64-80.[1]

Richels, R., A. S. Manne, T. M. L. Wigley, 2007: Moving beyond concentrations: The challenge of limiting temperature change. *Human Induced Climate Change: An Interdisciplinary Assessment*, M. Schlesinger, H. Kheshgi, J. Smith, F. de la Chesnaye, J. M. Reilly, T. Wilson and C. Kolstad, Eds., Cambridge University Press, 387-402.[4]

Smolarkiewicz, P. K., L. G. Margolin, 2007: MPDATA, Chapter 4d. *Implicit Large Eddy Simulation: Computing Turbulent Fluid Dynamics*, F. F. Grinstein, L. Margolin, and W. Rider, Eds., Cambridge University Press, 154-168.[3]

Smith, S. J., T. M. L. Wigley, 2006: Multi-gas forcing stabilization with MiniCAM. *The Energy Journal*, **Special Issue**, 373-391.[3]

Swenson, S., J. Wahr, 2007: Multi-sensor analysis of water storage variations of the Caspian Sea. *Geophysical Research*

*Letters*, **34**, L16401, doi: 10.1029/2007/GL030733.[3]

Eyring, V., D. W. Waugh, G. E. Bodeker, E. Cordero, H. Akiyoshi, J. Austin, S. R. Beagley, B. A. Boville, P. Braesicke, C. Bruehl, N. Butchart, M. P. Chipperfield, M. Dameris, R. Deckert, M. Deushi, S. M. Frith, R. R. Garcia, A. Gettelman, M. A. Giorgetta, D. E. Kinnison, E. Mancini, E. Manzini, D. R. Marsh, S. Matthes, T. Nagashima, P. A. Newman, J. E. Nielsen, S. Pawson, G. Pitari, D. A. Plummer, E. Rozanov, M. Schraner, J. F. Scinocca, K. Semeniuk, T. G. Shepherd, K. Shibata, B. Steil, R. S. Stolarski, W. Tian, M. Yoshiki, 2007: Multimodel projections of stratospheric ozone in the 21st century. *Journal of Geophysical Research*, **112**, D16303, doi: 10.1029/2006JD008332.[4]

Shindell, D. T., G. Faluvegi, D. S. Stevenson, M. C. Krol, L. K. Emmons, J.-F. Lamarque, G. Petron, F. J. Dentener, K. Ellingsen, M. G. Schultz, O. Wild, M. Amann, C. S. Atherton, D. J. Bergmann, I. Bey, T. Butler, J. Cofala, W. J. Collins, R. G. Derwent, R. M. Doherty, J. Drevet, H. J. Eskes, A. M. Fiore, M. Gauss, D. A. Hauglustine, L. W. Horowitz, I. S. A. Isaksen, M. G. Lawrence, V. Montanaro, J.-F. Mueller, G. Pitari, M. J. Prather, J. A. Pyle, S. Rast, J. M. Rodriquez, M. G. Sanderson, N. H. Savage, S. E. Strahan, K. Sudo, S. Szopa, N. Unger, T. P. C. Van Noije, G. Zeng, 2006: Multimodel simulations of carbon monoxide: Comparison with observations and projected near-future changes. *Journal of Geophysical Research*, **111**, D19306, doi: 10.1029/2006JD007100.[4]

Furrer, R., S. R. Sain, D. Nychka, G. A. Meehl, 2007: Multivariate Bayesian analysis of atmosphere-ocean general circulation models. *Environmental and Ecological Statistics*, **14(3)**, 249-266, doi: doi:10.1007/s10651-007-0018-z.[2]

LeMone, M. A., F. Chen, J. Alfieri, R. Cuenca, Y. Hagimoto, P. Blanken, D. Niyogi, S. Kang, K. Davis, R. Grossman, 2007: NCAR/CU surface, soil, and vegetation observation network during the IHOP_2002 field campaign. *Bulletin of the American Meteorological Society*, **88**, 65-81.[4]

Carter, T. R., R. N. Jones, X. Lu, S. Bhadwal, C. Conde, L. O. Mearns, B. C. O'Neill, M. D. A. Rousevell, M. B. Zurek, 2007: New assessment methods and the characterization of future conditions. Chapter 2. *Climate Change 2007 - Impacts, Adaptation and Vulnerability: Working Group II contribution to the Fourth Assessment Report of the IPCC*, M. L. Parry, O. F. Canziani, J .P. Palutikov, P .F. Vander Linden, C. E. Hanson, Eds., Cambridge University Press, Fourth Assessment Re, 133-171.[4]

Rasmussen, R. M., C. Wade, F. Hage, S. Landolt, M. Tryhane, J. Cole, A. Ramsay, D. Fleming, R. K. Moore, A. Davis, B. Reis, T. Lisi, M. Kjolleberg, K. M. Rosenlund, 2006: New ground deicing hazard associated with freezing drizzle ingestion by jet engines. *Journal of Aircraft*, **43(5)**, 1448-1457.[3]

Farahani, E., H. Fast, R. L. Mittermeier, Y. Makino, K. Strong, C. McLandress, T. G. Shepherd, M. P. Chipperfield, J. W. Hannigan, M. T. Coffey, S. Mikuteit, F. Hase, T. Blumenstock, U. Raffalski, 2007: Nitric acid measurements at Eureka obtained in winter 2001-2002 using solar and lunar Fourier transform infrared absorption spectroscopy: Comparisons with observations at Thule and Kiruna and with results from three-dimensional models. *Journal of Geophysical Research*, **112**, D01305, doi: 10.1029/2006JD007096.[4]

Borbor-Cordova, M. J., E. W. Boyer, W. H. McDowell, C. A. Hall, 2006: Nitrogen and phosphorus budgets for a tropical watershed impacted by agricultural land use: Guayas, Ecuador. *Nitrogen Cycling in the Americas: Natural and Anthropogenic Influences and Controls*, L. Martinelli and R. Howarth, Ed., Springer, 135-161, doi: ISBN 978-1-4020-4717-6.[2]

Borbor-Cordova, M., E. W. Boyer, W. H. McDowell, C. A. Hall, 2006: Nitrogen and phosphorus budgets for a tropical watershed impacted by agricultural land use: Guayas, Ecuador. *Biogeochemistry*, **79**, 135-161, doi: 10.1007/s10533-006-9009-7.[2]

Moore, J. K., S. C. Doney, K. Lindsay, N. Mahowald, A. F. Michaels, 2006: Nitrogen fixation amplifies the ocean biogeochemical response to decadal timescale variations in mineral dust deposition. *Tellus*, **58B**, 560-572.[4]

Miesch, M. S., P. A. Gilman, M. Dikpati, 2007: Nonlinear evolution of global magnetoshear instabilities in a three-dimensional thin-shell model of the solar tachocline. *The Astrophysical Journal, Supplement Series*, **168**, 337, doi: 10.1086/509880.[1]

Kwon, Y.-O., C. Deser, 2007: North Pacific decadal variability in the Community Climate System Model Version 2. *Journal of Climate*, **20**, 2416-2433.[1]

Powers, J. G., 2007: Numerical Prediction of an Antarctic severe wind event with the weather research and forecasting (WRF) model. *Monthly Weather Review*, **135**, 3134-3157, doi: 10.1175/MWR3459.1.[1]

Andrejczuk, M., W. W. Grabowski, S. P. Malinowski, P. K. Smolarkiewicz, 2006: Numerical simulation of cloud-clear air interfacial mixing: Effects on cloud microphysics. *Journal of the Atmospheric Sciences*, **63**, 3204-3225.[2]

Lane, T. P., R. Sharman, R. G. Frehlich, J. M. Brown, 2006: Numerical simulations of the wake of Kauai with implications for the Helios flights. *Journal of Applied Meteorology and Climatology*, **45**, 1313-1331.[4]

Kang, S.-L., K. Davis, M. LeMone, 2007: Observation of variable ABL structures over a heterogeneous land surface. *Journal of Hydrometeorology*, **8**, 221-244.[2]

Randel, W. J., D. J. Seidel, L. L. Pan, 2007: Observational characteristics of double tropopauses. *Journal of Geophysical Research*, **112**, D07309, doi: 10.1029/2006JD007904.[3]

Stott, P. A., J. F. Mitchell, M. R. Allen, T. L. Delworth, J. M. Gregory, G. A. Meehl, B. D. Santer, 2006: Observational constraints on past attributable warming and predictions of future global warming. *Journal of Climate*, **19**, 3055-3069, doi: 10.1175/JCLI3783.1.[4]

Horowitz, L. W., A. M. Fiore, G. P. Milly, R. C. Cohen, A. Perring, P. J. Wooldridge, P. G. Hess, L. K. Emmons, J.-F. Lamarque, 2007: Observational constraints on the chemistry of isoprene nitrates over the eastern United States. *Journal of Geophysical Research*, **112**, D12S08, doi: 10.1029/2006JD007747.[4]

Pierce, D. W., T. P. Barnett, K. AchutaRao, P. Gleckler, J. Gregory, W. M. Washington, 2006: Observations and model results. *Journal of Climate*, **19**, 1873-1900.[3]

Bowman, K. P., L. L. Pan, T. Campos, R. Gao, 2007: Observations of fine-scale transport structure in the upper troposphere from the High-performance Instrumented Airborne Platform for Environmental Research. *Journal of Geophysical Research*, American Geophysical Union, **112**, D18111, doi: 10.1029/2007JD008685.[4]

Ikeda, K., R. M. Rasmussen, W. Hall, G. Thompson, 2007: Observations of freezing drizzle in extratropical cyclonic storms during IMPROVE-2. *Journal of the Atmospheric Sciences*, **64**, 3016-3043, doi: 10.1175/JAS3999.1.[1]

Judge, P., 2006: Observations of the solar chromosphere. *Extended Abstracts, Solar MHD Theory and Observations: A High Spatial Resolution Perspective, Astronomical Society of the Pacific Conference Series*, Sunspot, NM, Astronomical Society of the Pacific, 354, 259.[1]

Pawloska, H., W. W. Grabowski, J.-L. Brenguier, 2006: Observations of the width of cloud droplet spectra in stratocumulus. *Geophysical Research Letters*, **33**, L19819, doi: 10.1029/2006GL026841.[4]

Trenberth, K. E., P. D. Jones, P. Ambenje, R. Bojariu, D. Easterling, A. K. Tank, D. Parker, F. Rahimzadeh, J. A. Renwick, M. Rusticucci, B. Soden, P. Zhai, 2007: Observations: Surface and Atmospheric Climate Change. Chapter 3. *Climate Change 2007 - The Physical Science Basis: Working Group I contribution to the Fourth Assessment Report of the IPCC*, S. Solomon, D. Qin, M. Manning, Z. Chen, M. C. Marquis, K. B. Avery, M. Tignor, and H. L. Miller, Eds., IPCC, Cambridge University Press, 235-236.[4]

Trenberth, K. E., 2006: Observed changes to the climate and their causes. Chapter 9. *Confronting Climate Change: Critical Issues for New Zealand*, R. Chapman, J. Boston, and M. Schwass, Eds., Victoria University Press, 93-102, doi: ISBN 0 86473 546 4.[1]

Jochum, M., M. Cronin, S. Kessler, D. Shea, 2007: Observed temperature advection by tropical instability waves. *Geophysical Research Letters*, **34**, L09604, doi: 10.1029/2007GL029416.[3]

Wu, W., G. Danabasoglu, W. G. Large, 2007: On the effects of parameterized Mediterranean overflow on North Atlantic ocean circulation and climate. *Ocean Modelling*, **19**, 31-52, doi: 10.1016/j.ocemod.2007.06.003.[1]

Liu, H.-L., 2007: On the large wind shear and fast meridional transport above the mesopause. *Geophysical Research Letters*, **34**, 8815, doi: 10.1029/2006GL028789.[1]

MacGregor, K. B., S. Jackson, A. Skumanich, T. S. Metcalfe, 2007: On the structure and properties of differentially rotating main-sequence stars in the 1-2 M_sun range. *The Astrophysical Journal*, **663**, 560-572, doi: 10.1086/518303.[3]

Wang, X., C. Snyder, T. M. Hamill, 2007: On the theoretical equivalence of differently proposed ensemble/3D-Var hybrid analysis schemes. *Monthly Weather Review*, **135**, 222-227.[3]

Ehhalt, D. H., F. Rohrer, D. R. Blake, D. E. Kinnison, P. Konopka, 2007: On the use of nonmethane hydrocarbons for the determination of age spectra in the lower stratosphere. *Journal of Geophysical Research*, **112**, D12208, doi: 10.1029/2006JD007686.[4]

Jimenez-Reyes, S. J., W. J. Chaplin, Y. Elsworth, R. A. Garcia, R. Howe, H. Socas-Navarro, T. Toutain, 2007: On the variation of the peak asymmetry of low-l solar p modes. *The Astrophysical Journal*, **654**, 1135, doi: 10.1086/509700.[4]

McFarlane, S. A., W. Grabowski, 2007: Optical properties of shallow tropical cumuli derived from ARM ground-based remote sensing. *Geophysical Research Letters*, **34**, L06808, doi: 10.1029/2006GL028767.[3]

St-Cyr, A., M. J. Gander, S. J. Thomas, 2006: Optimized restricted additive Schwarz. *Domain Decomposition Methods in Science and Engineering XVI*, O. B. Widlund, D. E. Keyes, Eds., Springer-Verlag, 55, 213-220, doi: ISBN 978-3-540-34468-1.[2]

Rempel, M., 2007: Origin of solar torsional oscillations. *The Astrophysical Journal*, **655**, 651-659, doi: 10.1086/509866.[1]

Wigley, T. M. L., R. Richels, J. A. Edmonds, 2007: Overshoot pathways to CO2 stabilization in a multi-gas context. *Human Induced Climate Change: An Interdisciplinary Assessment*, M. Schlesinger, H. Kheshgi, J. Smith, F. de la Chesnaye, J. M. Reilly, T. Wilson and C. Kolstad, Eds., Cambridge University Press, 84-92.[3]

Pfister, G. G., L. K. Emmons, P. G. Hess, R. Honrath, J.-F. Lamarque, M. Val Martin, R. C. Owen, M. A. Avery, E. V. Browell, J. S. Holloway, P. Nedelec, R. Purvis, T. B. Ryerson, G. W. Sachse, H. Schlager, 2006: Ozone production from the 2004 North American boreal fires. *Journal of Geophysical Research*, **111**, D24S07, doi: 10.1029/2006JD007695.[4]

Hess, P. G., J.-F. Lamarque, 2007: Ozone source attribution and its modulation by the Arctic oscillation during the spring months. *Journal of Geophysical Research*, **112**, D11303, doi: 10.1029/2006JD007557.[1]

Jansen, E., J. Overpeck, K. R. Briffa, J. C. Duplessy, F. Joos, V. Masson-Delmotte, D. O. Olago, B. L. Otto-Bliesner, W. R. Peltier, S. Rahmstorf, R. Ramesh, D. Raynaud, D. H. Rind, O. Solomina, R. Villalba, D. Zhand, 2007: Palaeoclimate. Chapter 6. *Climate Change 2007 - The Physical Science Basis: Working Group I contribution to the Fourth Assessment Report of the IPCC*, S. Solomon, D. Qin, M. Manning, Z. Chen, M. C. Marquis, K. B. Avery, M. Tignor, and H. L. Miller, Eds., IPCC, Cambridge University Press, 433-497.[3]

Wilder, M., P. Romero-Lankao, 2006: Paradoxes of decentralization: Water reform and social implications in Mexico. *World Development*, **34(11)**, 1977-1995, doi: 10.1016/j.worlddev.2005.22.026.[2]

St-Cyr, A., S. J. Thomas, 2006: Parallel atmospheric modeling with high-order continuous and discontinuous Galerkin methods. *Parallel Computational Fluid Dynamics: Theory and Applications*, A. Deane, G. Brenner, A. Ecer, D. Emerson, J. McDonough, J. Periaux, N. Satofuka, D. Tromeur-Dervout, Eds., Elsevier Science, 485-492, doi: ISBN10-0-444-52206-9.[1]

Zobitz, J. M., S. P. Burns, J. Ogee, M. Reichstein, D. R. Bowling, 2007: Partitioning net ecosystem exchange of CO2: a comparison of a Bayesian/isotope approach to environmental regression methods. *Journal of Geophysical Research*, **112**, G03013.[3]

Hacker, J., D. Rostkier-Edelstein, 2007: PBL state estimation with surface observations, a column model, and an ensemble Kalman filter. *Monthly Weather Review*, **135**, 2958-2972.[2]

Verver, G., M. Fujiwara, P. Dolmans, C. Becker, P. Fortuin, L. Miloshevich, 2006: Performance of the Vaisala RS80 A/H and RS90 Humicap sensors and the Meteolabor "Snow White" chilled-mirror hygrometer in Paramaribo, Suriname. *Journal of Atmospheric and Oceanic Technology*, **23**, 1506-1518.[3]

Serreze, M. C., M. M. Holland, J. Stroeve, 2007: Perspectives on the Arctic's shrinking sea-ice cover. *Science*, **315**, 1533-1536.[4]

Nair, R. D., H. M. Tufo, 2007: Petascale atmospheric general circulation models. *Journal of Physics: Conference Series*, Boston, MA, **78**, 012078, doi: 10.1088/1742-6596/78/1/012078.[1]

Fernandez, R. p., G. G. Palancar, S. Madronich, B. M. Toselli, 2007: Photolysis rate coefficients in the upper atmosphere: Effect of line by line calculations of the O2 absorption cross section in the Schumann-Runge bands. *Journal of Quantitative Spectroscopy and Radiative Transfer*, Elsevier Ltd., **104**, 1-11, doi: 10.1016/j.jqsrt.2006.08.005.[2]

Kay, J. E., M. Baker, D. Hegg, 2007: Physical controls on orographic cirrus inhomogeneity. *Atmospheric Chemistry and Physics*, **7**, 3771-3781.[2]

Lin, C. H., W. Wang, M. E. Hagan, C. C. Hsiao, T. J. Immel, M. Hsu, J. Y. Liu, L. J. Paxton, T.-W. Fang, C. H. Liu, 2007: Plausible effect of atmospheric tides on the equatorial ionosphere observed by the FORMOSAT-3/COSMIC: Three-dimensional electron density structures. *Geophysical Research Letters*, **34**, 11112, doi: 10.1029/2007GL029265.[4]

Mayor, S. D., S. M. Spuler, B. M. Morley, E. Loew, 2007: Polarization lidar at 1.54-microns and observations of plumes from aerosol generators. *Optical Engineering*, **46**, 096201,1-11, doi: 10.1117/1.2786406.[1]

Deng, Y., A. J. Ridley, 2007: Possible reasons for underestimating Joule heating in global models: E field variability spatial resolution and vertical velocity. *Journal of Geophysical Research*, **112**, A09308, doi: 10.1029/2006JA012006.[2]

Kennedy, J., J. Ashmore, E. Babister, I. Kelman, 2007: Post-tsunami transitional settlement and shelter: Field experience from Aceh and Sri Lanka. *Humanitarian Exchange*, **37**, 28-36.[4]

McNeeley, S., O. Huntington, 2007: Postcards from the (not so) frozen North: Talking about climate change in Alaska. *Creating a Climate for Change: Communicating Climate Change and Facilitating Social Change*, S. C. Moser and L. Dilling, Ed., Cambridge University Press, 139-152.[3]

Irvine, J., B. Law, K. A. Hibbard, 2007: Postfire carbon pools and fluxes in semi-arid ponderosa pine in central Oregon. *Global Change Biology*, **13(8)**, 1748-1760.[2]

Field, P. R., R. Wood, 2007: Precipitation and cloud structure in midlatitude cyclones. *Journal of Climate*, **20**, 233-254.[3]

Lopez, R. E., S. Hernandez, M. Wiltberger, C.-L. Huang, E. L. Kepko, H. Spence, C. C. Goodrich, J. G. Lyon, 2007: Predicting magnetopause crossings at geosynchronous orbit during the Halloween storms. *Space Weather*, **5**, S01005, doi: 10.1029/2006SW000222.[4]

Byrne, M. A., A. G. Laing, C. B. Connor, 2007: Predicting tephra dispersion with a mesoscale atmospheric model and a particle fall model: Application of Cerro Negro volcano. *Journal of Applied Meteorology and Climatology*, **46**, 121-135.[2]

Kleypas, J. A., 2006: Predictions of climate change in the tropical oceans, and how that should shape our conservation efforts. *Proceedings of the World Maritime Technology Conference*, IMAREST Publications, doi: ISBN 1-902536-54-1.[1]

Baker, D. N., M. J. Wiltberger, R. S. Weigel, S. R. Elkington, 2007: Present status and future challenges of modeling the Sun-Earth end-to-end system. *Journal of Atmospheric and Solar-Terrestrial Physics*, **69**, 3-17.[2]

Flanner, M. G., C. S. Zender, J. T. Randerson, P. J. Rasch, 2007: Present-day climate forcing and response from black carbon in snow. *Journal of Geophysical Research*, **112**, D11202, doi: 10.1029/2006JD008003.[2]

Levis, S., G. B. Bonan, P. J. Lawrence, 2007: Present-day springtime high-latitude surface albedo as a predictor of simulated climate sensitivity. *Geophysical Research Letters*, **34**, L17703, doi: 10.1029/2007GL030775.[2]

Weinstock, E. M., J. V. Pittman, D. S. Sayres, J. B. Smith, J. G. Anderson, S. C. Wofsy, I. Xueref, C. Gerbig, B. C. Daube, L. Pfister, E. C. Richard, B. A. Ridley, A. J. Weinheimer, H.-J. Jost, J. P. Lopez, M. Loewenstein, T. L. Thompson, 2007: Quantifying the impact of the North American monsoon and deep midlatitude convection on the subtropical lowermost stratosphere using in situ measurements. *Journal of Geophysical Research*, American Geophysical Union, **112**, D18310, doi: 10.1029/2007JD008554.[4]

Lang, T. J., D. A. Ahijevych, S. W. Nesbitt, R. E. Carbone, S. A. Rutledge, R. Cifelli, 2007: Radar-observed characteristics of precipitating systems during NAME 2004. *Journal of Climate*, **20(9)**, 1713-1733, doi: 10.1175/JCLI4082.1.[4]

Fei, Y., A. A. Chan, S. R. Elkington, M. J. Wiltberger, 2006: Radial diffusion and MHD particle simulations of relativistic electron transport by ULF waves in the September 1998 storm. *Journal of Geophysical Research*, **111**, 12209, doi: 10.1029/2005JA011211.[4]

Rigler, E. J., M. Wiltberger, D. N. Baker, 2007: Radiation belt electrons respond to multiple solar wind inputs. *Journal of Geophysical Research - Space Physics*, **112**, A06208-A06208, doi: ISSN: 0148-0227.[2]

Voemel, H., H. Selkirk, L. Miloshevich, J. Valverde-Canossa, J. Valdes, E. Kyro, R. Kivi, W. Stolz, G. Peng, J. A. Diaz, 2007: Radiation dry bias of the Vaisala RS92 humidity sensor. *Journal of Atmospheric and Oceanic Technology*, **24**, 953-963, doi: 10.1175/JTECH2019.1.[4]

Liu, H., J. H. Crawford, R. B. Pierce, P. Norris, S. E. Platnick, G. Chen, J. A. Logan, R. M. Yantosca, M. J. Evans, C. Kittaka, Y. Feng, X. Tie, 2006: Radiative effect of clouds on tropospheric chemistry in a global three-dimensional chemical transport model. *Journal of Geophysical Research*, **111**, D20303, doi: 10.1029/2005JD006403.[4]

Spuler, S. M., S. D. Mayor, 2007: Raman Shifter optimized for lidar at 1.5 microns wavelength. *Applied Optics*, **46**, 2990-2995.[1]

Lee, W.-C., M. M. Bell, 2007: Rapid intensification, eyewall contraction, and breakdown of Hurricane Charley (2004) near landfall. *Geophysical Research Letters*, **34**, L02802, doi: 10.1029/2006GL027889.[1]

Singh, H. B., L. Salas, D. Herlth, R. Kolyer, E. Czech, M. Avery, J. H. Crawford, R. B. Pierce, G. W. Sachse, D. R. Blake, R. C. Cohen, T. H. Bertram, A. Perring, P. J. Wooldridge, J. Dibb, G. Huey, R. C. Hudman, S. Turquety, L. K. Emmons, F. Flocke, Y. Tang, G. R. Carmichael, L. W. Horowitz, 2007: Reactive nitrogen distribution and partitioning in the North American troposphere and lowermost stratosphere. *Journal of Geophysical Research*, **112**, D12S04, doi: 10.1029/2006JD007664.[4]

Bellon, A., G. W. Lee, A. Kilambi, 2006: Real-time comparisons of VPR-corrected daily rainfall estimates with a gauge mesonet. *Journal of Applied Meteorology and Climatology*, **46**, 726-741.[2]

Chapin III, F. S., G. M. Woodwell, J. T. Randerson, G. M. Lovett, E. B. Rastetter, D. D. Baldocchi, D. A. Clark, M. E. Harman, D. S. Schimel, R. Valentini, C. Wirth, J. D. Aber, J. J. Cole, A. Giblin, M. L. Goulden, J. W. Harden, M. Heimann, R. W. Howarth, P. A. Matson, A. D. McGuire, J. M. Melillo, H. A. Mooney, J. C. Neff, R. A. Houghton, M. L. Pace, M. G. Ryan, S. W. Running, O. E. Sala, W. H. Schlesinger, E.-D. Schulze, 2006: Reconciling carbon-cycle concepts, terminology, and methodology. *Ecosystems*, **9**, 1041-1050, doi: 10.1007/s10021-005-0105-7.[4]

Nakashiki, N., D. H. Kim, F. O. Bryan, Y. Yoshida, D. Tsumune, K. Maruyama, H. Kitabata, 2006: Recovery of the thermohaline circulation and sea ice area under CO2 stabilization and overshoot scenarios. *Ocean Modelling*, **15**, 200-217.

Heymsfield, A. J., A. Bansemer, C. Twohy, 2007: Refinements to ice particle mass dimensional and terminal velocity relationships for ice clouds: Part I: Temperature dependence. *Journal of the Atmospheric Sciences*, **64(4)**, 1047-1067.[2]

Heymsfield, A. J., A. Bansemer, C. Twohy, 2007: Refinements to ice particle mass dimensional and terminal velocity relationships for ice clouds: Part II: Evaluation and parameterizations of ensemble ice particle sedimentation velocities. *Journal of the Atmospheric Sciences*, **64(4)**, 1068-1088.[2]

Desai, A. R., P. R. Moorcroft, P. V. Bolstad, K. J. Davis, 2007: Regional carbon fluxes from an observationally constrained dynamic ecosystem model: Impacts of disturbance, CO2 fertilization, and heterogeneous land cover. *Journal of Geophysical Research*, **112**, G01017, doi: 10.1029/2006JG000264.[2]

Christensen, J. H., B. Hewitson, A. Busuioc, A. Chen, X. Gao, I. Held, R. Jones, R. K. Kolli, W.-T. Kwon, R. Laprise, V. Magana-Rueda, L. O. Mearns, C. G. Menendez, J. Raisanen, A. Rinke, A. Sarr, P. Whetton, 2007: Regional climate projections. Chapter 11. *Climate Change 2007 - The Physical Science Basis: Working Group I contribution to the Fourth Assessment Report of the IPCC*, S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor, and H. L. Miller, Eds., IPCC, Cambridge University Press, 847-940.[4]

Kelman, I., E. Karnes, 2007: Relocalising disaster risk reduction in Boulder, Colorado. *Australian Journal of Emergency Management*, **22(1)**, 18-25.[3]

Randel, W. J., F. Wu, 2007: Reply. *Journal of Climate*, **20**, 3710-3711, doi: 10.1175/JCLI4209.1.[1]

Moncrieff, M. W., C. Liu, 2006: Representing convective organization in prediction models by a hybrid approach. *Journal of the Atmospheric Sciences*, **63**, 3404-3420.[1]

Spence, R., I. Kelman, A. Brown, G. Toyos, D. Purser, P. Baxter, 2007: Residential building and occupant vulnerability to pyroclastic density currents in explosive eruptions. *Natural Hazards and Earth Systems Sciences*, **7**, 219-230.[4]

Bryan, F. O., M. W. Hecht, R. D. Smith, 2007: Resolution convergence and sensitivity studies with North Atlantic circulation models. Part I: The western boundary current system. *Ocean Modelling*, **16**, 141-159.[3]

Li, J., T. Amari, Y. Fan, 2007: Resolution of the 180 degree ambiguity for inverse horizontal magnetic field configurations. *The Astrophysical Journal*, **654**, 675, doi: 10.1086/509062.[2]

Bulkeley, H., S. C. Moser, 2007: Responding to climate change: Governance and social action beyond Kyoto. *Global Environmental Politics*, **7(2)**, 1-10.[2]

Bryan, F. O., N. Nakashiki, Y. Yoshida, K. Maruyama, 2007: Response of the thermohaline circulation during different pathways toward greenhouse gas stabilization. *Ocean Circulation: Mechanisms and Impacts*, A. Schmittner, J. Chiang, and S. Hemming, Eds., American Geophysical Union, 173, 304 pp.[3]

Kozyra, J., C. Crowley, B. A. Emery, X. H. Fang, G. Maris, M. G. Mlynczak, R. J. Niciejewski, S. E. Palo, L. J. Paxton, C. E. Randall, P.-P. Rong, J. M. Russell III, W. Skinner, S. C. Solomon, E. R. Talaat, Q. Wu, J.-H. Yee, 2006: Response of the upper/middle atmosphere to coronal holes and powerful high-speed solar wind streams in 2003. *Geophysical Monograph Series*, B. Tsurutani, R. McPherron, W. Gonzales, G. Lu, and J. H. Sobral, Eds., American Geophysical Union, 167, 319-340.[4]

Heymsfield, A. J., C. Schmitt, A. Bansemer, G.-J. vanZadelhoff, M. J. McGill, C. Twohy, D. Baumgardner, 2007: Responses to comments on "Effective radius of ice cloud particle populations derived from aircraft probes" by Heymsfield et al, 2006. *Journal of Atmospheric and Oceanic Technology*, **24**, 1511-1518, doi: 10.1175/JTECH2077.1.[3]

Bracconot, P., B. L. Otto-Bliesner, S. Harrison, M. Abe-Ouchi, C. Crucifix, D. Hewitt, M. Kageyama, A. Kitoh, O. Marti, U. Merkel, T. Motoi, R. Ohgaito, W. R. Peltier, J. Valdes, L. Weber, Y. Zhao, 2007: Results of the PMIP2 coupled simulations of the mid-Holocene and Last Glacial Maximum Part 1: Experiments and large scale features. *Climate of the Past*, **3**, 261-277.[3]

Bracconot, P., B. L. Otto-Bliesner, S. Harrison, M. Abe-Ouchi, C. Crucifix, D. Hewitt, M. Kageyama, A. Kitoh, O. Marti, U. Merkel, T. Motoi, R. Ohgaito, W. R. Peltier, J. Valdes, L. Weber, Y. Zhao, 2007: Results of the PMIP2 coupled simulations of the mid-Holocene and Last Glacial Maximum Part 2: Feedbacks with emphasis on the location of the ITCZ and mid- and high-latitude heat budgets. *Climate of the Past*, **3**, 279-296.[3]

Deeter, M. N., D. P. Edwards, J. C. Gille, 2007: Retrievals of carbon monoxide profiles from MOPITT observations using lognormal a priori statistics. *Journal of Geophysical Research*, **112**, D11311, doi: 10.1029/2006JD007999.[1]

Tomassini, L., L. P. Reichert, R. Knutti, T. F. Stocker, M. Borsuk, 2007: Robust Bayesian uncertainty analysis of climate system properties using Markov chain Monte Carlo methods. *Journal of Climate*, **20**, 1239-1254.[3]

Mann, M. E., S. Rutherford, E. Wahl, C. Ammann, 2007: Robustness of proxy-based climate field reconstruction methods. *Journal of Geophysical Research*, **112**, D12109, doi: 10.1029/2006JD008272.[4]

Hu, A., G. A. Meehl, W. Han, 2007: Role of the Bering Strait in the thermohaline circulation and abrupt climate change. *Geophysical Research Letters*, **34**, L05704, doi: 10.1029/2006GL028906.[2]

Bryan, G. H., R. Rotunno, J. M. Fritsch, 2007: Roll circulations in the convective region of a simulated squall line. *Journal of the Atmospheric Sciences*, **64**, 1249-1266.[4]

Anderson, J. L., N. Collins, 2007: Scalable implementations of ensemble filtering algorithms for data assimilation. *Journal of Atmospheric and Oceanic Technology*, **24**, 1452-1463, doi: 10.1175/JTECH2049.1.[1]

Tomczyk, S., 2007: Scattered light from internal reflection in a coronagraph objective lens. *COronal Solar Magnetism Observatory (COSMO) Web Site*, COSMO TN #7, 4pp.[1]

Socas-Navarro, H., 2007: Semiempirical models of solar magnetic structures. *The Astrophysical Journal*, **169**, 439-457, doi: 10.1086/510336.[1]

Shell, K. M., R. C. J. Somerville, 2007: Sensitivity of climate forcing and response to dust optical properties in an idealized model. *Journal of Geophysical Research*, **112**, D03206, doi: 10.1029/2006JD07198.[2]

Liu, C., M. W. Moncrieff, 2007: Sensitivity of cloud-resolving simulations of warm-season convection to cloud microphysics parameterizations. *Monthly Weather Review*, **135**, 2854-2868, doi: 10.1175/MWR3437.1.[1]

Arellano Jr., A. F., P. G. Hess, 2006: Sensitivity of top-down estimates of CO sources to GCTM transport. *Geophysical Research Letters*, **33**, L21807, doi: 10.1029/2006GL027371.[1]

Helmig, D., J. Ortega, T. Duhl, D. Tanner, A. Guenther, P. Harley, C. Wiedinmyer, J. Milford, T. Sakulyanontvittaya, 2007: Sesquiterpene emissions from Pine Trees - Identifications, Emission Rates and Flux Estimates for the Contiguous United States. *Environmental Science and Technology*, **41**, 1545 -1553, doi: 10.1021/es0618907.[2]

Field, P. R., A. J. Heymsfield, A. Bansemer, 2006: Shattering and particle interarrival times measured by optical array probes in ice clouds. *Journal of Atmospheric and Oceanic Technology*, **23**, 1357-1371.[1]

Val Martin, M., R. E. Honrath, R. C. Owen, G. Pfister, P. Fialho, F. Barata, 2006: Significant enhancements of nitrogen oxides, black carbon, and ozone in the North Atlantic lower free troposphere resulting from North American boreal wildfires. *Journal of Geophysical Research*, **111**, D23S60, doi: 10.1029/2006JD007530.[2]

AchutaRao, K. M., M. Ishii, B. D. Santer, P. J. Gleckler, K. E. Taylor, T. P. Barnett, D. W. Pierce, R. J. Stouffer, T. M. L. Wigley, 2007: Simulated and observed variability in ocean temperature and heat content. *Proceedings of the National Academy of Sciences (PNAS)*, **104**, 10768-10773, doi: 10.1073/pnas.0611375104.[4]

Holland, M. M., J. Finnis, M. C. Serreze, 2006: Simulated Arctic ocean freshwater budgets in the 20th and 21st centuries. *Journal of Climate*, **19**, 6221-6242.[2]

Dikpati, M., P. A. Gilman, G. deToma, S. S. Ghosh, 2007: Simulating solar cycles in northern and southern hemispheres by assimilating magnetic data into a calibrated flux-transport dynamo. *Solar Physics*, 120, doi: 10.1007/s11207-007-9016-4.[1]

Barthe, C., J. P. Pinty, 2007: Simulation of a supercellular storm using a three-dimensional mesoscale model with an explicit flash scheme. *Journal of Geophysical Research*, **112**, D06210, doi: 10.1029/2006JD007484.[3]

Doumbia, V., A. Maute, A. D. Richmond, 2007: Simulation of equatorial electrojet magnetic effects with the thermosphere-ionosphere-electrodynamics general circulation model. *Journal of Geophysical Research*, **112**, A09309, doi: 10.1029/2007JA012308.[2]

Qian, T., A. Dai, K. E. Trenberth, K. W. Oleson, 2006: Simulation of global land surface conditions from 1948 to 2004. Part I: Forcing data and evaluation. *Journal of Hydrometeorology*, **7**, 953-975, doi: 10.1175/JHM540.1.[1]

Garcia, R. R., D. R. Marsh, D. E. Kinnison, B. A. Boville, F. Sassi, 2007: Simulation of secular trends in the middle atmosphere, 1950-2003. *Journal of Geophysical Research*, **112**, D09301, doi: 10.1029/2006JD007485.[1]

Deser, C., A. Phillips, 2006: Simulation of the 1976/1977 climate transition over the North Pacific: Sensitivity to tropical forcing. *Journal of Climate (CLIVAR special issue)*, **19**, 6170-6180.[1]

Barth, M. C., S.-W. Kim, W. C. Skamarock, A. L. Stuart, K. E. Pickering, L. E. Ott, 2007: Simulations of the redistribution of formaldehyde, formic acid, and peroxides in the 10 July 1996 stratospheric-tropospheric experiment: Radiation, aerosols, and ozone deep convection storm. *Journal of Geophysical Research*, **112**, D13310, doi: 10.1029/2006JD008046.[2]

Mininni, P. D., A. G. Pouquet, D. C. Montgomery, 2006: Small-scale structures in three-dimensional magnetohydrodynamic turbulence. *Physical Review Letters*, **97**, 244503, doi: 10.1103/PhysRevLett.97.244503.[2]

Gladwin, H., J. K. Lazo, B. H. Morrow, W. G. Peacock, H. E. Willoughby, 2007: Social science research needs for the hurricane forecast and warning system. *Natural Hazards Review*, **8(3)**, 87-95.[4]

Lazo, J. K., W. G. Peacock, 2007: Social science research needs for the hurricane forecast and warning system: An Introduction. *Natural Hazards Review*, **8(3)**, 43-44.[2]

Romero-Lankao, P., 2006: Sociales: Una relacion evidente? *Ciencia y Desarrollo*, **Diciembre**, 36-41.[1]

Seneviratne, S. I., R. D. Koster, Z. Guo, P. A. Dirmeyer, E. Kowalczyk, D. Lawrence, P. Liu, C. H. Lu, D. Mocko, K. W. Oleson, D. Verseghy, 2006: Soil moisture memory in AGCM simulations: Analysis of global Land-Atmosphere Coupling Experiments (GLACE) data. *Journal of Hydrometeorology*, **7**, 1090-1112.[3]

Howe, R., M. Rempel, J. Christensen-Dalsgaard, F. Hill, R. Komm, R. M. Larsen, J. Schou, M. J. Thompson, 2006: Solar convection zone dynamics: How sensitive are inversions to subtle dynamo features? *The Astrophysical Journal*, **649**, 1155, doi: 10.1086/506931.[4]

Ammann, C. M., F. Joos, D. S. Schimel, B. L. Otto-Bliesner, R. A. Tomas, 2007: Solar influence on climate during the past millennium: Results from transient simulations with the NCAR Climate System Model. *Proceedings of the National Academy of Sciences (PNAS)*, **104**, 3713-2718.[3]

Warn-Varnas, A., J. Hawkins, P. K. Smolarkiewicz, S. A. Chin-Bing, D. King, 2007: Solitary wave effects north of Strait of Messina. *Ocean Modelling*, **18**, 97-121, doi: 10.1016/j.ocemod.2007.03.003.[3]

Tomczyk, S., 2007: Some considerations for a high etendue birefringent filter. *COronal Solar Magnetism Observatory (COSMO) Web Site*, COSMO TN #6, 4pp.[1]

Shim, C., Y. Wang, H. B. Singh, D. R. Blake, A. B. Guenther, 2007: Source characteristics of oxygenated volatile organic compounds and hydrogen cyanide. *Journal of Geophysical Research*, **112**, D10305, doi: 10.1029/2006JD007543.[4]

Williams, J. K., J. Vivekanandan, 2007: Sources of error in dual-wavelength radar remote sensing of cloud liquid water content. *Journal of Atmospheric and Oceanic Technology*, **24**, 1317-1336.[1]

Lee, G. W., 2007: Sources of errors in precipitation measurements by polarimetric radar: Sensitivity of polarimetric parameters to drop deformation. *Journal of the Korean Meteorological Society*, **43**, 41-57.[1]

Gochis, D. J., J. Garatuza-Payan, 2007: Spatial and temporal patterns of precipitation intensity as observed by the NAME Event Rain Gauge Network from 2002 to 2004. *Journal of Climate*, **20**, 1734-1750.[2]

Furrer, R., R. Knutti, S. R. Sain, D. W. Nychka, G. A. Meehl, 2007: Spatial patterns of probabilistic temperature change projections from a multivariate Bayesian analysis. *Geophysical Research Letters*, **34**, L06711, doi: 10.10.1029/2006GL027754.[2]

Norton, A. A., J. Pietarila Graham, R. K. Ulrich, J. Schou, S. Tomczyk, Y. Liu, B. W. Lites, A. Lopez Ariste, R. I. Bush, H. Socas-Navarro, P. H. Scherrer, 2006: Spectral line selection for HMI: A comparison of Fe I 6173 Aa and Ni I 6768 Aa. *Solar Physics*, **239**, 69, doi: 10.1007/s11207-006-0279-y.[4]

Judge, P. G., B. C. Low, R. Casini, 2006: Spectral lines for polarization measurements of the coronal magnetic field. IV. Stokes signals in current-carrying fields. *The Astrophysical Journal*, **651**, 1229-1237, doi: 10.1086/507982.[1]

Judge, P. G., 2007: Spectral lines for polarization measurements of the coronal magnetic field. V. Information content of magnetic dipole lines. *The Astrophysical Journal*, **662**, 677-690, doi: 10.1086/515433.[1]

Pietarila, A., H. Socas-Navarro, T. Bogdan, 2007: Spectropolarimetric observations of the Ca II 8498 A and 8542 A lines in the quiet Sun. *The Astrophysical Journal*, **663**, 1386-1405, doi: 10.1086/518714.[3]

Gault, J., S. Sain, L. Hu, I. A. Awad, 2006: Spectrum of genotype and clinical manifestations in cerebral cavernous malformations. *Neurosurgery*, **59**, 1278-1285.[4]

Sanchez-Andrade Nuno, B., R. Centeno, K. G. Puschmann, J. TrujilloBueno, J. Blanco-Rodriguez, F. Kneer, 2007: Spicule emission profiles observed in He I 10 830 Aa. *Astronomy and Astrophysics*, **472**, L51-L54, doi: 10.1051/0004-6361:20077936.[3]

Dryoff, C., P. Weibring, A. Fried, D. Richter, J. G. Walega, A. Zahn, W. Freude, P. Werle, 2007: Stark-enhanced diode-laser spectroscopy of formaldehyde using a modified Herriott-type multipass cell. *Applied Physics B: Lasers and Optics*, **88**, 117-123, doi: 10.1007/s00340-007-2671-1.[3]

Schmidli, J., C. M. Goodess, C. Frei, M. R. Haylock, Y. Hundecha, J. Ribalaygua, T. Schmith, 2007: Statistical and dynamical downscaling for precipitation: An evaluation and comparison of scenarios for the European Alps. *Journal of Geophysical Research - Atmospheres*, **112 (D4)**, D04105, doi: 10.1029/2005JD007026.[4]

Herring, J. R., Y. Kimura, R. James, J. Clyne, P. A. Davidson, 2006: Statistical and dynamical questions in stratified turbulence. *Mathematical and Physical Theory of Turbulence*, J. Canon and B. Shivamoggi, Ed., Chapman and Hall / CRC, 250, 101-114.[3]

Harper, B. R., R. W. Katz, R. C. Harriss, 2007: Statistical methods for quantifying the effect of the El Nino-Southern Oscillation on wind power in the northern Great Plains of the United States. *Wind Engineering*, **31**, 123-137.[2]

Dikpati, M., P. A. Gilman, 2007: Steps for building a calibrated flux-transport dynamo for the Sun. *Solar Physics*, **241**, 1, doi: 10.1007/s11207-007-0380-x.[1]

Armstrong, J. A., S. K. Avery, H. B. Bluestein, E. W. Friday, M. A. Geller, E. A. Holland, C. F. Kolb, M. A. LeMone, R. E. Lopez, S. Solomon, J. M. Wallace, R. A. Weller, S. E. Zebiak, 2007: Strategic guidance for the National Science Foundation's support of the atmospheric sciences. *National Research Council of the National Academy of Sciences, Board of Atmospheric Sciences and Climate*, A.M Staudt and C. Mengelt, Ed., National Research Council.[4]

Tribbia, J., 2007: Stuck in the slow lane of behavior change? A not-so-superhuman perspective on getting out of our cars. *Creating a Climate for Change: Communicating Climate Change and Facilitating Social Change*, S. C. Moser and L. Dilling, Ed., Cambridge University Press, 251-265.[1]

Smolarkiewicz, P. K., L. G. Margolin, 2007: Studies in geophysics. Chapter 14. *Implicit Large Eddy Simulation: Computing Turbulent Fluid Dynamics*, F. F. Grinstein, L. Margolin, and W. Rider, Eds., Cambridge University Press, 413-438.[3]

IPCC WGII, ., . (including P. Romero-Lankao), 2007: Summary for policymakers. *Climate Change 2007 - Impacts, Adaptation and Vulnerability: Working Group II contribution to the Fourth Assessment Report of the IPCC*, M. L. Parry, O. F. Canziani, J .P. Palutikov, P .F. Vander Linden, C. E. Hanson, Eds., Cambridge University Press, AR4, 7-22.[4]

Liang, Q., L. Jaegle, R. C. Hudman, S. Turquety, D. J. Jacob, M. A. Avery, E. V. Browell, G. W. Sachse, D. R. Blake, W. Brune, X. Ren, R. C. Cohen, J. E. Dibb, A. Fried, H. Fuelberg, M. Porter, B. G. Heikes, G. Huey, H. B. Singh, P. O. Wennberg, 2007: Summertime influence of Asian pollution in the free troposphere over North America. *Journal of Geophysical Research*, **112**, D12S11, doi: 10.1029/2006JD007919.[4]

Hudman, R. C., D. J. Jacob, S. Turquety, E. M. Leibensperger, L. T. Murray, S. Wu, A. B. Gilliland, M. Avery, T. H. Bertram, W. Brune, R. C. Cohen, J. E. Dibb, F. M. Flocke, A. Fried, J. Holloway, J. A. Neuman, R. Orville, A. Perring, X. Ren, G. W. Sachse, H. B. Singh, A. Swanson, P. J. Woolridge, 2007: Surface and lightning sources of nitrogen oxides over the United States: Magnitudes, chemical evolution, and outflow. *Journal of Geophysical Research*, **112**, D12S05, doi: 10.1029/2006JD007912.[4]

Miesch, M. S., 2007: Sustained Magnetoshear Instabilities in the solar Tachocline. *The Astrophysical Journal*, **658**, L131, doi: 10.1086/515571.[1]

Duane, G. S., J. J. Tribbia, J. B. Weiss, 2006: Synchronicity in predictive modelling: A new view of data assimilation. *Nonlinear Processes in Geophysics*, **13**, 601.[2]

Higgins, R. W., D. J. Gochis, 2007: Synthesis of results from the North American Monsoon Experiment (NAME) Process Study. *Journal of Climate*, **20**, 1601-1607.[3]

Moser, S. C., 2006: Talk of the city: Engaging urbanites on climate change. *Environmental Research Letters*, **1(1)**, 014006 (10pp.), doi: 10.1088/1748-9326/1/1/014006.[1]

Cohn, S. A., J. Hallett, J. W. Lewis, 2006: Teaching graduate atmospheric measurement. *Bulletin of the American Meteorological Society*, **87**, 1673-1678, doi: 10.1175/BAMS-87-12-1673.[4]

Li, T., P. Liu, X. Fu, B. Wang, G. A. Meehl, 2006: Tempo-spatial structures and mechanisms of the tropospheric biennial oscillation in the Indo-pacific warm ocean. *Journal of Climate*, **19**, 3070-3087.[3]

Mitchell, D. L., A. J. Baran, W. P. Arnott, C. G. Schmitt, 2006: Testing and comparing the modified anomalous diffraction approximation. *Journal of the Atmospheric Sciences*, **63**, 2948-2962, doi: 10.1175/JAS3775.1.[3]

Huang, C.-Y., Y.-H. Kuo, S.-Y. Chen, A. S. K. A. V. Prasad Rao, C.-J. Wang, 2007: The assimilation of GPS radio occultation data and its impact on rainfall prediction along the west coast of India during monsoon 2002. *Pure and Applied Geophysics*, **164**, 1577-1591, doi: 10.1007/s00024-007-0246-z.[3]

Metcalfe, T. S., 2006: The citation impact of digital preprint archives for solar physics papers. *Solar Physics*, **239**, 549-553, doi:

10.1007/s11207-006-0262-7.[1]

Creevey, O. L., M. J. P. F. G. Monteiro, T. S. Metcalfe, T. M. Brown, S. J. Jimenez-Reyes, J. A. Belmonte, 2007: The complementary roles of interferometry and asteroseismology in determining the mass of solar-type stars. *The Astrophysical Journal*, **659**, 616-625, doi: 10.1086/512097.[4]

Aiouaz, T., H. Peter, P. Lemaire, 2007: The correlation between coronal Doppler shifts and the supergranular network. *Astronomy and Astrophysics*, **466**, 689, doi: 10.1051/0004-6361:20042159e.[3]

Edson, J., T. Crawford, J. Crescenti, T. Farrar, J. French, N. Frew, G. Gerbi, C. Helmis, T. Hristov, D. Khelif, A. Jessup, H. Jonsson, M. Li, L. Mahrt, W. McGllis, A. Plueddmann, L. Shen, E. Skyllingstad, T. Stanton, P. Sullivan, J. Sun, J. Trowbridge, D. Vickers, S. Wang, Q. Wang, R. Weller, J. Wilkin, D. Yue, C. Zappa, 2007: The coupled boundary layers and air-sea transfer experiment in low winds (CBLAST-Low). *Bulletin of the American Meteorological Society*, **88**, 341-356, doi: 10.1175/BAMS-88-3-341.[4]

Letson, D., D. Sutter, J. K. Lazo, 2007: The economic value of hurricane forecasts: An overview and research needs. *Natural Hazards Review*, **8(3)**, 78-86.[2]

Textor, C., M. Schulz, S. Guibert, S. Kinne, Y. Balkanski, S. Bauer, T. Berntsen, T. Berglen, O. Boucher, M. Chin, F. Dentener, T. Diehl, J. Feichter, D. Fillmore, P. Ginoux, S. Gong, A. Grini, J. Hendricks, L. Horowitz, P. Huang, I. S. A. Isaksen, T. Iversen, S. Kloster, D. Koch, A. Kirkevaeg, J. E. Kristajansson, M. Krol, A. Lauer, J.-F. Lamarque, X. Liu, V. Montanaro, G. Myhre, J. E. Penner, G. Pitari, M. S. Reddy, O. Seland, P. Stier, T. Takemura, X. Tie, 2007: The effect of harmonized emissions on aerosol properties in global models - an AeroCom experiment. *Atmospheric Chemistry and Physics*, **7**, 4489-4501.[4]

Lericos, T. P., H. E. Fuelberg, A. I. Watson, M. L. Weisman, 2007: The effects of coast-lines on the evolution of strong, long-lived squall lines. *Monthly Weather Review*, **135**, 1710�1731, doi: 10.1175/MWR3381.1.[3]

Williamson, D. L., 2007: The evolution of dynamical cores for Global Atmospheric Models. *Journal of the Meteorological Society of Japan*, **85B**, 241-269.[1]

Darby, L. S., G. S. Poulos, 2006: The evolution of mountain waves and rotors in the lee of Pike's Peak under the influence of a cold front: Implications for aircraft safety. *Monthly Weather Review*, **134**, 2857-2876, doi: 10.1175/MWR3208.1.[3]

Gibson, S. E., Y. Fan, T. Torok, B. Kliem, 2006: The evolving Sigmoid: Evidence for magnetic flux fopes in the corona before, during, and after CMES. *Space Science Reviews*, **124**, 131, doi: 10.1007/s11214-006-9101-2.[4]

Davis, C. A., L. F. Bosart, 2006: The formation of Hurricane Humberto (2001): The importance of extra-tropical precursors. *Quarterly Journal of the Royal Meteorological Society*, **132**, 2055-2085.[2]

Metcalfe, T. S., 2007: The future of computational asteroseismology. *Communications in Asteroseismology*, **150**, 227.[1]

Gettelman, A., E. J. Fetzer, A. Eldering, F. W. Irion, 2006: The global distribution of supersaturation in the upper troposphere from the atmospheric infrared sounder. *Journal of Climate*, **19**, 6089-6103, doi: 10.1175/JCLI3955.1.[3]

Gettelman, A., D. E. Kinnison, 2007: The global impact of supersaturation in a coupled chemistry-climate model. *Atmospheric Chemistry and Physics*, **7**, 1629-1643.[1]

Wilbanks, T. J., P. Romero-Lankao, 2007: The human dimensions of global environmental change. Chapter 24. *The SAGE Handbook of Environment and Society*, J Pretty, A. S. Ball, T. Benton, J. Guivant, D. R. Lee, D. Orr, M. J. Pfeffer, and H. Ward, Eds., SAGE Publications, 353-361.[3]

Park, S., M. A. Alexander, C. Deser, 2006: The impact of cloud radiative feedback, remote ENSO forcing, and entrainment on the persistence of North Pacific sea surface temperature anomalies. *Journal of Climate*, **19, 23**, 6243-6261.[3]

Zhang, X., Q. Xiao, P. J. Fitzpatrick, 2007: The impact of multi-satellite data on the initialization and simulation of Hurricane Lili's (2002) rapid weakening phase. *Monthly Weather Review*, **135**, 526-548, doi: 10.1175/MWR3287.1.[2]

Barth, M. C., 2006: The importance of cloud drop representation on cloud photo-chemistry. *Atmospheric Research*, **82**, 294-309.[1]

McKelvey, R., P. V. Golubtsov, G. Cripe, K. A. Miller, 2007: The incomplete information stochastic split-stream model: An overview. *Advances in Fisheries Economics*, T. Bjorndal, D. Gordon, R. Arnason, and U. R. Somalia, Eds., Blackwell Publishing, 159-183, doi: ISBN 13:978-1-4051-4161-1.[2]

Asensio Ramos, A., H. Socas-Navarro, A. Lopez Ariste, M. J. Martinez Gonzales, 2007: The intrinsic dimensionality of spectro-polarimetric data. *The Astrophysical Journal*, **660**, 1690-1699, doi: 10.1086/513069.[4]

Burns, A. G., S. C. Solomon, W. Wang, T. L. Killeen, 2007: The ionospheric and thermospheric response to CMEs: Challenges and successes. *Journal of Atmospheric and Solar-Terrestrial Physics*, **69**, 77.[1]

Serreze, M. C., A. P. Barrett, A. J. Slater, M. Steele, J. Zhang, K. E. Trenberth, 2007: The large-scale energy budget of the Arctic. *Journal of Geophysical Research*, **112**, D11122, doi: 10.1029/2006JD008230.[2]

Weber, S. L., S. S. Drijfhout, A. Abe-Ouchi, M. Crucifix, M. Eby, A. Ganopolski, S. Murakami, B. L. Otto-Bliesner, W. R. Peltier, 2007: The modern and glacial overturning circulation in the Atlantic ocean in PMIP coupled model simulations. *Climate of the Past*, **3**, 51-64.[3]

Schultz, D. M., K. M. Kanak, J. M. Straka, R. J. Trapp, B. A. Gordon, D. S. Zrnic, G. H. Bryan, A. J. Durant, T. J. Garrett, P. M. Klein, D. K. Lilly, 2006: The mysteries of mammatus clouds: Observations and formation mechanisms. *Journal of the Atmospheric Sciences*, **63**, 2409-2435.[4]

Judge, P. G., S. H. Saar, 2007: The outer solar atmosphere during the Maunder Minimum: A stellar perspective. *The Astrophysical Journal*, **663**, 643-656, doi: 10.1086/513004.[3]

Lawrence, D. M., P. E. Thornton, K. W. Oleson, G. B. Bonan, 2007: The partitioning of evapotranspiration into transpiration, soil evaporation, and canopy evaporation in a GCM: Impacts on land-atmosphere interaction. *Journal of Hydrometeorology*, **8**, 862-880, doi: 10.1175/JHM596.1.[1]

Warner, T., P. Benda, S. Swerdlin, J. Knievel, E. Argenta, B. Aronian, B. Balsley, J. Bowers, R. Carter, P. Clark, K. Clawson, J. Copeland, A. Crook, R. Frehlich, M. Jensen, Y. Liu, S. Mayor, Y. Meillier, B. Morley, R. Sharman, S. Spuler, D. Storwold, J. Sun, J. Weil, M. Xu, A. Yates, Y. Zhang, 2007: The pentagon SHIELD field program: toward critical infrastructure protection. *Bulletin of the American Meteorological Society*, **88**, 167-176, doi: 10.1175/BAMS-88-2-166.[4]

Collins, W. D., R. Colman, M. R. Manning, P. Mote, 2007: The physical science behind climate change. *Scientific American*, **297**, 64-73.[3]

Lamarque, J.-F., J. T. Kiehl, J. J. Orlando, 2007: The role of hydrogen sulfide in a Permian-Triassic boundary ozone collapse. *Geophysical Research Letters*, **34**, L02801, doi: 10.1029/2006GL028384.[1]

Trenberth, K. E., 2006: The role of the oceans in climate. *Flotsam and Jetsam*, **35**, 1, 5-7.[1]

Camredon, M., B. Aumont, J. Lee-Taylor, S. Madronich, 2007: The SOA/VOC/Nox system: an explicit model of secondary organic aerosol formation. *Atmospheric Chemistry and Physics Discussions*, **7**, 11223-11256.[2]

Socas-Navarro, H., A. A. Norton, 2007: The solar oxygen crisis: Probably not the last word. *The Astrophysical Journal*, **660**, L153, doi: 10.1086/518389.[3]

Corbosiero, K. L., J. Molinari, A. R. Aiyyer, M. L. Black, 2006: The structure and evolution of Hurricane Elena, 1985: Convective asymmetries and evidence for vortex Rossby waves. *Monthly Weather Review*, **134**, 3073-3091.[4]

Borrero, J. M., 2007: The structure of sunspot penumbrae. IV. MHS equilibrium for penumbral flux tubes and the origin of dark core penumbral filaments and penumbral grains. *Astronomy and Astrophysics*, **471**, 967-975, doi: 10.1051/0004-6361:20066776.[1]

Deser, C., R. A. Tomas, S. Peng, 2007: The transient atmospheric circulation response to North Atlantic SST and sea ice anomalies. *Journal of Climate*, **20**, 4751-4767.[3]

Waite, M. L., P. Bartello, 2006: The transition from geostrophic to stratified turbulence. *Journal of Fluid Mechanics*, **33**, 89-108, doi: 10.1029/2006/GL026925.[2]

Kirshbaum, D. J., G. H. Bryan, R. Rotunno, D. R. Durran, 2007: The triggering of orographic rainbands by small-scale topography. *Journal of the Atmospheric Sciences*, **64**, 1530-1549, doi: 10.1175/JAS3924.1.[2]

Karl, T., A. Guenther, R. J. Yokelson, J. Greenberg, M. Potosnak, D. R. Blake, P. Artaxo, 2007: The tropical forest and fire emissions experiment: Emission, chemistry, and transport of biogenic volatile organic compounds in the lower atmosphere over Amazonia. *Journal of Geophysical Research*, American Geophysical Union, **112**, D18302, doi: 10.1029/2007JD008539.[4]

Karl, T. G., T. J. Christian, R. J. Yokelson, P. Artaxo, W. M. Hao, A. Guenther, 2007: The tropical forest and fire emissions experiment: method evaluation of volatile organic compound emissions measured by PTR-MS, FTIR, and GC from tropical biomass burning. *Atmospheric Chemistry and Physics Discussions*, **7**, 8755-8793.[2]

Yokelson, R. J., T. Karl, P. Artaxo, D. R. Blake, T. J. Christian, D. W. T. Griffith, A. Guenther, W. M. Hao, 2007: The Tropical Forest and fire emissions experiment: overview and airborne fire emission factor measurements. *Atmospheric Chemistry and Physics Discussions*, **7**, 6903-6958.[4]

Borrero, J., M. Rempel, S. Solanki, 2006: The uncombed penumbra. *Proc. Solar Polarization 4, Astronomical Society of the Pacific Conference Series*, R. Casini and B. W. Lites, Ed., Boulder, CO, Astronomical Society of the Pacific, 358, 19.[3]

Tebaldi, C., R. Knutti, 2007: The use of multi-model ensemble in probabilistic climate projections. *Philosophical Transactions of the Royal Society A*, **365**, 2053-2075, doi: 10.1098/rsta.2007.2076.[3]

Banta, R. M., L. Mahrt, D. Vickers, J. Sun, B. B. Balsley, Y. Pichugina, E. J. Williams, 2007: The very stable boundary layer on nights with weak low-level jets. *Journal of the Atmospheric Sciences*, **64**, 3068-3090, doi: 10.1175/JAS4002.1.[4]

Barsanti, K. C., J. F. Pankow, 2007: Thermodynamics of the formation of atmospheric organic particulate matter by accretion reactions - Part 3: Carboxylic and dicarboxylic acids. *Atmospheric Environment*, **40**, 6676-6686.[2]

Penner, J. E., N. Andronova, R. C. Oehmke, J. Brown, Q. F. Stout, C. Jablonowski, B. van Leer, K. G. Powell, M. Herzog, 2007: Three dimensional adaptive mesh refinement on a spherical shell for atmosphere models using lagrangian coordinates. *Journal of Physics: Conference Series*, **78**, 012072, doi: 10.1088/1742-6596/78/1/012072.[4]

Sun, J., 2007: Tilt corrections over complex terrain and its implication for CO2 transport. *Boundary-Layer Meteorology*, **124**, 143-159, doi: 10.1007/s10546-007-9186-5.[1]

Niciejewski, R., Q. Wu, W. Skinner, D. Gell, M. Cooper, A. Marshall, T. Killeen, S. Solomon, D. Ortland, 2006: TIMED Doppler Interferometer on the Thermosphere Ionosphere Mesosphere Energetics and Dynamics satellite: Data product overview. *Journal of Geophysical Research*, **111**, A11S90, doi: 10.1029/2005JA011513.[4]

Barsanti, K. C., W. Luo, L. M. Isabelle, J. F. Pankow, H. H. Peyton, 2007: Tobacco smoke particulate matter chemistry by NMR. *Magnetic Resonance in Chemistry*, **45**, 167-170.[2]

Pan, L., T. Chai, G. R. Carmichael, Y. Tang, D. Streets, J.-H. Woo, H. R. Friedli, L. F. Radke, 2007: Top-down estimate of mercury emission in China using four-dimensional variational data assimilation. *Atmospheric Environment*, Elsevier Ltd., **41**, 2804-2819, doi: 10.1016/j.atmosenv.2006.11.048.[4]

Chien, F.-C., Y.-H. Kuo, 2006: Topographic effects on a winter-time cold front in Taiwan. *Monthly Weather Review*, **134**, 3297-3316.[2]

Moser, S. C., L. Dilling, 2007: Toward the social tipping point: Conclusions. *Creating a Climate for Change: Communicating Climate Change and Facilitating Social Change*, S. C. Moser and L. Dilling, Ed., Cambridge University Press, 491-516.[2]

Nelson, P., D. Elmore, S. Tomczyk, 2007: Trade study summary for reflecting vs. refracting primary objectives for the COSMO large coronagraph. *COronal Solar Magnetism Observatory (COSMO) Web Site*, COSMO TN #5, 20pp.[1]

Park, M., W. J. Randel, A. Gettelman, S. T. Massie, J. H. Jiang, 2007: Transport above the Asian summer monsoon anticyclone inferred from Aura Microwave Limb Sounder tracers. *Journal of Geophysical Research*, **112**, D16309, doi: 10.1029/2006JD008294.[3]

Pittman, J. V., E. M. Weinstock, R. J. Oglesby, D. S. Sayres, J. B. Smith, J. G. Anderson, O. R. Cooper, S. C. Wofsy, I. Xueref, C. Gerbig, B. C. Daube, E. C. Richard, B. A. Ridley, A. J. Weinheimer, M. Loewenstein, H.-J. Jost, J. P. Lopez, M. J. Mahoney, T. L. Thompson, W. W. Hargrove, F. M. Hoffman, 2007: Transport in the subtropical lowermost stratosphere during the Cirrus Regional Study of Tropical Anvils and Cirrus Layers- Florida Area Cirrus Experiment. *Journal of Geophysical Research*, **112**, D08304, doi: 10.1029/2006JD007851.[4]

Flyer, N., G. Wright, 2007: Transport schemes on a sphere using radial basis functions. *Journal of Computational Physics*, **226**, 1059-1084, doi: 10.1016/j.jcp.2007.05.009.[2]

Jochum, M., C. Deser, A. Phillips, 2007: Tropical atmospheric variability forced by oceanic internal variability. *Journal of Climate*, **20**, 765-771, doi: 10.1175/JCLI4044.1.[1]

Graham, N. E., M. R. Hughes, C. M. Ammann, K. M. Cobb, M. P. Hoerling, D. J. Kennett, J. P. Kennett, B. Rein, L. Stott, P. E. Wigand, T. Xu, 2007: Tropical pacific - mid-latitude teleconnections in medieval times. *Climatic Change*, doi: 10.1007/s10584-007-9239-2.[3]

Miesch, M. S., 2007: Turbulence in the tachocline. Chapter 5. *The Solar Tachocline*, D. Hughes, R. Rosner, and N. Weiss, Eds., Cambridge University Press, 108-127, doi: ISBN-13: 9780521861014.[1]

Alexakis, A., P. D. Mininni, A. Pouquet, 2007: Turbulent cascades, transfer, and scale interactions in magnetohydrodynamics. *New Journal of Physics*, **9**, 298, doi: 10.1088/1367-2630/9/8/298.[1]

Lo, J. C. F., A. K. H. Lau, F. Chen, J. C. H. Fung, K. K. M. Leung, 2007: Urban modification in a mesoscale model and the effects on the local circulation in the Pearl River Delta region. *Journal of Applied Meteorology and Climatology*, **46**, 457-476.[2]

Morss, R. E., F. M. Ralph, 2007: Use of information by National Weather Service forecasters and emergency managers during CALJET and PACJET-2001. *Weather and Forecasting*, **22**, 539-555, doi: 10.1175/WAF1001.1.[3]

Spence, R., J. Palmer, M. Petal, I. Kelman, K. Saito, 2007: Using eyewitness reports to assess the impact of the 26.12.04 Southern Asian tsunami. *Maritime Engineering*, **160(ME2)**, 75-85.[4]

Monaham, K. P., L. L. Pan, A. J. McDonald, G. E. Bodeker, J. Wei, S. E. George, C. D. Barnet, E. Maddy, 2007: Validation of AIRS v4 ozone profiles in the UTLS using ozonesondes from Lauder, NZ and Boulder, USA. *Journal of Geophysical Research*, **112**, D17304, doi: 10.1029/2006JD008181.[4]

Bian, J. C., A. K. Gettelman, H. Chen, L. L. Pan, 2007: Validation of satellite ozone profile retrievals using Beijing ozonesonde data. *Journal of Geophysical Research*, **112**, D06305, doi: 10.1029/2006JD007502.[3]

Seidel, D. J., W. J. Randel, 2006: Variability and trends in the global tropopause estimated from radiosonde data. *Journal of Geophysical Research*, **111**, D21101, doi: 10.1029/2006JD007363.[3]

Lee, C. K., G. W. Lee, K.-E. Kim, 2007: Variability of the raindrop size distributions within a storm. *Journal of the Korean Meteorological Society*, **43**, 1-16.[3]

Huang, X.-P., S. M. Spuler, A. D. Sappey, 2007: Varied line-space grating for flat spectral response of coupling to single-mode fiber. *Applied Optics*, **46**, 147-153.[3]

Cooley, D., P. Naveau, P. Poncet, 2006: Variograms for spatial max-stable random fields. *Dependence in Probability and Statistics*, P. Bertail, P. Doukhan, P. Soulier, Eds., Springer, 373-390, doi: ISBN 978-0-387-31741-0.[3]

Burns, A. G., W. Wang, T. L. Killeen, S. C. Solomon, M. Wiltberger, 2006: Vertical variations in the N2 mass mixing ratio during a thermospheric storm that have been simulated using a coupled magnetosphere-ionosphere-thermosphere model. *Journal of Geophysical Research*, **111**, 11309, doi: 10.1029/2006JA011746.[1]

Muraki, D. M., C. Snyder, 2007: Vortex dipoles for surface quasigeostrophic models. *Journal of the Atmospheric Sciences*, **64**, 2961-2967, doi: 10.1175/JAS3958.1.[2]

Moser, S. C., J. Tribbia, 2007: Vulnerability to coastal impacts of climate change: Coastal managers' attitudes, knowledge, perceptions, and actions. *Vulnerability to coastal impacts of climate change: Coastal managers' attitudes, knowledge, perceptions, and actions*, California Environmental Protection Agency.[2]

Moser, S. C., J. Tribbia, 2007: Vulnerability to inundation and climate change impacts in California: Coastal managers' attitudes and perceptions. *Marine Technology Society Journal*, **40(3)**, 4-13.[2]

Trenberth, K. E., 2007: Warmer oceans, stronger hurricanes. *Scientific American*, **297 (1)**, 26-33.[1]

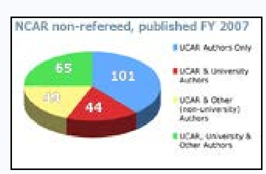
Stephens, B. B., K. R. Gurney, P. P. Tans, C. Sweeney, W. Peters, L. Bruhwiler, P. Ciais, M. Ramonet, P. Bousquet, T. Nakazawa, S. Aoki, T. Machida, G. Inoue, N. Vinnichenko, J. Lloyd, A. Jordan, M. Heimann, O. Shibistova, R. L. Langenfelds, L. P. Steele, R. J. Francey, A. S. Denning, 2007: Weak northern and strong tropical land carbon uptake from vertical profiles of atmospheric CO2. *Science*, **316**, 1732-1735, doi: 10.1126/science.1137004.[4]

Ramaswamy, V., J. W. Hurrell, G. A. Meehl, 2006: Why do temperatures vary vertically (from the surface to the stratosphere) and what do we understand about why they might vary and change over time? *Temperature Trends in the Lower Atmosphere: Steps for Understanding and Reconciling Differences*, T. R. Karl, S. J. Hassol, C. D. Miller, and W. L. Murray, Eds., The Climate Change Science Program and the Subcommittee on Global Change Research, 15-28.[3]

Hodzic, A., S. Madronich, B. Bohn, S. Massie, L. Menut, C. Wiedinmyer, 2007: Wildfire particulate matter in Europe during summer 2003: meso-scale modeling of smoke emissions, transport and radiative effects. *Atmospheric Chemistry and Physics*, **7**, 4043-4064.[4]

## NCAR Non-Refereed and Published Publications for Fiscal Year 2007 top

**259 Publication(s) for the time period 2006-10-01 to 2007-09-30**
**Group(s): CISL, SERE, RAL, EOL, ESSL**
**Class: Nonrefereed**
**Status: Published; (alphabetical by title, NCAR Annual Report format)**




***Author Collaborations Summary:***
**UCAR Only: 101**
**UCAR & University: 44**

**UCAR & Other: 49**
**UCAR, University, & Other: 65**

***Click to enlarge.* Chart showing the collaborative output of non-refereed publications in fiscal year 2007."**

***Legend:***
*[1] = UCAR Only Collaboration, [2] = UCAR & University Collaboration, [3] = UCAR & Other Collaboration, [4] = UCAR, University, & Other Collaboration*

Richter, D., P. Weibring, A. Fried, O. Tadanaga, Y. Nishida, M. Asobe, H. Suzuki, 2007: 15 mW, Tunable difference frequency generation source for absorption spectroscopy. *Quantum Electronics and Laser Science Conference*, Baltimore, MD, OSA.[3]

Huang, X.-Y., Q. Xiao, Xin. Zhang, J. Michalakes, W. Huang, D. M. Barker, J. Bray, Z. Ma, T. Henderson, J. Dudhia, X. Zhang, D.-J. Won, Y. Chen, Y.-R. Guo, H.-C. Lin, Y.-H. Kuo, 2007: 4-Dimensional variational data assimilation for the weather research and forecasting model. *22nd Conf. on Weather Analysis and Forecasting/18th Conf. on Numerical Weather Prediction*, Park City, UT, AMS.[4]

Brown, W., P. B. Chilson, S. Cohn, T. Hock, J. Jordan, D. Law, B. Lindseth, R. Palmer, M. Politovich, 2007: A 449MHz modular wind profiler development study. *Proc. 33rd International Conference on Radar Meteorology*, Cairns, AMS.[4]

Briegleb, B. P., B. Light, 2007: A Delta-Eddington multiple scattering parameterization for solar radiation in the sea ice component of the Community Climate System Model. *NCAR Technical Note*, NCAR/TN-472+STR, 100p.[2]

Brimeyer, T., C. Martin, E. Loew, G. Farquharson, S. Khatri, S. Paul, 2007: A generic radar processor design using software defined radio. *33rd International Conference on Radar Meteorology*, Cairns, American Meteorology Society and Australian Bureau of Meteorology Research, 5.[2]

Hill, C. M., P. J. Fitzpatrick, Q. Xiao, J. Sun, Y. Li, N. Tran, 2007: A HWRF numerical study of the wind field expansion with Hurricane Katrina during a period of rapid intensification. *11th Symposium on Integrated Observing and Assimilation Systems for the Atmosphere, Oceans, and Land Surface*, San Antonio, TX, American Meteorological Society.[4]

Williams, J. K., J. Craig, A. Cotter, J. K. Wolff, 2007: A hybrid machine learning and fuzzy logic approach to CIT diagnostic development. *Proc. 5th Conference on Artificial Intelligence Applications to Environmental Science*, San Antonio, TX, American Meteorological Society, 1.2.[1]

Vassiliadis, D., D. N. Baker, S. F. Fung, S. G. Kanekal, E. J. Rigler, R. S. Selesnick, R. S. Weigel, 2006: A modular radiation-belt electron flux model. *2006 Fall Meeting*, AGU, 42, 7.[4]

Brito, A. T., M. Borbor-Cordova, P. Gagliuffi, M. Riofrio, 2007: A monitoring programme for the Admiralty Bay Antarctic specially managed area. *Proc. 30th Antarctic Treaty Consultative Meeting*, New Delhi.[3]

Smolarkiewicz, P. K., J. Szmelter, 2007: A MPDATA based solver for compressible flows. *ICFD Conference on Numerical Methods For Fluid Dynamics*, Reading.[2]

Aksoy, A., D. C. Dowell, C. Snyder, 2007: A multi-case study of ensemble-based assimilation of radar observations into cloud-resolving WRF using DART. *18th Conference on Numerical Weather Prediction*, Park City, UT, AMS.[1]

Farquharson, G., E. Loew, J. Vivekanandan, W.-C. Lee, 2007: A new high-altitude airborne millimeter-wave radar for atmospheric research. *Proc. International Geoscience and Remote Sensing Symposium*, Barcelona, Institute of Electrical and Electronics, CD.[1]

Farquharson, G., E. Loew, J. Vivekanandan, W.-C. Lee, 2007: A new high-altitude airborne millimeter-wave radar for atmospheric research. *33rd International Conference on Radar Meteorology*, Cairns, American Meteorological Society.[1]

Hsu, H., M. W. Moncrieff, 2006: A new multiscale verification method: The error spectra. *Proc. Developmental Testbed Center Visitor Report*, Boulder, CO, NCAR.[1]

Fitzpatrick, P. J., C. Hill, Y. Li, S. Bhate, Y. Lau, Q. Xiao, 2007: A numerical study of the wind field expansion with Hurricane Katrina during a period of rapid intensification. *22nd Conf. on Weather Analysis and Forecasting/18th Conf. on Numerical Weather Prediction*, Park City, UT, AMS.[4]

Cotter, A., J. K. Williams, R. K. Goodrich, J. A. Craig, 2007: A random-forest turbulence prediction algorithm. *Proc. 5th Conference on Artificial Intelligence Applications to Environmental Science*, San Antonio, TX, American Meteorological Society, 1.3.[1]

Wedi, N. P., P. K. Smolarkiewicz, 2007: A reduced model of the Madden-Julian oscillation. *ICFD Conference on Numerical Methods For Fluid Dynamics*, Reading.[3]

Gelinas, L. J., J. H. Hecht, R. G. Roble, R. Walterscheid, 2006: A seasonal study of mesospheric temperatures and emission

intensities at Adelaide and Alice Springs. *2006 Fall Meeting*, AGU, 21, 221.

Maute, A. I., A. D. Richmond, 2006: A set of empirical models of the high-latitude magnetosphere-ionosphere energy transfer based on dynamic explorer 2 data. *2006 Fall Meeting*, AGU, 13, 259.[1]

Mills, B., R. E. Morss, J. Lazo, H. Brooks, B. G. Brown, P. T. Ganderton, 2006: A societal and economic research and applications agenda for the North American THORPEX programme. *Proc. 2nd THORPEX International Science Symposium*, Landshut, DE, WMO.[4]

Wang, W., S. C. Solomon, M. Wiltberger, A. G. Burns, A. D. Richmond, B. T. Foster, T. L. Killeen, J. G. Lyon, 2006: A study of the magnetosphere-ionosphere-thermosphere coupling and its impact on lower latitude ionosphere. *36th Committee On Space Research Scientific Assembly*, Beijing, 36, 2031.[2]

Coen, J. L., J. D. Beezley, L. S. Bennethum, C. C. Douglas, M. Kim, R. Kremens, J. Mandel, G. Qin, A. Vodacek, 2007: A wildland fire dynamic data-driven application system. *11th Symposium on Integrated Observing and Assimilation Systems for the Atmosphere, Oceans, and Land Surface*, San Antonio, TX, American Meteorological Society, CD-ROM, JP3.12.[4]

Weibring, P., D. Richter, A. Fried, J. Walega, 2007: Airborne Difference Frequency Spectrometer for Ultra Sensitive Formaldehyde Measurements. *Conference on Lasers and Electro-Optics*, Baltimore, MD, OSA.[1]

Manning, K. W., M. G. Duda, J. G. Powers, 2007: AMPS update--June 2007. *2nd Antarctic Meteorological Observation, Modeling and Forecasting workshop*, Rome, PRNA.[1]

Wei, Y., Y. Liu, T. Warner, 2007: An evaluation of 3DVAR, nudging-based FDDA and a hybrid scheme for summer convection forecast using WRF-ARW model. *8th WRF Users' Workshop*.[1]

Wei, Y., Y. Liu, T. Warner, 2007: An evaluation of 3DVAR, nudging-based FDDA and a hybrid scheme for summer convection forecast using WRF-ARW model. *Proc. 22nd Conference on Weather Analysis and Forecasting*, Park City, UT, American Meteorological Society.[1]

Dudhia, J., M. Tewari, F. Chen, 2007: An improvement in moisture flux over snow. *8th WRF Users' Workshop*, Boulder, CO.[1]

Huang, X.-Y., H. Wang, Y. Chen, X. Zhang, S. A. Tjemkes, R. Stuhlmann, 2007: An observing system simulation experiment using both MM5 and WRF: experiment configuration and preliminary results. *8th WRF Users' Workshop*, Boulder, CO, UCAR.[4]

Fitzpatrick, P. J., Q. Xiao, G. J. Holland, Y.-H. Kuo, J. J. Cione, C. M. Hill, 2007: Analysis of hurricanes using Unmanned Aircraft Systems (UAS) and COSMIC satellite data. *11th Symposium on Integrated Observing and Assimilation Systems for the Atmosphere, Oceans, and Land Surface*, San Antonio, TX, American Meteorological Society.[3]

Farr, N., D. N. Baker, M. Wiltberger, 2006: Analysis of the substorm recovery phase using a multisatellite view and LFM MHD simulation. *2006 Fall Meeting*, AGU, 53, 1436.[2]

Knight, C. A., A. L. DeVries, 2007: Antifreeze fundamentals: Explaining the dependence of freezing point upon concentration. *234th National Meeting and Exposition*, Boston, MA, ACS.[2]

Guo, Y.-R., S.-Y. Fan, W. Wang, M. Chen, X.-Y. Huang, Y.-C. Wang, Y.-H. Kuo, 2007: Application of WRFVar (3DVar) to a high resolution (3-km) model over Beijing area. *8th WRF Users' Workshop*, Boulder, CO, UCAR.[4]

Demuth, J., R. E. Morss, J. K. Lazo, A. E. Stewart, 2007: Assessing how the U.S. public understands and uses weather forecast uncertainty information. *16th Conference on Applied Climatology*, San Antonio, TX, AMS.[2]

Barkley, M. P., P. S. Monks, A. J. Hewitt, T. Machida, A. Desai, N. Vinnichenko, T. Nakazawa, M. Y. Arshinov, N. Fedoseev, T. Watai, 2007: Assessing the near surface sensitivity of SCIAMACHY atmospheric CO2 retrieved using (FSI) WFM/DOAS. *Atmospheric Chemistry and Physics Discussions*, 7, 3597-3619.[4]

Kuo, Y.-H., S. Sokolovskiy, R. Anthes, F. Vandenberghe, 2006: Assimilation of GPS radio occultation data for numerical weather prediction. *5th International Conference on Mesoscale Meteorology and Typhoon*, Boulder, CO.[3]

Fox, P., L. Gundersen, K. Lehnert, D. McGuinness, K. Sinha, W. Snyder, 2006: At the fall meeting: Toward broad community collaboration in geoinformatics. *EOS, Transactions, American Geophysical Union*, 87, 513, doi: 10.1029/2006EO460005.[4]

Harasti, P. R., Q. Zhao, J. Cook, M. Frost, S. Potts, L. J. Wagner, J. Pinto, D. Megenhardt, B. Hendrickson, C. Kessinger, 2007: At-sea demonstration of the SPS-48E radar weather extraction capability. *33rd Conference on Radar Meteorology and Cloud Physics*, Cairns, American Meteorological Society, 12B.5.[3]

Hanasoge, S. M., T. L. Duvall, M. L. Derosa, M. S. Miesch, 2007: Can we detect convection in the Sun? *Proc. International Astronomical Union Symposium*, Prague, IAU, Cambridge University Press, 239, 364-369, doi: 10.1017/S1743921307000737.[4]

Ricciuto, D. M., K. Keller, K. J. Davis, A. R. Desai, A. S. Denning, 2007: Carbon cycle data assimilation to improve terrestrial carbon flux diagnosis and prediction. *Proc. U.S. North American Carbon Program (NACP) Investigators Meeting*.[2]

Brun, A. S., M. S. Miesch, J. Toomre, 2007: Challenges of magnetism in the turbulent Sun. *Proc. International Astronomical Union Symposium*, Prague, IAU, Cambridge University Press, 239, 488-493, doi: 10.1017/S1743921307000956.[4]

Powers, J. G., V. Johnson, D. Kiessling, 2007: Challenging forecasts for a challenging environment: An educational module for Antarctic weather and forecasting. *2nd Antarctic Meteorological Observation, Modeling and Forecasting workshop*, Rome, PRNA.[1]

Ye, Q., 2007: China's 1998 Great Yangtze River floods. *Heads Up! Early Warning Systems for Climate, Water and Weather*, Tsinghua University Press, 95-98, doi: ISBN 978-7-302-14633-9.[1]

Politovich, M. K., C. Wolff, B. Bernstein, F. McDonough, 2006: CIP Severity Scientific and Technical Document. *Aviation Weather Technology Transfer Technical Review Panel*, 33pp..[1]

Wang, W., A. G. Burns, W. J. Hughes, J. A. Linker, J. G. Luhmann, L. G. Lyon, Z. Mikic, D. Odstrcil, S. C. Solomon, M. Wiltberger, 2006: CISM space weather modeling of the Sun-to-Earth system. *36th Committee On Space Research Scientific Assembly*, Beijing, 36, 2569.[4]

Podesta, G., F. Bert, B. Rajagopalan, S. Apipattanavis, E. Weber, C. Laciana, W. Easterling, R. W. Katz, D. Letson, 2007: Climate and complexity in agricultural production systems of the Argentine Pampas. *Extended Abstracts, Regional Meeting Integrating Analysis of Regional Climate Change and Response Options*, Nadi, IPCC Task Group on Data &Scenario Support for Impact and Climate Analysis.[2]

McNeeley, S., 2007: Climate change and variability in interior Alaska: An interdisciplinary approach to data integration for understanding regional patterns relevant to stakeholders. *Proc. Amsterdam Conference on Human Dimensions of Global Environmental Change*, Amsterdam, Institute for Environmental Studies.[1]

Trenberth, K. E., 2007: Climate Feedback: the climate change blog. *Nature.com*.[1]

Moser, S. C., 2006: Climate scenarios and projections: The known, the unknown, and the unknowable as applied to California. *Climate scenarios and projections: The known, the unknown, and the unknowable as applied to California*, Aspen Global Change Institute, Ed., Aspen, CO, Aspen Global Change Institute, Aspen Global Change Institute.[1]

Levizzani, V., R. E. Carbone, R. Ginnetti, A. G. Laing, M. Masotti, S. Melani, M. Pasqui, 2007: Climatology of warm season precipitating clouds: first results for Europe and Mediterranean. *Climate and Climate Change: Research Activities of the National Research Council*, B. Carli, G. Cavarretta, M. Colacino, S. Fuzzi, National Research Council, Eds., 113-116.[2]

Barth, M. C., S.-W. Kim, C. Wang, K. E. Pickering, L. E. Ott, G. Stenchikov, M. Leriche, S. Cautenet, J.-P. Pinty, C. Barthe, C. Mari, J. H. Helsdon, R. D. Farley, A. M. Fridlind, A. S. Ackerman, V. Spiridonov, B. Tosko, 2007: Cloud-scale model intercomparison of chemical constituent transport in deep convection. *Atmospheric Chemistry and Physics Discussions*, 7, 8035-8085.[4]

Deng, Y., A. J. Ridley, T. Zhan, M. Larsen, R. Pfaff, 2006: Comparison between GITM simulation and JOULE rocket observation. *2006 Fall Meeting*, San Francisco, CA, AGU, SA12A-07.[4]

Young, K., J. Wang, 2007: Comparison of 10-Year (1996-2005) Operational Radiosonde Data with ARM Radiosonde and Remote Sensing Data. *14th Symposium on Meteorological Observations and Instrumentation*, San Antonio, TX, American Meteorological Society.[1]

Ahijevych, D., G. Bryan, M. Weisman, S. Trier, C. Davis, D. Dowell, 2006: Composite bow echo observed during BAMEX. *23rd Conference on Severe Local Storms*, St. Louis, MO.[1]

Pallamraju, D., S. Chakrabarti, S. Solomon, G. Crowley, 2006: Compositional changes in thermosphere during a geomagnetic storm inferred using ground- based daytime OI 630.0nm optical airglow emissions. *2006 Fall Meeting*, AGU, 13, 264.[4]

Washington, W. M., 2006: Computer modeling the twentieth- and twenty-first-century climate. *Proceedings of the American Philosophical Society*, 150, 414-427.[1]

Desai, A. R., K. J. Davis, P. V. Bolstad, B. Helliker, 2006: Constraining regional CO2 flux with multiple top-down and bottom-up approaches. *Proc. Ameriflux Science Meeting*.[4]

Jee, G., A. Burns, W. Wang, S. C. Solomon, R. W. Schunk, L. Scherliess, D. C. Thompson, J. J. Sojka, L. Zhu, 2006: Continual Initialization of The TING Model with GAIM Electron Densities: Ionospheric Effects on The Thermosphere. *2006 Fall Meeting*, AGU, 13, 263.[2]

Kleypas, J. A., 2007: Coral reef bleaching. *Heads Up! Early Warning Systems for Climate, Water and Weather*, M. H. Glantz, Ed., Tsinghua University Press, 133-136, doi: ISBN 978-7-302-14633-9.[1]

Fan, Y., S. Gibson, 2007: Coronal Mass Ejections Due to Loss of Confinement of Coronal Flux Ropes. *2007 American Astronomical Society Meeting/American Association of Physics Teachers Joint Meeting*, Seattle, WA, American Astronomical Society, 210, 29.19.[1]

Schad, T. A., D. Seely, S. L. Keil, S. Tomczyk, 2007: Coronal seismology: The search for propagating waves in coronal loops. *210th American Astronomical Society Meeting*, Honolulu, HI, American Astronomical Society.[4]

Burkepile, J., S. Tomczyk, H. Lin, T. Zurbuchen, R. Casini, 2007: COSMO: The Coronal Solar Magnetism Observatory. *Proc. 2007 American Astronomical Society Meeting/American Association of Physics Teachers Joint Meeting*, Honolulu, HI, American Astronomical Society, 210, 25.19.[2]

Cobabe-Ammann, E., P. Fox, 2006: Crafting access to the virtual observatories and their data: The challenge of the non-specialist user. *2006 Fall Meeting*, San Francisco, CA, AGU, ED52A-03.[2]

Douglas, C. C., J. D. Beezley, J. Coen, R. E. Ewing, Y. Efendiev, G. Haase, M. Iskandarani, M. Kritz, R. A. Lodder, J. Mandel, G. Qin, A. Vodacek, 2006: DDDAS approaches to wildland fire modeling and contaminant tracking. *Winter Simulation Conference*, Monterey, CA, University of Kentucky.[4]

Brown, B. G., R. E. Morss, J. K. Lazo, H. E. Brooks, P. T. Ganderton, B. N. Mills, 2007: Defining societal and economic research and applications (SERA) priorities related to developments in numerical weather prediction and THORPEX. *18th Conference on Numerical Weather Prediction*, Park City, UT, AMS.[4]

Weibring, P., D. Richter, A. Fried, J. Walega, 2007: Demonstration of a ultra sensitive airborne difference frequency spectrometer. *Field Laser Applications in Industry and Research*, Florence, INOA-CNR, IMK-IFU.[1]

Abell, A., B. Smith, M. Fournier, T. Betz, L. Gaul, J. L. Robles-Lopez, C. A. Carrillo, A. Rodriguez-Trujilllo, C. Moya-Rabelly, O. Velasquez-Monroy, P. Kuri-Morales, L. Anaya-Lopez, M. Hayden, E. Zielinski, J. Munoz, M. Beatty, I. Sosa, S. Wenzel, M. Escobedo, S. Waterman, M. Ramos, B. K. Kapella, H. Mohammed, R. Taylor, J. Brunkard, 2007: Dengue hemorrhagic fever - U.S.-Mexico border, 2005. *MMWR Weekly*, 56(31), 785-789.[4]

Kwak, Y., A. Richmond, 2006: Dependence of the high-latitude lower thermospheric momentum forcing on the interplanetary magnetic field. *2006 Fall Meeting*, AGU, 13, 268.[1]

Kozyra, J. U., R. Barnes, N. J. Fox, P. A. Fox, M. M. Kuznetsova, D. Morrison, D. Pallamraju, V. Papitashvili, A. Ridley, E. R. Talaat, M. Weiss, C. A. Young, L. J. Zanetti, 2006: Developing cyber-infrastructure for addressing grand challenge questions in Sun-Earth system science: First results of a testbed worldwide online conference series. *2006 Fall Meeting*, San Francisco, CA, AGU, IN13B-1167.[4]

Cai, H., J. Wilson, J. Pinto, D. Albo, C. Mueller, 2006: Developing NIWOT ---- a regional 1-6 hr short-term thunderstorm forecast. *5th International Conference on Mesoscale Meteorology and Typhoon*, Boulder, CO, American Meteorological Society.[1]

Politovich, M. K., S. A. Cohn, T. Hock, P. Chilson, C. Martin, 2007: Development of a Modular Profiling Network. *A White Paper to the NSF Mid-Size Infrastructure Account*.[1]

Huang, X.-Y., M. Chen, J.-W. Kim, B. Skamarock, T. Henderson, 2007: Development of digital filter initialization for WRF and its implementation at IUM. *8th WRF Users' Workshop*, Boulder, CO, UCAR.[3]

Kelman, I., 2007: Disaster diplomacy: Hope despite evidence? *Worldwatch Institute Guest Essay*.[1]

Nitta, A., S. J. Kleinman, J. Krzesinski, T. S. Metcalfe, A. Mukadam, F. Mullally, R. E. Nather, D. J. Sullivan, S. E. Thompson, D. E. Winget, M. A. Wood, 2007: Doubling the number of DBVs and a closer look at their instability strip. *Proc. Communications in Asteroseismology*, Vienna, Austrian Academy of Sciences, 150, 249.[4]

Herrmann, S., 2007: Drought in Africa. *Heads Up! Early Warning Systems for Climate, Water and Weather*, M. H. Glantz, Ed., Tsinghua University Press, 111-118, doi: ISBN 978-7-302-14633-9.[1]

Chu, Y., Y.-H. Kuo, J. Braun, C. Zhang, Y. Wang, 2006: Dry bias in the Beijing radiosonde sounding as revealed by the GPS and WVR measurements. *5th International Conference on Mesoscale Meteorology and Typhoon*, Boulder, CO.[4]

Ye, Q., 2007: Dust and sandstorm early warning. *Heads Up! Early Warning Systems for Climate, Water and Weather*, Tsinghua University Press, 87-90, doi: ISBN 978-7-302-14633-9.[1]

Dikpati, M., P. A. Gilman, G. de Toma, 2006: Dynamo-based simulations of solar activity differences between north and south hemispheres and forecasts for cycle 24. *2006 Fall Meeting*, AGU, 22, 6.[1]

St. Cyr, O. C., J. M. Davila, W. Thompson, B. J. Thompson, J. B. Gurman, J. T. Burkepile, G. de Toma, 2007: Early Results from STEREO SECCHI COR1. *2007 American Astronomical Society Meeting/American Association of Physics Teachers Joint Meeting*, Seattle, WA, American Astronomical Society, 210, 119.03.[3]

Kuo, Y.-H., C. Rocken, W. Schreiner, R. A. Anthes, N. Yen, L. Wu, 2007: Early results from the COSMIC/FORMOSAT-3 Mission. *11th Symposium on Integrated Observing and Assimilation Systems for the Atmosphere, Oceans, and Land Surface*, San Antonio, TX, American Meteorological Society.[4]

Dixon, M., C. Kessinger, J. Hubbert, 2006: Echo classification within the spectral domain to discriminate ground clutter from meteorological targets. *22nd International Conference on Interactive Information and Processing Systems for Meteorology, Oceanography and Hydrology*, Atlanta, GA, American Meteorological Society, 9.6.[3]

Lazo, J. K., 2007: Economics of weather impacts and weather forecasts - secure and sustainable living: The societal and economic benefits of weather, climate and water products and services. *8th European Conference on Applications of Meteorology*, Madrid, World Meteorological Organization.[1]

Mayor, S. D., S. M. Spuler, B. M. Morley, S. C. Himmelsbach, R. A. Rilling, T. M. Weckwerth, E. G. Patton, D. H. Lenschow, 2007: Elastic backscatter lidar and in situ observations of sea-breeze fronts in Dixon, California. *7th Conference on Coastal Atmospheric and Oceanic Prediction and Processes*, San Diego, CA, AMS.[3]

Mayor, S. D., B. M. Morley, S. M. Spuler, S. C. Himmelsbach, D. Flanigan, T. M. Weckwerth, T. Warner, 2007: Elastic backscatter lidar observations of a gust front passage over Washington DC on 7 May 2004. *7th Symposium on the Urban Environment*, San Diego, CA, AMS.[3]

Talaat, E. R., J. Yee, G. Crowley, R. Roble, 2006: Energetics of the solar maximum ionosphere, thermosphere and mesosphere. *2006 Fall Meeting*, AGU, 23, 6.[4]

Turner, N. E., J. R. Dwyer, E. J. Mitchell, D. J. Knipp, B. A. Emery, 2006: Energy transfer and geoeffectiveness in CIR-driven and Ejecta-driven magnetic storms. *2006 Fall Meeting*, AGU, 22, 2.[3]

Zhang, F., C. Snyder, 2007: Ensemble-based data assimilation. *Bulletin of the American Meteorological Society*, 88(4), 565-568.[2]

Schaeffer, S., S. P. Burns, D. E. Anderson, J. Sun, C. Yi, D. R. Bowling, 2006: Environmental controls on the delta C13 of forest respired CO2 across a vertical canopy profile in a subalpine coniferous forest. *Proc. 2006 Fall Meeting*, San Francisco, CA, AGU.[3]

Harley, P., J. Greenberg, Ulo. Niinemets, A. Guenther, 2007: Environmental controls over methanol emission from leaves. *Biogeosciences Discussion*, 4, 2593-2640.[1]

Smolarkiewicz, P. K., J. Prusa, A. Wyszogrodzki, 2007: EULAG: A high-resolution computational model for research. *Conference on Mathematical and Computational Issues in the Geosciences*, Santa Fe, NM, SIAM.[4]

Weckwerth, T. M., L. J. Bennett, C. Kiemle, A. M. Blyth, C. Flamant, Y. P. Richardson, 2007: Evolution of the moisture field during the development of the daytime convective boundary layer. *3rd Symposium on Lidar Atmospheric Applications*, San Antonio, TX, American Meteorological Society.[4]

Smith, D. C., E. R. Talaat, J. Yee, T. Woods, R. G. Roble, G. Crowley, 2006: Examination of cadence of solar soft X-ray flux on the ionosphere and thermosphere. *2006 Fall Meeting*, AGU, 13, 273.[4]

Cope, J., T. Voran, M. Woitaszek, A. Boggs, S. McCreary, M. Oberg, H. M. Tufo, 2007: Experiences deploying a 10-gigabit ethernet computing environment to support regional computational science. *Proc. 8th LCI Conference on High Performance Clustered Computing*, South Lake Tahoe, NV, Linux Clusters Institute, CdRom.[2]

Spuler, S. M., S. D. Mayor, 2007: Eye-safe aerosol lidar at 1.5 microns: progress toward a scanning lidar network. *Proc. Society of Photo-Optical Instrument Engineers (SPIE)*, Upendra N. Singh, Ed., San Diego, CA, SPIE, 668102, doi: 10.1117/12.739519.[1]

Guild, T. B., H. E. Spence, J. G. Lyon, C. C. Goodrich, M. Wiltberger, 2006: Fast flow channels in the LFM plasma sheet. *2006 Fall Meeting*, AGU, 51, 1397.[2]

Latham, J., W. A. Petersen, W. Deierling, H. J. Christian, 2007: Field identification of a unique globally dominant mechanism of thunderstorm electrification. *Proc. 13th International Conference on Atmospheric Electricity*.[2]

Gilbert, H., G. deToma, D. Tripathi, 2007: Filament activation due to a Moreton wave observed on Dec. 6, 2006. *2007 American Astronomical Society Meeting/American Association of Physics Teachers Joint Meeting*, Seattle, WA, American Astronomical Society, 210, 25.05.[2]

Wolff, C., F. McDonough, M. K. Politovich, B. C. Bernstein, 2007: FIP Severity Technical Document. *Aviation Weather Technology Transfer Technical Review Panel*, 13pp..[1]

Brown, D. I., M. Haley, F. Clare, R. Grubin, D. Shea, 2007: Frameworks for geoscience data analysis and visualization. *Proc. 2007 Joint Assembly*, Acapulco, American Geophysical Union.[1]

Lu, G., 2006: Geoeffectiveness of High-Speed Streams, Coronal Mass Ejections, and Interplanetary Shocks. *2006 Fall Meeting*, AGU, 33, 5.[1]

Boehnert, J., 2007: Geographic information systems. *Heads Up! Early Warning Systems for Climate, Water and Weather*, M. H. Glantz, Ed., Tsinghua University Press, 20-21, doi: ISBN 978-7-302-14633-9.[1]

Wilhelmi, O., 2006: GIS in weather, climate and impacts. *GIS in weather, climate and impacts*, UCAR/NCAR.[1]

Ridley, A. J., Y. Deng, D. Pawlowski, H. Liu, 2006: Global ionosphere thermosphere model results of the Halloween storm. *2006 Fall Meeting*, San Francisco, CA, American Geophysical Union, SA13A-0270.[2]

Gilman, P. A., M. Dikpati, M. S. Miesch, 2007: Global MHD instabilities in a three-dimensional thin-shell model of solar tachocline. *Proc. The Astrophysical Journal, Supplement Series*, Sheffield, 170, 203, doi: 10.1086/512016.[1]

Eastes, R., L. Andersson, W. McClintock, A. Aksnes, D. Anderson, A. Burns, M. Codrescu, R. Daniell, F. Eparvier, J. Harvey, A. Krywonos, M. Lankton, J. Lumpe, G. Prolss, A. Richmond, D. Rusch, S. Solomon, D. Strickland, T. Woods, 2006: Global-scale Observations of the Limb and Disk (GOLD): Continuous, global-scale ultraviolet observations of Earth. *2006 Fall Meeting*, AGU, 33, 337.[4]

McClintock, W., M. Lankton, R. Estes, A. Aksens, D. Anderson, L. Andersson, M. Codrescu, A. Burns, R. Daniell, F. Eparvier, J. Harvey, A. Krywonos, J. Lumpe, G. Prolss, T. Woods, A. Richmond, D. Rusch, S. Solomon, D. Strickland, 2006: Global-scale Observations of the Limb and Disk (GOLD): Mission implementation. *2006 Fall Meeting*, AGU, 41, 1413.[4]

Eastes, R., W. McClintock, A. Aksnes, D. Anderson, L. Andersson, A. Burns, M. Codrescu, R. Daniell, F. Eparvier, J. Harvey, A. Krywonos, J. Lumpe, G. Prolss, A. Richmond, D. Rusch, S. Solomon, D. Strickland, T. Woods, 2006: Global-scale Observations of the Limb and Disk (GOLD): Science objectives. *2006 Fall Meeting*, AGU, 43, 6.[4]

Brun, A. S., M. S. Miesch, J. Toomre, 2006: Global-scale turbulent convection and magnetic dynamo action in the solar envelope. *arXiv:astro-ph*, 10073.[2]

Glantz, M. H., 2007: Heads Up! Early warning systems for climate, water, and weather. *Heads Up! Early Warning Systems for Climate, Water and Weather*, M. H. Glantz, Ed., Tsinghua University Press, 173 pp, doi: ISBN 978-7-302-14633-9.[4]

Richter, D., B. P. Wert, P. Weibring, J. G. Walega, A. Fried, 2007: High-precision Carbon Isotope Laser Absorption Spectrometer (CILAS). *2007 International Workshop on Stable Isotope Ratio Infrared Spectrometry*, Florence, INTROP.[2]

Ichimoto, K., Y. Suematsu, S. Tsuneta, Y. Katsukawa, M. Shimojo, M. Kubo, T. Shimizu, R. Shine, T. Tarbell, A. Title, B. Lites, D. Elmore, T. Yokoyama, S. Nagaka, 2007: Hinode/SOT Observation of Fine Structure of the Evershed Flow. *Proc. 210th American Astronomical Society Meeting*, Honolulu, HI, American Astronomical Society.[4]

Glantz, M. H., 2007: How about a spare-time university? *WMO Bulletin*, 56(2), 126-129.[1]

Xiao, Q., X. Zhang, C. Davis, J. Tuttle, G. Holland, P. Fitzpatrick, 2007: Hurricane initialization using airborne doppler radar data for WRF. *8th WRF Users' Workshop*, Boulder, CO, UCAR.[2]

Glantz, M. H., 2006: Hurricane Katrina rekindles thoughts about fallacies of a so-called "natural" disaster. *Natural Disasters: Management and Preparedness*, P. S. Ranade, Ed., ICFAI University Press, 138-147.[1]

Glantz, M. H., 2007: Hurricane Katrina: Good forecast, poor response. *Heads Up! Early Warning Systems for Climate, Water and Weather*, M. H. Glantz, Ed., Tsinghua University Press, 30-33, doi: ISBN 978-7-302-14633-9.[1]

Luhmann, J. G., Y. Li, B. Lynch, M. Wiltberger, D. Odstrcil, J. A. Linker, P. Riley, 2006: ICME polarity: it's origins and effects on the magnetosphere, and STEREO's potential for resolving key problems. *2006 Fall Meeting*, AGU, SM22A-01.[4]

Kumar, A., F. Chen, K. Manning, M. Ek, K. Mitchell, 2007: Impact of canopy resistance formulation on the long-term evolution of soil moisture and evaporation. *21st Conference on Hydrology*, San Antonio, TX, AMS.[3]

Schuster, D. C., S. J. Worley, N. C. Wilhelmi, B. Raoult, M. Fuentes, J. Urban, 2007: Implementation of the phase I of TIGGE. *Proc. 87th AMS Annual Meeting*, San Antonio, TX, American Meteorological Society, 1B.2.[3]

Rigler, E. J., M. Wiltberger, 2006: Improving global magnetosphere models with optimized ionospheric boundary conditions.

*2006 Fall Meeting*, AGU, 21, 276.[1]

Fransen, T., O. Wilhelmi, 2007: Increasing societal resilience to winter weather. *Proc. 16th Conference on Applied Meteorology*, San Antonio, TX, American Meteorological Society, 3.10.[3]

Lopez Ariste, A., R. Casini, 2006: Inference of the Magnetic Field in Spicules from Spectro-Polarimetry of He I D3. *Proc. Solar Polarization 4, Astronomical Society of the Pacific Conference Series*, R. Casini and B. W. Lites, Ed., Boulder, CO, Astronomical Society of the Pacific, 358, 443.[3]

Zagar, N., E. Andersson, M. Fisher, A. Untch, 2007: Influence of quasi-biennial oscillation on the ECMWF model short-range forecast errors in the tropical stratosphere. *ECMWF Technical Memo*, 534, 19 pp.[4]

Trier, S. B., F. Chen, K. W. Manning, 2007: Influences of land-atmosphere interactions on precipitation during 9-21 June IHOP-2002. *21st Conference on Hydrology*, San Antonio, TX.[1]

Xiao, Q., C. Davis, X. Zhang, J. Tuttle, G. Holland, Y.-H. Kuo, 2007: Initialization of Hurricane Jeanne (2004) using airborne doppler radar data. *11th Symposium on Integrated Observing and Assimilation Systems for the Atmosphere, Oceans, and Land Surface*, San Antonio, TX, American Meteorological Society.[1]

Smolarkiewicz, P. K., A. Dornbrack, 2007: Integrating adiabatic Durran's equations. *ICFD Conference on Numerical Methods For Fluid Dynamics*, Reading.[3]

Dixon, M., J. C. Hubbert, S. Ellis, C. Kessinger, G. Meymaris, 2007: Intelligent mitigation of normal and anomalous propagation clutter. *33rd International Conference on Radar Meteorology*, Cairns, American Meteorological Society.[1]

Moser, S. C., 2007: Is California preparing for sea-level rise? The answer is disquieting. *California Coast and Ocean*, 22(4), 24-30.[1]

Schmidli, J., G. S. Poulos, 2007: Large-scale influences on mesoscale valley circulations in a deep valley. *Proc. 12th Conference on Mesoscale Processes*, Waterville Valley, NH, AMS.[1]

Sun, J., M. Chen, X. Tan, Y. Wang, 2006: Low-level wind analysis and prediction during Beijing 2006 forecast demonstration project. *5th International Conference on Mesoscale Meteorology and Typhoon*, Boulder, CO.[3]

Ichimoto, K., Y. Suematsu, T. Shimizu, Y. Katsukawa, S. Tsuneta, T. D. Tarbell, R. A. Shine, C. M. Hoffmann, A. M. Title, B. W. Lites, D. F. Elmore, K. V. Streander, 2006: Magnetic field diagnostic capability of solar-B/SOT: Filtergraph instrument. *Proc. Solar Polarization 4, Astronomical Society of the Pacific Conference Series*, R. Casini and B. W. Lites, Ed., Boulder, CO, Astronomical Society of the Pacific, 358, 189.[3]

Ouellette, J., B. N. Rogers, M. J. Wiltberger, M. A. Shay, J. G. Lyon, 2006: Magnetopause reconnection in the LFM code. *2006 Fall Meeting*, AGU, 41, 1453.[2]

Weigel, R. S., M. Wiltberger, 2006: Magnetospheric activity during undriven recovery. *2006 Fall Meeting*, AGU, 53, 6.[2]

Wilhite, D. A., D. M. Diodato, K. Jacobs, R. Palmer, B. Raucher, K. Redmond, D. Sada, K. Helm-Smith, J. Warwick, O. Wilhelmi, 2007: Managing drought: A roadmap for change in the United States. *Managing Drought: A Roadmap for change in the United States*, Longmont, CO, Geological Society of America.[4]

Leblanc, T., I. S. McDermid, J. Howe, R. Aspey, T. D. Walsh, H. Voemel, T. G. McGee, L. Twigg, G. Sumnicht, D. Whiteman, B. Demoz, R. Connell, D. Venable, R. Forno, M. Cadirola, G. McIntire, L. Miloshevich, 2007: Measurements of humidity in the atmosphere: validation experiments (MOHAVE) overview of the campaign and first results. *Annual Meeting American Meteorological Society*, San Antonio, TX.[4]

Burns, S. P., R. K. Monson, M. V. Losleben, A. A. Turnipseed, M. W. Williams, N. P. Molotch, 2006: Measurements of snowpack temperature in a Colorado subalpine forest. *2006 Fall Meeting*, AGU.[2]

Bryan, G. H., M. L. Weisman, 2006: Mechanisms for the production of severe surface winds in a simulation of an elevated convective system. *23rd Conference on Severe Local Storms*, St. Louis, MO.[1]

Lazo, J. K., T. J. Teisberg, R. F. Weiher, 2007: Methodologies for assessing economic benefits of national meteorological and hydrological services. *Secure and Sustainable Living: The Societal and Economic Benefits of Weather, Climate and Water Products and Services*, Madrid, World Meteorological Organization.[3]

Wiltberger, M., R. Weigel, 2006: MHD experiments to isolate different influences on seasonal variation in MI coupling. *2006 Fall Meeting*, AGU, 53, 3.[2]

Petch, J., N. McFarlane, D. Pendlebury, M. C. Barth, T. Birner, 2007: Modeling of deep convection and chemistry in the tropical tropopause layer: outcomes from the SPARC-GEWEX-IGAC workshop. *GEWEX News*, 10-12.[4]

Barth, M., T. Birner, N. McFarlane, D. Pendlebury, J. Petch, 2006: Modeling of deep convection and of chemistry and their roles in the tropical tropopause layer: SPARC-GEWEX/GCSS-IGC Workshop. *IGACtivities newsletter*, Victoria, BC, SPARC-GEWEX/GCSS-IGC, n34.[4]

Barth, M., T. Birner, N. McFarlane, D. Pendlebury, J. Petch, 2007: Modeling of deep convection and of chemistry and their roles in the tropical tropopause layer: SPARC-GEWEX/GCSS-IGC Workshop. *Stratospheric Processes and their Role in Climate Newsletter*, Victoria, BC, SPARC-GEWEX/GCSS-IGC, n28, 7-11.[4]

Maruyama, N., T. J. Fuller-Rowell, M. V. Codrescu, D. N. Anderson, A. D. Richmond, A. Maute, S. Sazykin, F. R. Toffoletto, R. W. Spiro, R. A. Wolf, G. H. Millward, 2006: Modeling of the storm-time ionospheric electric fields. *2006 Fall Meeting*, AGU, 41, 1396.[2]

Qian, L., S. C. Solomon, B. R. Bowman, T. J. Kane, 2006: Modeling the semiannual variation of thermospheric neutral density. *2006 Fall Meeting*, AGU, 12, 2.[4]

Burns, A. G., M. Mendillo, W. Wang, T. L. Killeen, S. C. Solomon, 2006: Modelling the rate of recovery from geomagnetic storms at solar maximum and minimum. *2006 Fall Meeting*, AGU, 23, 4.[3]

Lyon, J., V. Merkin, M. Wiltberger, 2006: Multi-fluid simulations of the magnetosphere-ionosphere interaciotn and convection. *2006 Fall Meeting*, AGU, 44, 4.[2]

Coen, J. L., 2006: Multiple fire interactions. *5th International Conference on Forest Fire Research*, Coimbra, ADAI/CEIF, 12.[1]

Schmidli, J., G. S. Poulos, F. K. Chow, M. H. Daniels, 2007: Nocturnal flow dynamics and pressure-driven channeling in a deep valley. *Proc. 29th International Conference on Alpine Meteorology*, Chambery, Meteo-France.[2]

Rempel, M., 2006: Non-kinematic flux-transport dynamos and torsional oscillations. *SOHO/18/GONG2006/HELAS I Conference*, Karen Fletcher, Ed., Sheffield, European Space Agency SP-624, 624, 18.4.[1]

Moser, S. C., 2007: Nor'easters. *Heads Up! Early Warning Systems for Climate, Water and Weather*, M. H. Glantz, Ed., Tsinghua University Press, 57-60, doi: ISBN 978-7-302-14633-9.[1]

Garcia, J. H., P. Fox, P. West, 2006: Object persistence within information systems, how relational databases and data access frameworks interoperate with ontology based portals. *2006 Fall Meeting*, San Francisco, CA, AGU, IN43C-0920.[1]

Davis, C. A., B. G. Brown, R. Bullock, 2006: Object-based verification of precipitation forecasts from different models. *2nd THORPEX International Science Symposium*, Landshut.[1]

Wu, W., G. Danabasoglu, W. G. Large, 2006: On the effects of parameterized Mediterranean overflow on North Atlantic ocean circulation and climate. *2006 Fall Meeting*, American Geophysical Union, OS51B-1056.[1]

Liu, H., 2006: On the large wind shear above the mesopause. *2006 Fall Meeting*, AGU, 12, 8.[1]

Wilson, D. K., E. L. Andreas, C. L. Pettit, E. Patton, P. P. Sullivan, J. W. Weatherly, 2006: On the predictability of sound propagation from vertical profile observations. *12th International Symposium on Long Range Sound Propagation*, New Orleans, LA.[3]

Potter, N., P. West, J. Gallagher, J. Garcia, P. Fox, 2006: OPeNDAP Server4: Building a high-performance server for the DAP by leveraging existing software. *2006 Fall Meeting*, San Francisco, CA, AGU, IN13D-1181.[3]

Moncrieff, M. W., 2006: Orogenic organized propagating convective systems: Dynamics, parameterization, and numerical prediction. *Report No. 39/2006 - Mathematical Theory and Modelling in Atmosphere-Ocean Science Workshop*, Mathematisches Forschungsinstitut Oberwolfach, 2313-2314.[1]

Barker, D. M., J. R. Bray, M. Demirtas, H. Huang, Z. Liu, H. Shao, Q. Xiao, 2007: Overview of recent developments and results from WRF-Var. *8th WRF Users' Workshop*, Boulder, CO, UCAR.[1]

Klemp, J., 2006: Overview of the WRF model and model dynamics. *Proc. Joint US/Taiwan WRF Workshop*.[1]

Gibson, S. E., Y. Fan, 2006: Partially ejected flux ropes: Implications for space weather. *Proc. Symposium No. 233 on Solar Activity and its Magnetic Origin*, Cairo, IAU, 319.[1]

Moser, S. C., 2007: Passing the buck: Money, leadership, and responsibility for adaptation to sea-level rise. *Proc. Proceedings of Coastal Zone '07*, Charleston, SC, NOAA Coastal Services Center.[1]

Powers, J. G., K. W. Manning, 2007: Polar WRF testing in Antarctica. *8th WRF Users' Workshop*, Boulder, CO, UCAR.[1]

Beck, C., W. Schmidt, L. R. Bellot Rubio, R. Schlichenmaier, P. Suetterlin, B. W. Lites, 2006: Polarimetric observations of the formation of a G-band bright point. *Proc. Solar Polarization 4, Astronomical Society of the Pacific Conference Series*, R. Casini and B. W. Lites, Ed., Boulder, CO, Astronomical Society of the Pacific, 358, 72.[3]

Moser, S. C., L. Dilling, 2007: Preface. *Creating a Climate for Change: Communicating Climate Change and Facilitating Social Change*, S. C. Moser and L. Dilling, Ed., Cambridge University Press, ix-xii.[2]

Richter, D., J. G. Walega, P. Weibring, A. Fried, M. Trainer, 2007: Preliminary results of formaldehyde measurements during TexAQS 2006. *NOAA Workshop*, Austin, TX, NOAA.[3]

Huang, X.-Y., Q. Xiao, W. Huang, D. Barker, J. Michalakes, J. Bray, Y.-R. Guo, H.-C. Lin, Y.-H. Kuo, 2006: Preliminary results of WRF 4D-Var. *7th International Workshop on Adjoint Applications in Dynamic Meteorology*, Tyrol, University of Innsbruck.[1]

Middleton, D., D. McGuinness, P. Fox, 2006: Progress in earth and space science infrastructure: Grids, frameworks and semantics. *2006 Fall Meeting*, San Francisco, CA, AGU, IN21A-1210.[2]

Glantz, M. H., 2007: Prototype training workshop on Water Affairs. *Proc. Prototype Training Workshop on Water Affairs*, Hanoi, World Meteorological Organization, UCAR/NCAR, 33 pp.[4]

Lopez Ariste, A., J. C. Ramirez Velez, S. Tomczyk, R. Casini, M. Semel, 2006: Quiet-sun magnetism seen with a Mn line: km-sized magnetic structures. *Proc. Solar Polarization 4, Astronomical Society of the Pacific Conference Series*, R. Casini and B. W. Lites, Ed., Boulder, CO, Astronomical Society of the Pacific, 358, 54.[3]

Trainer, M., E. Atlas, J. de Gouw, F. Flocke, A. Fried, J. Holloway, A. Neuman, J. Nowak, J. Peischl, D. Richter, T. Ryerson, J. Walega, C. Warnecke, P. Weibring, W. Zheng, 2007: Rapid and efficient production of ozone over Houston, October 6, 2006 - a case study. *NOAA Workshop*, Austin, TX, NOAA.[4]

Hubbert, J. C., M. Dixon, C. J. Kessinger, 2007: Real time clutter identification and mitigation for NEXRAD. *23rd International Conference on Interactive Information and Processing Systems for Meteorology, Oceanography and Hydrology*, San Antonio, TX, American Meteorological Society.[1]

Desai, A. R., D. S. Schimel, K. J. Davis, W. J. Sacks, 2007: Regional carbon fluxes by simultaneous assimilation of multiple flux towers in a simple ecosystem model. *Proc. U.S. North American Carbon Program (NACP) Investigators Meeting*.[2]

Kelman, I., E. Karnes, M. Brownlee, L. M. Hanthorn, 2006: Relocalisation as a disaster risk management education tool. *RiskPost (New Zealand Society for Risk Management)*, 6(2), 4-5.[1]

Herrmann, S., 2007: Remote sensing for early warning. *Heads Up! Early Warning Systems for Climate, Water and Weather*, M. H. Glantz, Ed., Tsinghua University Press, 22-24, doi: ISBN 978-7-302-14633-9.[1]

Mann, M. E., S. Rutherford, E. Wahl, C. M. Ammann, 2007: Reply to comment on "Testing the fidelity of methods used in proxy-based reconstructions of past climate. *Journal of Climate*, 20, 3699-3703.[4]

Richter, J. H., M. A. Geller, R. R. Garcia, F. Zhang, 2007: Report on the Gravity Wave Retreat. *Stratospheric Processes and their Role in Climate Newsletter*, 28, 26-27.[3]

Klemp, J. B., 2006: Research community priorities for WRF-system development. *WRF Research Applications Board*.[1]

Spuler, S., B. Morley, S. Mayor, 2007: Research into the high-spectral resolution lidar technique as means of calibration for the Raman-shifted Eye-Safe Aerosol Lidar. *Research into the high-spectral resolution lidar technique as means of calibration for the Raman-shifted Eye-Safe Aerosol Lidar*, 13pp..[1]

Katz, R. W., 2007: Review of "Statistical methods in the atmospheric sciences," by D. S. Wilks. *Bulletin of the American Meteorological Society*, 88, 741-743.[1]

Kelman, I., 2007: Review of Marshall Frech's "The Water's Edge". *Weather and Society Watch*, 1(2), 9.[1]

Catlett, C., S. Goasguen, J. Marsteller, S. Martin, D. Middleton, K. J. Price, A. Shankar, V. Welch, N. Wilkins-Diehr, 2007: Science Gateways on the TeraGrid. *Proc. TeraGrid '07*, Madison, WI, TeraGrid.[4]

Moser, S. C., 2007: Sea-level rise. *Heads Up! Early Warning Systems for Climate, Water and Weather*, M. H. Glantz, Ed., Tsinghua University Press, doi: ISBN 978-7-302-14633-9.[1]

Fang, T., J. Liu, A. Richmond, P. Chang, C. Lin, 2006: Seasonal Variation of the Global Ionosphere. *2006 Fall Meeting*, AGU, 33, 272.[4]

Qian, L., R. G. Roble, S. C. Solomon, T. J. Kane, 2007: Secular change in the coupled thermosphere and ionosphere system. *2007 Spring Meeting*, Acapulco, American Geophysical Union.[2]

McGuinness, D. L., P. Fox, L. Cinquini, J. Benedict, P. West, J. Garcia, T. Darnell, D. Middleton, 2006: Semantic web cyberinfrastructure for virtual observatories. *2006 Fall Meeting*, San Francisco, CA, AGU, IN43D-02.[3]

Raskin, R., P. Fox, D. McGuinness, K. Sinha, 2006: Semantically-enabled science data integration: Current progress. *2006 Fall Meeting*, San Francisco, CA, AGU, IN43D-05.[3]

Cinquini, L., D. McGuinness, P. Fox, P. West, T. Darnell, J. Garcia, J. Benedict, D. Middleton, 2006: Semantics and interopability in the virtual solar-terrestrial observatory. *2006 Fall Meeting*, San Francisco, CA, AGU, IN41B-0890.[3]

Morss, R., 2007: Severe weather. *Heads Up! Early Warning Systems for Climate, Water and Weather*, M. H. Glantz, Ed., Tsinghua University Press, 69-74, doi: ISBN 978-7-302-14633-9.[1]

Wierzbicki, A., C. A. Knight, C. N. Henderson, 2007: Significance of non-polar interactions at the water-ice interface for non-equilibrium antifreeze activity. *234th National Meeting and Exposition*, Boston, MA, ACS.[2]

Lotko, W., J. Lyon, P. Melanson, D. Murr, M. Wiltberger, 2006: Simulated response of the magnetosphere-ionosphere system to different forms of empirically regulated ionospheric outflows. *2006 Fall Meeting*, AGU, 11, 8.[2]

Browning, M. K., M. S. Miesch, A. S. Brun, J. Toomre, 2007: Simulations of solar magnetic dynamo action in the convection zone and tachocline. *Proc. International Astronomical Union Symposium*, Prague, IAU, Cambridge University Press, 239, 510-512, doi: 10.1017/S1743921307001020.[4]

Romero-Lankao, P., 2007: Socioeconomic impacts of multiple stresses on cities. *Understanding Multiple Environmental Stresses: Report of a Workshop*, 127-133.[1]

Zita, E. J., J. Maxwell, N. Song, M. Dikpati, 2006: Solar physics at Evergreen: Solar dynamo and chromospheric MHD. *2006 American Astronomical Society Meeting/American Association of Physics Teachers Joint Meeting*, American Astronomical Society, 209, 14.04.[2]

Casini, R., B. W. Lites, 2006: Solar polarization 4. *Proc. Solar Polarization 4, Astronomical Society of the Pacific Conference Series*, R. Casini and B. W. Lites, Ed., Boulder, CO, Astronomical Society of the Pacific.[1]

Fuller-Rowell, T., A. Richmond, N. Maruyama, 2006: Sources of electrodynamic variability at mid and low latitudes: Quiet and disturbed. *2006 Fall Meeting*, AGU, 44, 1.[4]

Ahijevych, D. A., B. Brown, E. Ebert, E. Gilleland, C. Davis, L. Holland, 2007: Spatial verification of high-resolution weather forecasts: beyond traditional metrics. *22nd Conf. on Weather Analysis and Forecasting/18th Conf. on Numerical Weather Prediction*, Park City, UT.[3]

Smolarkiewicz, P., 2006: Spectral preconditioners for non-hydrostatic atmospheric models. *Clive Temperton Symposium-from FFT to SL2TL and Adjoint*, Reading.[1]

Rosenberg, D., A. Pouquet, K. Germanschewski, C.-S. Ng, A. Bhattacharjee, 2006: Spectral-element adaptive refinement magnetohydrodynamic simulations of the island coalescence instability. *Proc. 48th Annual Meeting of the Division of Plasma Physics*, Philadelphia, PA, American Physics Society, 51, 167.[2]

Meymaris, G., J. K. Williams, 2007: Spectrum width estimators for the NEXRAD ORDA: evaluation and recommendation. *Proc. 23rd International Conference on Interactive Information and Processing Systems for Meteorology, Oceanography and Hydrology*, San Antonio, TX, American Meteorological Society, 5B.5.[1]

Gibson, S. E., Y. Fan, 2007: Splitting flux ropes: Modeling the eruption of magnetic structures on the Sun. *2007 American Astronomical Society Meeting/American Association of Physics Teachers Joint Meeting*, Seattle, WA, American Astronomical Society, 210, 58.06.[1]

Huang, X.-Y., Q. Xiao, Xin. Zhang, J. Michalakes, W. Huang, D. M. Barker, J. Bray, Z. Ma, T. Henderson, J. Dudhia, X. Zhang, D.-J. Won, Y. Chen, Y.-R. Guo, H.-C. Lin, Y.-H. Kuo, 2007: Status of WRF 4D-Var. *8th WRF Users' Workshop*, Boulder, CO, UCAR.[4]

Pinto, J., C. Kessinger, B. Hendrickson, D. Megenhardt, P. R. Harasti, Q. Xu, P. Zhang, Q. Zhao, M. Frost, J. Cook, S. Potts, 2007: Storm characterization and short term forecasting potential using a phased array radar. *33rd International Conference on Radar Meteorology*, Cairns, American Meteorological Society, P5.18.[3]

Miesch, M. S., A. S. Brun, M. L. DeRosa, J. Toomre, 2007: Structure and evolution of giant cells in global models of solar convection. *Proc. 210th American Astronomical Society Meeting*, Honolulu, HI, AAS.[4]

Miesch, M. S., N. N. Mansour, T. Hartlep, 2006: Subgrid-scale modeling in solar convection simulations. *Summer Program 2006*, Center for Turbulence Research, National Technical Information Service, 111-121.[3]

Washenfelder, R. A., G. C. Toon, Z. Yang, G. K. Aleks, P. O. Wennbert, A. R. Desai, D. M. Ricciuto, A. E. Answers, 2006: Surface exchange of CO2 observed by column measurements. *Proc. EOS, Transactions, American Geophysical Union*.[2]

Niciejewski, R., W. Skinner, M. Cooper, A. Marshall, T. Killeen, Q. Wu, S. Solomon, D. Ortland, 2006: Systematic Observations of High Latitude Dynamics in the Mesosphere and Lower Thermosphere (MLT) From Orbit. *2006 Fall Meeting*, AGU, 21, 215.[2]

Schmidli, J., G. S. Poulos, S. Mobbs, 2007: T-REX EOPs III: Mesoscale valley circulations and sensitivity to synoptic conditions. *Proc. 29th International Conference on Alpine Meteorology*, Chambery, Meteo-France.[2]

Cai, H., R. Roberts, D. Megenhardt, E. Nelson, M. Steiner, 2007: Tackling the challenge of nowcasting elevated convection. *33rd International Conference on Radar Meteorology*, Cairns, American Meteorological Society.[1]

Pietarila, A., H. Socas-Navarro, T. Bogdan, 2007: The Ca IR Triplet as a diagnostic for chromospheric magnetism in The Physics of Chromospheric Plasmas. *Proc. The Physics of Chromospheric Plasmas, Astronomical Society of the Pacific Conference Series*, Heinzel, P.; Dorotovic, I.; and Rutten, R. J., Eds., Coimbra, Astronomical Society of the Pacific, 368, 139.[1]

Creevey, O., M. J. P. F. G. Monteiro, T. S. Metcalfe, T. M. Brown, 2006: The complementary roles of interferometry and asteroseismology. *Proc. SOHO/18/GONG2006/HELAS I Conference*, Sheffield, ESA, 18, 114.1.[4]

Tomczyk, S., T. Zurbuchen, J. Kuhn, H. Lin, P. Judge, J. Burkepile, R. Casini, 2006: The Coronal Solar Magnetic Observatory (COSMO). *2006 Fall Meeting*, AGU, 12, 3.[2]

de Toma, G., J. T. Burkepile, O. C. St. Cyr, 2007: The declining and minimum phase of solar cycle 23. *2007 American Astronomical Society Meeting/American Association of Physics Teachers Joint Meeting*, Seattle, WA, American Astronomical Society, 210, 92.08.[3]

Sankarasubramanian, K., B. Lites, C. Gullixson, D. Elmore, S. Hegwer, K. Streander, T. Rimmele, S. Fletcher, S. Gregory, M. Sigwarth, 2006: The diffraction limited spectro-polarimeter. *Proc. Solar Polarization 4, Astronomical Society of the Pacific Conference Series*, R. Casini and B. W. Lites, Ed., Boulder, CO, Astronomical Society of the Pacific, 358, 201.[3]

Rempel, M., M. Schuessler, 2006: The dynamical disconnection of sunspots from their magnetic roots. *Proc. Solar MHD Theory and Observations: A High Spatial Resolution Perspective, Astronomical Society of the Pacific Conference Series*, J. Leibacher, R. F. Stein, and H. Uitenbroek, Eds., Sunspot, NM, Astronomical Society of the Pacific, 354, 148.[3]

Casini, R., R. Manso Sainz, 2006: The effect of turbulent electric fields on the scattering polarization of hydrogen lines. *Proc. Solar Polarization 4, Astronomical Society of the Pacific Conference Series*, R. Casini and B. W. Lites, Ed., Boulder, CO, Astronomical Society of the Pacific, 358, 429.[3]

Garner, T. W., G. Crowley, A. Richmond, R. G. Roble, 2006: The effects of mid and low latitude electric fields upon the ionosphere and magnetosphere. *2006 Fall Meeting*, AGU, 11, 365.[4]

Chen, L., Q. Xiao, 2007: The evaluation of hurricane BDA scheme with WRF 3D-Var. *8th WRF Users' Workshop*, Boulder, CO, UCAR.[1]

Xu, J., A. K. Smith, W. Yuan, H. Liu, Q. Wu, M. G. Mlynczak, 2006: The global structure and long term variations of the temperature observed by TIMED/SABER. *2006 Fall Meeting*, AGU, 21, 218.[3]

Judge, P. G., 2007: The HAO spectral diagnostic package for emitted radiation (HAOS-DIPER) Reference Guide (Version 1.0). *NCAR Technical Note*, NCAR/TN-473+473, 82.[1]

Fitzpatrick, P. J., Q. Xiao, J. Sun, E. Lim, C. M. Hill, Y. Li, N. Tran, J. L. Dyer, 2007: The impact of assimilating radar and SCAN data on a WRF simulation of a Mississippi Delta squall line. *11th Symposium on Integrated Observing and Assimilation Systems for the Atmosphere, Oceans, and Land Surface*, San Antonio, TX, American Meteorological Society.[4]

Lim, E., Q. Xiao, J. Sun, P. J. Fitzpatrick, Y. Li, J. L. Dyer, 2007: The impact of doppler radar data on rainfall forecast: A cave study of a convective rainband event in Mississippi Delta using WRF 3D-Var. *Proc. 22nd Conf. on Weather Analysis and Forecasting/18th Conf. on Numerical Weather Prediction*, Park City, UT, AMS.[2]

Fitzpatrick, P. J., Y. Lim, E. Lim, Q. Xiao, C. Hill, J. Sun, 2007: The impact of radar data assimilation on a squall line in Mississippi. *22nd Conf. on Weather Analysis and Forecasting/18th Conf. on Numerical Weather Prediction*, Park City, UT, AMS.[4]

Emery, B. A., D. S. Evans, M. S. Greer, E. Holeman, K. Kadinsky-Cade, F. J. Rich, W. Xu, 2006: The low energy auroral electron and ion hemispheric power after NOAA and DMSP intersatellite adjustments. *NCAR Technical Note*, National Center for Atmospheric Research, NCAR/TN-470+STR, 1-63.[4]

Skinner, W. R., R. Niciejewski, S. Solomon, Q. Wu, T. Killeen, D. Ortland, A. R. Marshall, M. L. Cooper, 2006: The MLT wind field during the declining phase of solar cycles 22 and 23. *2006 Fall Meeting*, AGU, 24, 6.[4]

Kelman, I., 2007: The myth of 9/11. *Disaster and Social Crisis Research Network Electronic Newsletter*, 28, 4.[1]

Gochis, D. J., R. W. Higgins, 2007: The path to improving predictions of the North American Monsoon. *Newsletter, U.S. CLIVAR Variations*, 5(1), 39306.[3]

Cobabe-Ammann, E., P. Fox, 2006: The plague of too much data? Challenges and opportunities for using virtual observatories in the classroom. *2006 Fall Meeting*, San Francisco, CA, AGU, ED42A-02.[2]

Schlosser, E., J. G. Powers, M. G. Duda, K. W. Manning, 2007: The precipitation regime of Dronning Maud Land Antarctica derived from AMPS (Antarctic Mesoscale Prediction System) archive data. *2nd Antarctic Meteorological Observation, Modeling and Forecasting workshop*, Rome, PRNA.[2]

Metcalfe, T. S., 2007: The production rate and employment of Ph.D. astronomers. *210th American Astronomical Society Meeting*, Honolulu, HI, AAS.[1]

Wierzbicki, A., C. A. Knight, P. A. Cziko, 2007: The role of non-polar interactions in the antifreeze activity of random alanine-lysine polypeptides. *233rd National Meeting and Exposition*, Chicago, IL, American Chemical Society.[3]

Fox, P., D. McGuinness, R. Raskin, K. Sinha, 2006: The technology behind data integration with semantics. *2006 Fall Meeting*, San Francisco, CA, AGU, IN24A-05.[3]

Fan, Y., 2007: The three-dimension evolution of buoyant magnetic flux tubes in the solar convective envelope. *2007 American Astronomical Society Meeting/American Association of Physics Teachers Joint Meeting*, Seattle, WA, American Astronomical Society, 210, 24.04.[1]

Fox, P., 2006: The virtual observatory as critical scientific cyber infrastructure. *2006 Fall Meeting*, AGU, 43, 3.[1]

West, P., L. Cinquini, P. Fox, D. L. McGuinness, J. Benedict, T. Darnell, J. Garcia, D. Middleton, 2006: The virtual solar-terrestrial observatory production release. *2006 Fall Meeting*, San Francisco, CA, AGU, IN54A-03.[4]

McGuinness, D., P. Fox, L. Cinquini, P. West, J. Garcia, J. Benedict, D. Middleton, 2007: The virtual solar-terrestrial observatory: A deployed semantic web application case study for scientific research. *Proc. 19th Conference on Innovative Applications of Artificial Intelligence*, Vancouver, BC, Association for the Advancement of Artificial Intelligence.[3]

Dudhia, J., 2007: The Weather Research and Forecasting Model. *8th WRF Users' Workshop*, Boulder, CO.[1]

Richmond, A. D., R. Akmaev, P. C. Anderson, G. Crowley, D. P. Drob, D. Lummerzheim, S. C. Solomon, W. Tobiska, 2006: Thermospheric density and composition: An integrated research approach. *2006 Fall Meeting*, AGU, SH22A-01.[4]

Solomon, S. C., L. Qian, R. G. Roble, 2006: Thermospheric global change during solar cycle 24. *2006 Fall Meeting*, AGU, 22, 7.[1]

Gizon, L., M. Rempel, 2006: Time-varying component of the solar meridional flow. *SOHO/18/GONG2006/HELAS I Conference*, Karen Fletcher, Ed., Sheffield, ESA SP-624, 18, 129.1.[3]

Wu, Q., S. C. Solomon, T. L. Killeen, D. A. Ortland, W. R. Skinner, R. J. Niciejewski, 2006: TIMED Doppler Interferometer (TIDI) observations of mesosphere and lower thermosphere tidal and planetary waves. *2006 Fall Meeting*, AGU, 31, 3.[4]

Woitaszek, M., 2007: Tornado codes for archival storage. *Ph.D. dissertation, University of Colorado*, 121.[1]

Dennis, J. M., R. Jacob, M. Vertenstein, T. Craig, R. Loy, 2007: Toward an ultra-high resolution community climate system model for the BlueGene platform. *Journal of Physics: Conference Series*, 78, 102030, doi: 10.1088/1742-6596/78/1/012030.[3]

Moser, S. C., 2007: Training a cavalry of "1,000 voices for climate change" - Observations and recommendations for ongoing support and future trainings. *The Climate Project and Report to Al Gore*, UCAR/NCAR, 35 pp.[1]

Kelman, I., S. H. M. Fakhruddin, 2007: Tsunamis. *Heads Up! Early Warning Systems for Climate, Water and Weather*, M. H. Glantz, Ed., Tsinghua University Press, 146-150, doi: ISBN 978-7-302-14633-9.[3]

Darnell, T., L. Cinquini, P. Fox, P. West, J. Garcia, D. Middleton, D. McGuinness, J. Benedict, 2006: Unifying workflows for finding and using data across discipline boundaries. *2006 Fall Meeting*, San Francisco, CA, AGU, IN54A-08.[4]

Laffea, L. L., J. K. Williams, R. Monson, R. Han, 2007: Using artificial intelligence to optimize wireless sensor network deployments for sub-alpine biogeochemical process studies. *Proc. 5th Conference on Artificial Intelligence Applications to Environmental Science*, San Antonio, TX, American Meteorological Society, 1.5.[3]

Manning, K. W., Y.-H. Kuo, 2006: Using COSMIC refractivity profiles in an evaluation of Antarctic forecast models. *First Formosat-3/COSMIC Data Users Workshop*, Boulder, CO.[1]

Hendrickson, B., C. Kessinger, P. Herzegh, J. Cowie, J. Craig, G. Blackburn, E. Williams, 2006: Using Satellite Based Techniques to Combine Volcanic Ash Detection Methods. *Proc. 2006 Fall Meeting*, San Francisco, CA, American Geophysical Union, V53A-1719.[1]

Lei, J., S. C. Solomon, W. Wang, A. Burns, Z. Zeng, 2006: Validation of the COSMIC ionospheric measurements by the ground-based data and the model predictions. *2006 Fall Meeting*, AGU, 33, 281.[1]

Xiao, Q., J. Sun, W. C. Lee, E. Lim, J. Gu, S. Sugimoto, X. Zhang, Y. R. Guo, D. M. Barker, X. Y. Huang, Y.-H. Kuo, 2007: Variational doppler radar data assimilation for the weather research and forecasting model. *11th Symposium on Integrated Observing and Assimilation Systems for the Atmosphere, Oceans, and Land Surface*, San Antonio, TX, American Meteorological Society.[3]

Wang, W., A. G. Burns, S. C. Solomon, M. Wiltberger, T. L. Killeen, 2006: Variations of disturbance dynamo and ionospheric electron densities during geomagnetic storms. *2006 Fall Meeting*, AGU, 44, 7.[1]

Hayden, M., 2007: Vector-borne disease. *Heads Up! Early Warning Systems for Climate, Water and Weather*, M. H. Glantz, Ed., Tsinghua University Press, 67-68, doi: ISBN 978-7-302-14633-9.[1]

Moser, S. C., 2006: Viewpoint. *Natural Resources Forum*, 30, 330.[1]

Morrison, D., M. Weiss, R. Daley, L. Immer, S. Nylund, J. Yee, E. Talaat, J. Russell, R. Heelis, J. Kozyra, D. Bilitza, B. McGuire, R. Candey, P. Fox, 2006: VITMO: A Virtual Observatory for the ITM Community. *2006 Fall Meeting*, AGU, 21, 252.[4]

Kelman, I., 2007: Volcano early warning systems. *Heads Up! Early Warning Systems for Climate, Water and Weather*, M. H. Glantz, Ed., Tsinghua University Press, 151-154, doi: ISBN 978-7-302-14633-9.[1]

Whiteman, D. N., B. B. Demoz, E. Joseph, D. Venable, R. M. Hoff, B. Bojkov, T. McGee, H. Voemel, L. Miloshevich, J. Fitzgibbon, F. J. Schmidlin, C. D. Barnet, I. M. Restrepo, 2007: Water vapor validation experiment-satellite/sondes-Overview and preliminary results. *Annual Meeting American Meteorological Society*, San Antonio, TX.[4]

Hartlep, T., M. S. Miesch, N. N. Mansour, 2006: Wave propagation in the magnetic sun. *Summer Program 2006*, Center for Turbulence Research, National Technical Information Service, 399-404.[3]

Petty, K., 2007: Weather applications and products enabled through Vehicle Infrastructure Integration (VII). *Federal Highway Administration Technical Report*.[1]

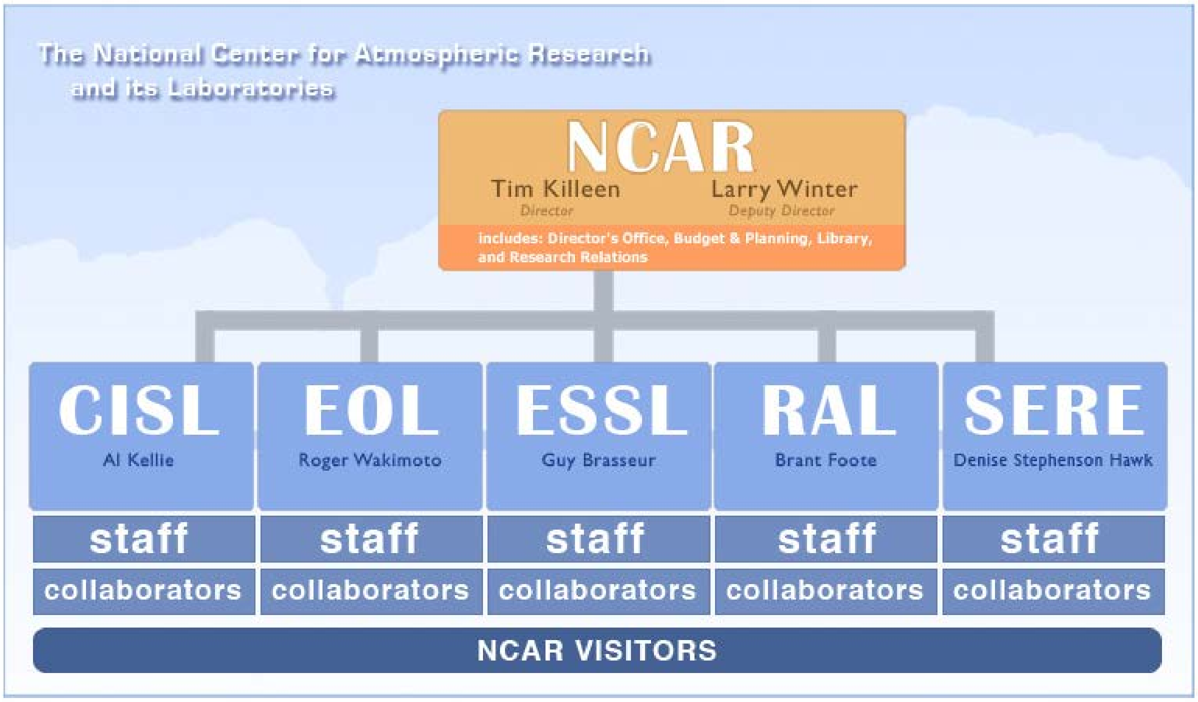
Kelman, I., 2007: Weather-related disaster diplomacy. *Weather and Society Watch*, 1(3), 4-9.[1]

Glantz, M. H., L. M. Cavanaugh, R. E. Morss, E. Gruntfest, J. Tribbia, 2006: Will recent "super" storms lead to seasons of superstorms? *Bulletin of the American Meteorological Society*, 87, 1173-1174.[1]

Cohn, S. A., W. O. J. Brown, 2007: Wind profiler observations of mountain waves and rotors at T-REX. *Proc. 33rd International Conference on Radar Meteorology*, Cairns, AMS.[1]

## NCAR PEOPLE & ORGANIZATION: FY 2007

Click on any organizational box to view NCAR's staff, scientific collaborators, or visitors.








*Postal Address: P.O. Box 3000, Boulder, CO 80307-3000 • Shipping Address: 1850 Table Mesa Drive, Boulder, CO 80305 • Contact*

# Message from CISL Director Al Kellie

I am proud to present the FY2007 Annual Report of NCAR's Computational and Information Systems Laboratory (CISL). As you will find in this report, CISL has completed another productive year and is well prepared to continue its research and service mission to the atmospheric and related sciences. Our plans for the future are organized by these five broad initiatives:

- Replace NCAR's computing facilities to advance the leading edge of geosciences simulation
- Procure, secure, and deploy robust and highly capable cyberinfrastructure that can support such advances
- Strengthen and extend our research arm that enables geoscientists to accomplish more
- Develop and improve tools and research environments that extend the reach of our communities of researchers
- Ensure that our work remains meaningful to others in academia, government, industry, and the general public

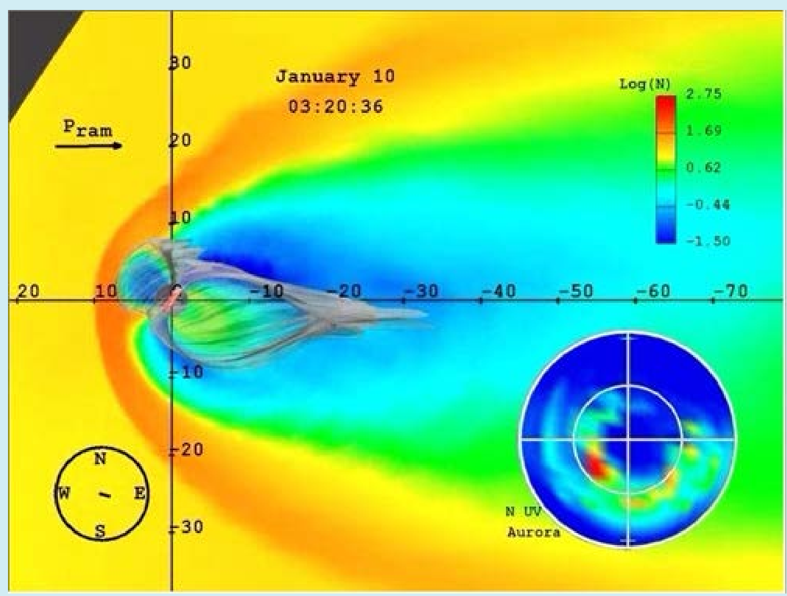
Specifically, our top priorities for FY2008 include:

- Pursuing the expansion of the geosciences computing facility with our partners in Wyoming
- Increasing our support of science with Breakthrough Computational Campaigns and TeraGrid-enabled applications
- Stimulating rising talent in the computer sciences, applied mathematics, and statistics communities with research challenges in geosciences simulation
- Releasing and improving powerful new knowledge-based tools for production use by our constituents
- Increasing the relevance of our work to science communities and society

The following overview points to highlights of CISL's 2007 report via links from the images.

**Ready to break ground for the NCAR Supercomputing Center:**
CISL, with the support of the geosciences modeling community, various advisory bodies, and the NSF, has established a partnership with the University of Wyoming, the State of Wyoming, and Wyoming businesses to develop a modern, energy-efficient NCAR Supercomputing Center (NSC) in Cheyenne, Wyoming.

This vision for the NSC is well aligned with the NSF strategic plan and the NSF vision for cyberinfrastructure. For example, CISL has been prototyping future NSC operations through our TeraGrid integration work. The NSC project is driven by science and is being proposed in direct response to the exploding demand for both capability and capacity HPC resources needed by Earth system science researchers. Regional climate simulations of the future with resolutions approaching 10-20 kilometers will require scaling up to petascale resources.




One of the many science drivers for NCAR's discipline-specific petascale supercomputing center, this visualization of a coronal mass ejection impacting the Earth's magnetosphere represents some of the significant challenges in this field that will benefit from petascale computing capability. These include first-principles modeling of solar convection and its contribution to the 22-year solar cycle, and crucially, modeling the emergence of magnetic flux from the solar convection zone and the conditions that lead to solar flares and coronal mass ejections. (Image courtesy of Michael Wiltberger, NCAR HAO.)

**Breakthrough Science initiative:**
NCAR and NSF created a new level of supercomputing resource allocation early in FY2007. Before NCAR's newest and most capable supercomputer was released for production use, NSF program managers in OCE and EAR, and the CISL HPC Advisory Panel (CHAP) invited a small number of researchers with successful records for using

large amounts of processor hours to run very large simulations. Because of its potential for discoveries through simulation, this initiative is named Breakthrough Science (BTS).

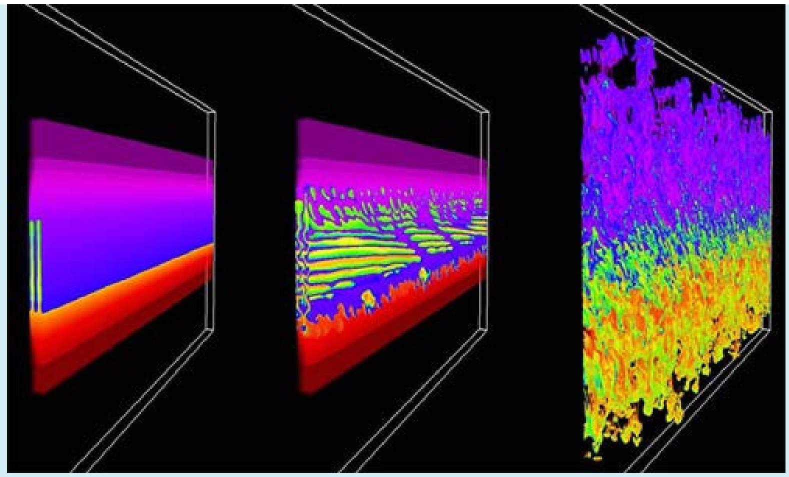
Six of the eight projects successfully used their large allocations, consuming almost 3 million processor hours on blueice. At end-FY2007, two of the six projects had submitted papers for publication, and three others have multiple papers in progress. Because of the BTS successes, the NCAR Executive Committee and CHAP both decided to continue this practice of allocating large amounts of computer time to a single project at a time.

This is significant because it shows that CISL can provide the necessary resources and that university researchers are ready and able to effectively use very large allocations for their geosciences research.

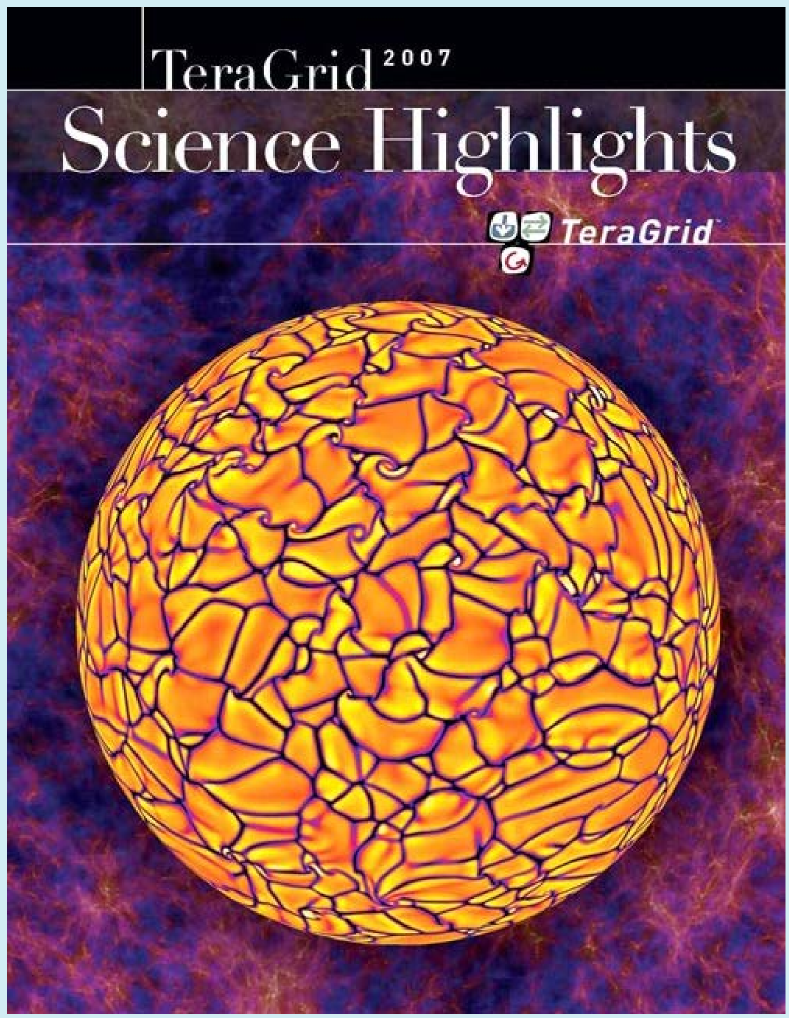
**TeraGrid computing resources enter production phase:**
NCAR's IBM Blue Gene/L (BG/L) supercomputer, named frost, became an operational TeraGrid resource on August 1, 2007, and it is expected to provide 4.5 million CPU hours annually to the TeraGrid research community. In addition to the computational resources, NCAR is also testing experimental systems and services on the TeraGrid. These include the wide-area versions of parallel file systems from IBM and Cluster File Systems, as well as a remote data visualization capability based on the VAPOR tool, an open source application developed by NCAR, the University of California at Davis, and Ohio State University under the sponsorship of the National Science Foundation.

The NCAR TeraGrid integration effort in FY2007 shifted from the equipment acquisition and deployment phase that dominated FY2006 to a new phase characterized by security-hardening TeraGrid components, CTSS software deployment, testing, and migration, and integration of accounting software. During this period, testing of the storage cluster capabilities expanded to experimentation with the capabilities of grid technologies to support wide-area parallel file systems and distributed scientific visualization workflows. The effort culminated on August 1, 2007 with the successful deployment of the frost resource on the TeraGrid.

**Integrating math, statistics, and geosciences:**
IMAGe, the math institute housed within CISL, strives to bring mathematical models and tools to bear on fundamental problems in the geosciences, and to be a center of activity for the mathematical and geophysical communities. Each year, IMAGe focuses on a



Visualizations from a large-scale simulation conducted as part of the Breakthrough Science initiative. Shown here are double diffusive convective motions organized by ambient shear into alternating planar regions of rising and sinking fluid that contain opposed horizontal flow patterns. This process depends heavily on the vast difference between the molecular diffusivities of heat and salt in water, which renders the simulation a computational grand challenge. Using 320,000 processor hours on blueice, these simulations were the first to take full account of that difference and evolve to a fully turbulent state. It is therefore the first simulation of the important and largely unexplored natural phenomenon of saltwater turbulence. (Image courtesy W.D. Smyth, Oregon State University.)




The cover of the 2007 TeraGrid Science Highlights brochure showcases a visualization of giant cell convection patterns beneath the surface of the sun. These processes, revealed by a recently developed model that allows scientists to examine inner workings of the sun that are hidden from any current observational technique, are being explored by researchers at the University of Colorado and NCAR using terabytes of data that reside at the Pittsburgh Supercomputing Center and the San Diego Supercomputer Center. Using NCAR's TeraGrid network node and VAPOR software, this new ability to explore remote data via the TeraGrid holds potential to significantly advance U.S. scientists' particular area of the geosciences or applied mathematics that has an impact on NCAR's scientific mission and develops a series of workshops plus a summer school to that theme. In FY2007, the Theme-of-the-Year focused on statistics for numerical models. This theme was undertaken with the goal of matching cutting-edge statistical methods to the needs of geophysical model development and to make statistical scientists aware of the particular scientific issues and research in the geophysical modeling community.

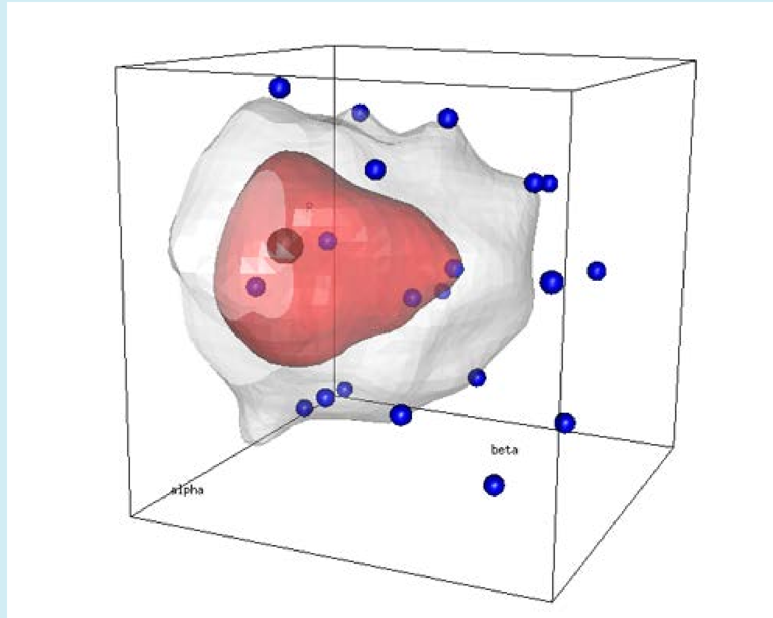
In collaboration with the Statistical and Applied Mathematical Sciences Institute (SAMSI) and the Mathematical Sciences Research Institute (MSRI), four modeling groups at NCAR were engaged to present their models and highlight potential statistical connections at the first workshop. Several collaborations between NCAR scientists and statisticians at SAMSI and the broader statistical community were begun, and the results of these efforts were presented at the second workshop. The next workshop focused on random matrices. Finally, a summer school program on the Carbon Cycle was hosted at NCAR. These kinds of coordinated activities have the potential to significantly increase the multidisciplinary training of young scientists. This also brings new mathematical approaches to challenging geophysical problems.

**Frameworks to standardize large-scale modeling efforts:**
Again in FY2007, The Earth System Modeling Framework (ESMF) has made significant strides in helping researchers manage the growing complexity of developing Earth system models. Disparate model components representing physical domains and processes—for example, atmosphere, ocean, and sea ice—are coupled into integrated systems to create realistic simulations. These models are computationally intensive and must run on a variety of parallel-processor supercomputing platforms. ESMF defines a set of standard software interfaces and a set of high-performance tools for common functions.

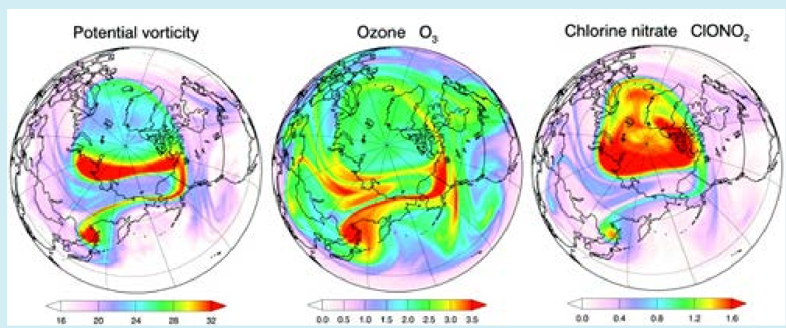
Now in its fifth year, ESMF has transitioned from NASA funding to multi-agency support and is the technical basis for the DoD Battlespace Environments Institute, the NASA Modeling Analysis and Prediction Program, and a host of smaller projects. The number of ESMF science components in the community is an important metric, since more standard components mean more options for researchers creating coupled systems. The adoption of ESMF grew steadily this year, with the number of available science components growing from 36 at end FY2006 to 58 at end FY2007.

**Initiating the next generation of computational scientists:**
A formalization of CISL's summer internship

ability to rapidly pursue research questions that demand large-scale resources. (Image courtesy of Mark Miesch, NCAR HAO.)




Generated as part of research being conducted in IMAGe, this figure displays contours of the posterior distribution of optimal calibration parameter values for the LFM model of the magnetosphere for a 1997 geomagnetic storm. A space-filling statistical design was used to choose a collection of values of the parameters (blue dots), and the resulting model runs were used to fit a statistical model to the surface representing the discrepancy between the LFM model output and satellite data from the date of the storm. The goal of this research is not only to improve the model and our understanding of the magnetosphere, but also to do so in a manner that uses computational resources most efficiently.




This image shows some of the first ultra-high-resolution results (2/3-degree longitude by 1/2-degree latitude) from the GEOS-5 atmospheric general circulation model coupled via ESMF to a sophisticated NASA stratospheric chemistry package (STRAT-CHEM). The GEOS-5 modeling and data assimilation system developed at NASA's Global Modeling and Assimilation Office consists of over 24 ESMF gridded components that can be coupled through the framework for a variety of applications, from atmospheric reanalysis and weather prediction to coupled climate modeling. The coupling of GEOS-5 and STRAT-CHEM enables scientists to perform calculations with a variety of interactions between the chemistry and the atmospheric radiation, large-scale dynamics, and sub-grid parameterizations.

These interns worked at NCAR in the mutually beneficial SIParCS program. The CISL-based SIParCS program challenges students in applied mathematics and computational science to help solve real-world problems associated with CISL's mission to support the atmospheric and related sciences. The students gain valuable work experience, and CISL is cultivating a skilled workforce for future supercomputing centers.

efforts, the Summer Internships in Parallel Computational Science (SIParCS) program is a prototype partnership between CISL and selected universities. SIParCS is sponsored and administered by CISL to provide opportunities for exceptional students with backgrounds in computational science, applied mathematics, computer science, or the computational geosciences.

This new program offers a significant opportunity to make a positive impact on the quality and diversity of the workforce needed to use and operate 21st century supercomputers. Ultimately, SIParCS aspires to help address shortages of trained scientists and engineers capable of using and maintaining high-end computer and data systems—people desperately needed to achieve the goals of future computational geoscience research.

In return, SIParCS provides a framework for interns to gain practical experience with a wide variety of parallel computational science problems by working under the guidance of CISL mentors on HPC systems and applications relevant to NCAR's Earth System science mission.

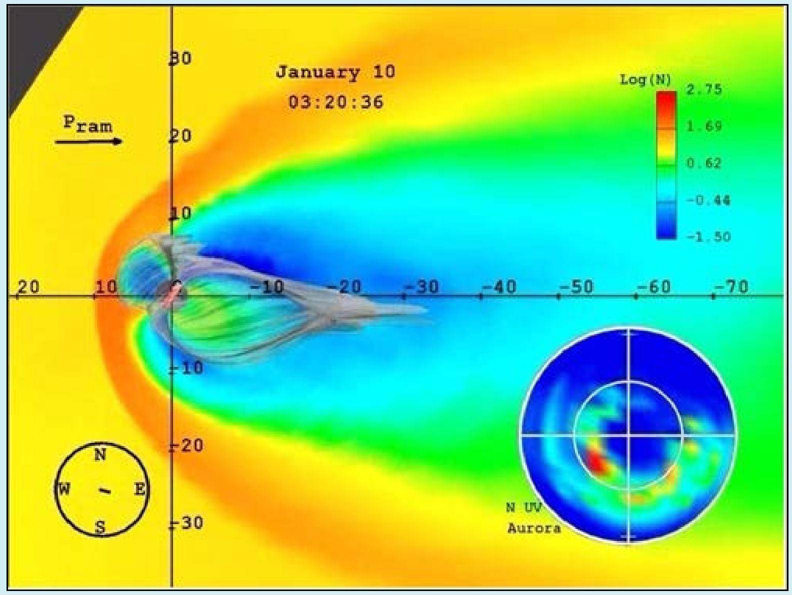

*Postal address: P.O. Box 3000, Boulder, CO 80307-3000 • Shipping address: 1850 Table Mesa Drive, Boulder, CO 80305 • Contact*

CISL Director's message
CISL annual report Table of contents
**Strategic goals**: science, facilities and technology
CISL research catalog

# Plan to expand the NCAR Supercomputing Facility (NSC) with Wyoming partners

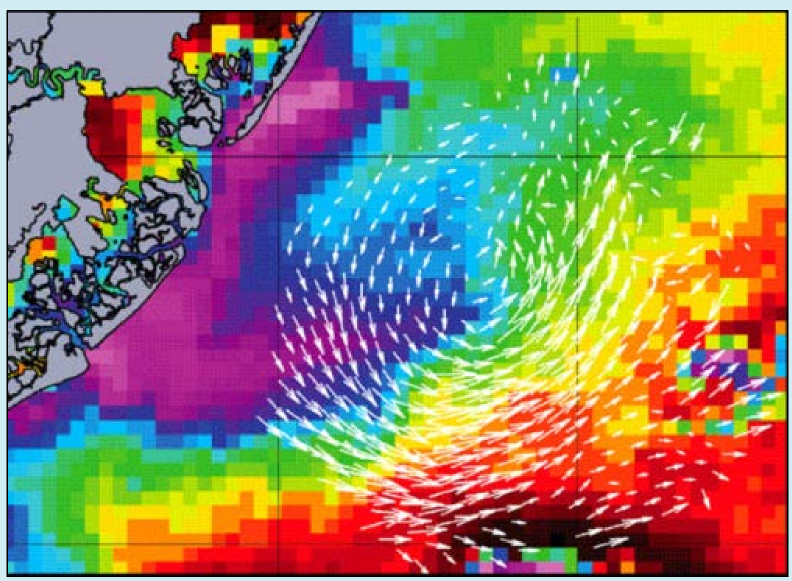
In partnership with the University of Wyoming, the State of Wyoming, and the NSF, NCAR proposes to develop an expanded NCAR Supercomputing Center (NSC) in Cheyenne, Wyoming. The shared vision for this project is summarized by the following points:

- The primary purpose of the NSC is to enable Earth System science discoveries.
- The facility should be dedicated to Earth system science problems.
- Because environmental problems know no boundaries, the NSC should serve to broaden participation in this geoscientific enterprise.
- The facility should be world class and built to last.
- The NSC facility should be efficient and as green to build and operate as practicable.
- Time is of the essence: many questions have huge societal impacts and won't wait.




This is a visualization of a coronal mass ejection impacting the Earth's magnetosphere. These phenomena can have significant impacts on satellites, astronauts, and systems ranging from GPS to power grids. Significant challenges in this field that will benefit from petascale computing include first-principles modeling of solar convection and its contribution to the 22-year solar cycle, and crucially, modeling the emergence of magnetic flux from the solar convection zone and the conditions that lead to solar flares and coronal mass ejections. (Image courtesy of Michael Wiltberger, NCAR HAO.)

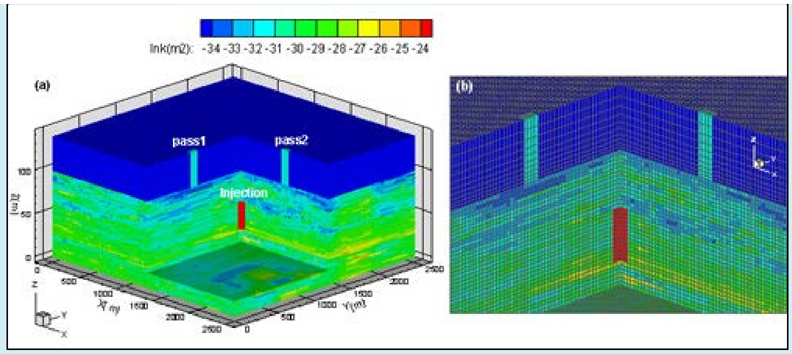
This vision for the NSC project is well aligned with the NSF strategic plan and the NSF vision for cyberinfrastructure. The project is driven by science and is being proposed in direct response to the exploding demand for both capability and capacity HPC resources needed by Earth System science researchers. Whether because of a need for greater model resolution, increased model complexity, better statistics, more predictive power, longer simulation times, or a combination of these factors, geosciences investigators are clamoring for petascale computing, data analysis, and visualization resources and exascale data management capabilities.



Hypoxia conditions off the Southern New Jersey Coast are set up by a combination of topography and upwelling factors. This process illustrates the intimate connection between biological, chemical, and physical processes in the ocean. (Image courtesy of Dale Haidvogel, Rutgers University.) The coastal oceans are also challenging to understand, being both complicated and complex not only physically, but also chemically and biologically. An important computing goal for the future will be to simulate regional oceanic ecosystem dynamics within the context of a unified Earth system climate model. Future progress will depend on petascale computing and associated technologies in the area of coastal ocean modeling and prediction.

Technology trends dictate that such capabilities require the availability of a large-scale computing center capable of handling the multi-megawatt heat loads of future systems. The size and infrastructure requirements for the NSC have been determined with these technology trends in mind, and the conceptual design for the facility will support the supercomputing needs of Earth System science researchers for the next two to three decades.

The NSC is designed to fit in with NSF's larger CI vision and will help foster the creation of a national petascale cyberinfrastructure. The proposed facility is sized to be a peer with other NSF Track-2 facilities and will thus be well positioned to serve as a "geosciences stepping stone" to the NSF's multi-disciplinary, one-petaflop-sustained Track-1 facility.




(a) This 500,000-cell grid was derived from a fully heterogenous geological model containing 2,388,015 hexahedral cells. It was developed for studying permeability heterogeneity in sedimentary aquifers. (b) A region of the grid reveals details near two passive wells. High-fidelity geological reservoir simulation tools improve our ability to investigate longstanding problems in soil permeability. This model can be applied to studies of enhanced oil recovery techniques and $CO_2$ injection. Underground $CO_2$ sequestration based on recaptured utility emissions is increasingly being advocated as a viable approach for mitigating global climate change. This work indicates the cross-disciplinary synergy that can arise within a petascale computing facility dedicated to Earth system science problems. (Image courtesy of Ye Zhang, University of Wyoming.)

## NSC partner selection background

During FY2006 and early FY2007, NCAR and UCAR personnel undertook an in-depth analysis of all possible options for securing a replacement facility for the aging NCAR ML machine room. This rigorous review process involved discussions with members of the community, various institutional governance and advisory bodies, NSF personnel, and subject matter experts. It was determined that pursuing new facility construction with a partner is the most cost-effective solution for meeting the ongoing high-performance computing needs of the atmospheric and related sciences.

Correspondingly, NCAR and UCAR initiated an effort to identify and explore possible facility construction partners, a process that involved conducting each of the following:

- Initial discussions with potential partners to outline the vision of the project and to determine initial interest in pursuing a partnership arrangement
- Technical feasibility studies of each potential partner institution to determine if a proposed partnership arrangement would meet the project technical requirements outlined in the facility conceptual design plan
- Financial feasibility studies of the offering made by each proposed facility partner that met the identified technical requirements

The initial list of possible facility partners included:

- Colorado School of Mines (CSM; Golden, Colorado)
- Colorado State University (CSU; Fort Collins, Colorado)
- IBM (Boulder, Colorado campus)
- Sun Microsystems/Storage Tek (Louisville, Colorado campus)
- University of Colorado at Boulder (CU; Boulder, Colorado)

During the initial discussions phase, most of these institutions expressed significant interest in at least hosting a facility. Some also expressed interest in forming full partnerships with NCAR, involving not only intellectual collaborations but also providing financial backing to the supercomputing facility construction effort. Sun Microsystems/Storage Tek declined to participate in further discussions, and IBM was eventually removed from consideration when the company elected not to respond to the technical feasibility questionnaire. While initial discussions were taking place with these five potential partners, a delegation from the State of Wyoming contacted NCAR and UCAR representatives and expressed strong interest in the proposed supercomputing facility construction project. After an initial meeting with NCAR and UCAR representatives to discuss the project, the Wyoming team was added to the list of potential project partners.

## Detailed FY2007 accomplishments

During FY2007, the Colorado School of Mines, Colorado State University, the University of Colorado at Boulder, and the University of Wyoming and partners in the State of Wyoming all provided plans for a strategic partnership. All four institutions presented proposals with compelling intellectual and research agendas. After reviewing the technical and financial feasibility responses received from CSM, CSU, CU, and Wyoming, NCAR and UCAR determined that CU and the University of Wyoming were offering facility partnership proposals with the greatest potential benefit to NCAR, UCAR, NSF, and the broader community. Over the course of a roughly two-to-three-month negotiating process, NCAR and UCAR staff reached agreement with both CU and the Wyoming team regarding the financial and technical terms of the facility partnership offers being made. Regular briefings with NSF/ATM management and the UCAR Board of Trustees were conducted during this same time to ensure that all entities remained fully apprised. In January 2007, NCAR formally announced the selection of the University of Wyoming and the State of Wyoming as partners for construction of the NSC. The Wyoming proposal was deemed to provide the best path forward for the community to gain access to the greatest amount of computing at the earliest possible time. The proposed site for the facility is in the Front Range Business Park on the west side of Cheyenne, Wyoming.

Throughout the remainder of FY2007, NCAR and Wyoming personnel held a series of formal and informal meetings to further discuss and develop ideas regarding the partnership plan. In April 2007, a retreat was held involving NCAR and University of Wyoming personnel to engage in dialogue regarding the intellectual components of the partnership. NCAR and Wyoming personnel also met in Cheyenne to begin discussing some of the technical aspects of the NSC construction process. During FY2007, NCAR project personnel worked on developing construction cost estimates and analyzing impacts on the construction budget that may be caused by ongoing volatility in materials and labor costs for commercial construction projects. In addition, the NCAR project team worked with the University of Wyoming to assemble a comprehensive project proposal detailing the scientific and technical drivers for the project, the partner selection process, and a comprehensive project management plan and budget for the NSC construction effort. NCAR personnel are also developing requirements and a draft statement of work (SOW) to be released as part of the RFP for NSC architecture and engineering services.

## Impacts

The impacts of this project have broad significance. As envisioned, the NSC will be a key component of provisioning HPC resources for Earth System sciences research well into the future. This large, complex project has involved five years of effort on the part of NCAR personnel to arrive at this point and will require nearly four more years of work before NSC supercomputing resources will be available for community use. NCAR plans to fully integrate the NSC into the NSF TeraGrid, and the project will be carried out within the guidelines of the NSF Strategic Plan and the NSF cyberinfrastructure vision. The challenges presented to researchers to effectively utilize petascale systems are immense, and the availabity of large-scale parallel systems to be provided by the NSC—coupled with access to software engineering and parallel algorithm research expertise—are needed to ensure that investigators can prepare their codes and simulations to run effectively on NSF Track-1 computing resources.

This work is supported by NSF Core funding.


*Postal address: P.O. Box 3000, Boulder, CO 80307-3000 • Shipping address: 1850 Table Mesa Drive, Boulder, CO 80305 • Contact*

CISL Director's message
CISL annual report Table of contents
**Strategic goals:** science, facilities and technology
CISL research catalog

# Table of contents

### Strategic priority: Research in computational science and math for geophysics: TDD and IMAGe

Supporting projects:



Followup reports on FY2006 research plans that are not featured this year:



### Strategic priority: Toward an Earth system knowledge environment

Supporting projects:



Followup reports on FY2006 Earth System Knowledge Environment plans that are not featured this year:

*Postal address: P.O. Box 3000, Boulder, CO 80307-3000 • Shipping address: 1850 Table Mesa Drive, Boulder, CO 80305 • Contact*

The National Center for Atmospheric Research sponsored by NSF
NCAR
CISL Annual Report 2007





# NCAR strategic goals

CISL focuses on two of NCAR's five strategic goals:

1. Understanding the Earth and Sun System
2. Resilience to Weather, Climate, and Atmospheric Hazards
3. Cultivating a Scientifically Engaged Citizenry
4. Providing Innovative Information Services
5. Providing World-Class Observational Facilities

*Download the NCAR Strategic Plan* (1.2 MB pdf file)


*Postal address: P.O. Box 3000, Boulder, CO 80307-3000 • Shipping address: 1850 Table Mesa Drive, Boulder, CO 80305 • Contact*

CISL Director's message
CISL annual report Table of contents
**Strategic goals**: science, facilities and technology
CISL research catalog

# Research catalog

This is an archive of research conducted by CISL staff in FY2007.

Fournier, Aimé. Development of spectral-element and other higher-order methods for atmospheric dynamics

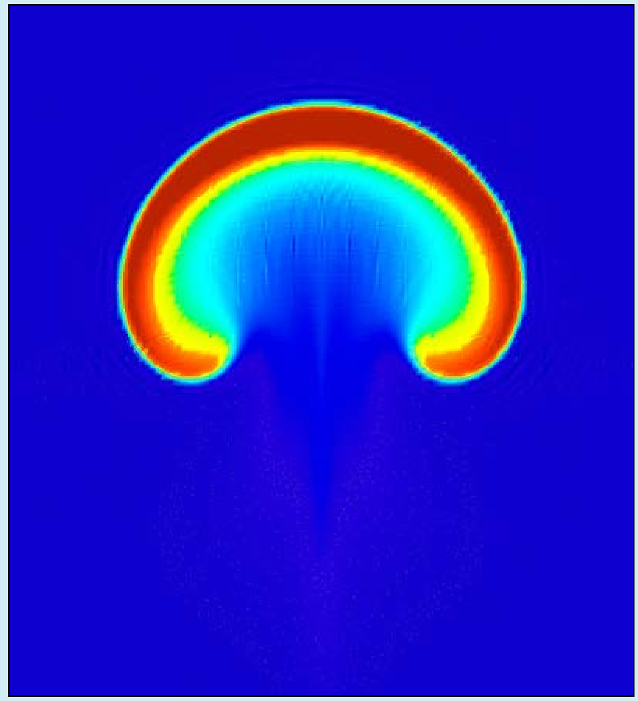
Graham, Jonathan Pietarila. Regularization modeling of turbulent flows

Mininni, Pablo. Energy transfer in hydrodynamics and magnetohydrodynamics

Mininni, Pablo. Neutral and conducting flows inside a rotating sphere

Pouquet, Annick and Pablo Mininni. **Breakthrough Simulations of Magnetohydrodynamics**

Rosenberg, Duane. GASpAR development



Visualization of a bubble of hot air evolving as it rises through a cooler medium. The computation that produced this image uses highly accurate numerical methods and can be implemented on large, massively parallel supercomputers.


*Postal address: P.O. Box 3000, Boulder, CO 80307-3000 • Shipping address: 1850 Table Mesa Drive, Boulder, CO 80305 • Contact*

CISL Director's message

CISL annual report Table of contents

**Strategic goals:** science, facilities and technology

CISL research catalog

# Breakthrough Science using blueice

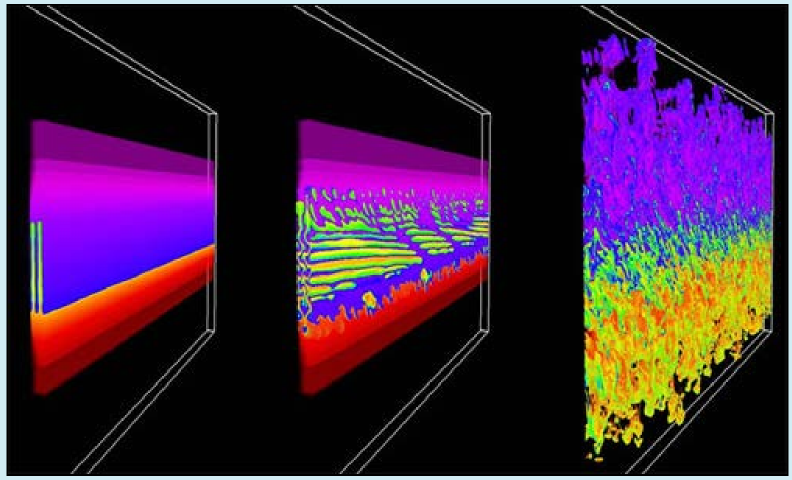
In fall 2006, NCAR and NSF took an opportunity to provide very large allocations of computational resources to a small number of geoscience researchers prior to the full allocation of blueice, NCAR's newest and most capable supercomputer. Proposals that could use very large amounts of computer time were solicited for computing allocations available during February, March, and April 2007.

NSF program managers in OCE and EAR were invited to nominate projects for their NSF-sponsored research, including researchers who may not have used NCAR supercomputing resources in the past. The CISL HPC Advisory Panel (CHAP) invited researchers who had a successful record of requesting and using large amounts of processor hours. NCAR solicited proposals from NCAR researchers who could use this opportunity to move their science forward.

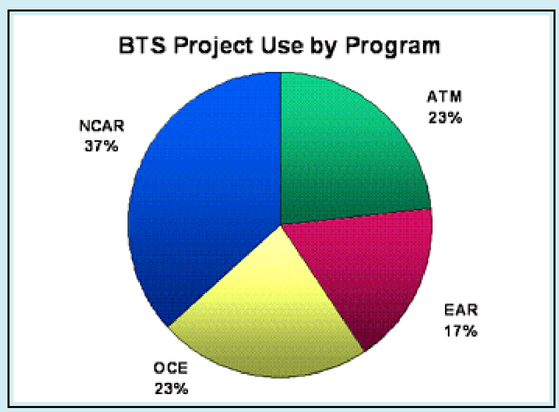
CISL reviewed all submissions for readiness to use a very large allocation on the IBM POWER5+ system. NSF selected five university proposals, the CHAP selected one university proposal, and NCAR selected two proposals.

This initiative supports NCAR's strategic goal to "Provide robust, accessible, and innovative information services and tools" to the university and NCAR communities. In addition, the research performed supports NCAR's strategic goal to "Improve understanding of the atmosphere, the Earth System, and the Sun."

Because of its potential for discoveries through simulation, this initiative is named Breakthrough Science (BTS).



Visualizations from a large-scale simulation in which double diffusive convective motions are organized by ambient shear into "salt sheets"—alternating planar regions of rising and sinking fluid that contain opposed horizontal flow patterns parallel to the sheets. (Also see 26 MB video in .mov format.) This process depends heavily on the vast difference between the molecular diffusivities of heat and salt in water, which renders the simulation a computational grand challenge. Using 320,000 processor hours on blueice, these simulations were the first to take full account of that difference and evolve to a fully turbulent state. It is therefore the first simulation of the important and largely unexplored natural phenomenon of saltwater turbulence. (Image produced using VAPOR, a visual data discovery environment developed at NCAR for very large data sets. Image courtesy W.D. Smyth, Oregon State University.)




This chart shows how blueice resources were used during the Breakthrough Science initiative, by NSF program and NCAR.

## Outcomes

Six of the eight projects successfully used their large allocations from February 2007 through May 2007, an extension of one additional month. Three university projects requested additional resources to continue their computations in June and July. By the end of the BTS initiative, six projects had consumed 2.6 million GAUs or almost 3 million processor hours on blueice. As shown in the pie chart, university research sponsored by ATM and OCE programs consumed 23% of the resources, while EAR-sponsored research consumed 17%. A total of 63% of the BTS computational resources were delivered to NSF-supported university research.

Two of the six projects had submitted papers for publication by the end of FY2007, and three others have multiple papers in progress. The sixth project is continuring to analyze the massive amounts of data they generated during BTS in preparation for publication. University researchers are reporting that their use of these very large allocations is changing their expectations for the pace of scientific progress that can be made through numerical simulations.

Among NCAR scientists the allocation of very large computational resources to a few research projects created a lot of interest. As a result, in April 2007 the NCAR Executive Committee decided to devote 6% of NCAR's supercomputer resources (out of NCAR's allocation) to one computational project at a time, usually for 4-5 months.

Also because of the BTS successes, the university panel (CHAP) began a pilot experiment of allocating a large number of GAUs to a single project at a time in April 2007.

CHAP will review the accomplishments of the BTS university projects when it meets in October 2007 and will evaluate the possibility of continuing these very large allocations to university geoscience researchers who are performing NSF-supported research.

The BTS initiative has shown:

1. CISL can effectively provide very large amounts of computer time to individual projects while continuing to serve its diverse research community.
2. University researchers are ready and able to effectively use very large allocations in the geosciences.
3. Invitations to participate in the BTS encouraged university geoscience researchers to think "big" in their simulations and propose computational experiments that take five to ten times more computational resources.
4. BTS researchers generated large amounts of data and needed CISL's mass storage and visualization resources to analyze and manage the output of their simulations.

## Project plan for FY2008-09

In FY2008 and FY2009, CISL will again offer a few very large allocations for accelerated scientific discovery on its next installed supercomputer. This program will be offered to university and NCAR scientists under the program name "Breakthrough Computations" (BTC). Some of the key parameters of the BTC program for FY2008-09 include:

1. The next CISL supercomputer will be an IBM POWER6 computer named bluefire. The BTC initiative will run from September through November 2008.
2. The BTC computational resources will be split between university and NCAR researchers in the atmospheric and closely related sciences. The CISL HPC Advisory Panel (CHAP) will review the university requests and select the top proposals. NCAR management will select the NCAR projects. The evaluation criteria will include computational efficiency and readiness.
3. Researchers will be given two to three months' advance notice so they can prepare and tune their models. Researchers will be expected to benchmark their models on the IBM POWER5+, blueice, in the spring and on the new IBM POWER6 as soon as it is available. CISL's Consulting Support Group will assign individual consultants to each selected project. This support model worked well in FY2007.
4. At the conclusion of the BTC initiative, researchers will be expected to provide detailed progress reports on their scientific accomplishments and publications that are being prepared. CISL will follow up with projects later in the year on the specific papers that were published. These progress reports, publications, and other outcomes will be included in future annual reports.

## Sponsorship

The Breakthrough Science initiative was sponsored the National Science Foundation through the provision of computational and support resources. The university researchers who used these resources were funded by NSF awards from ATM, OCE, and EAR. NCAR researchers utilizing the BTS computational resources were also sponsored by the NSF.

# TeraGrid integration

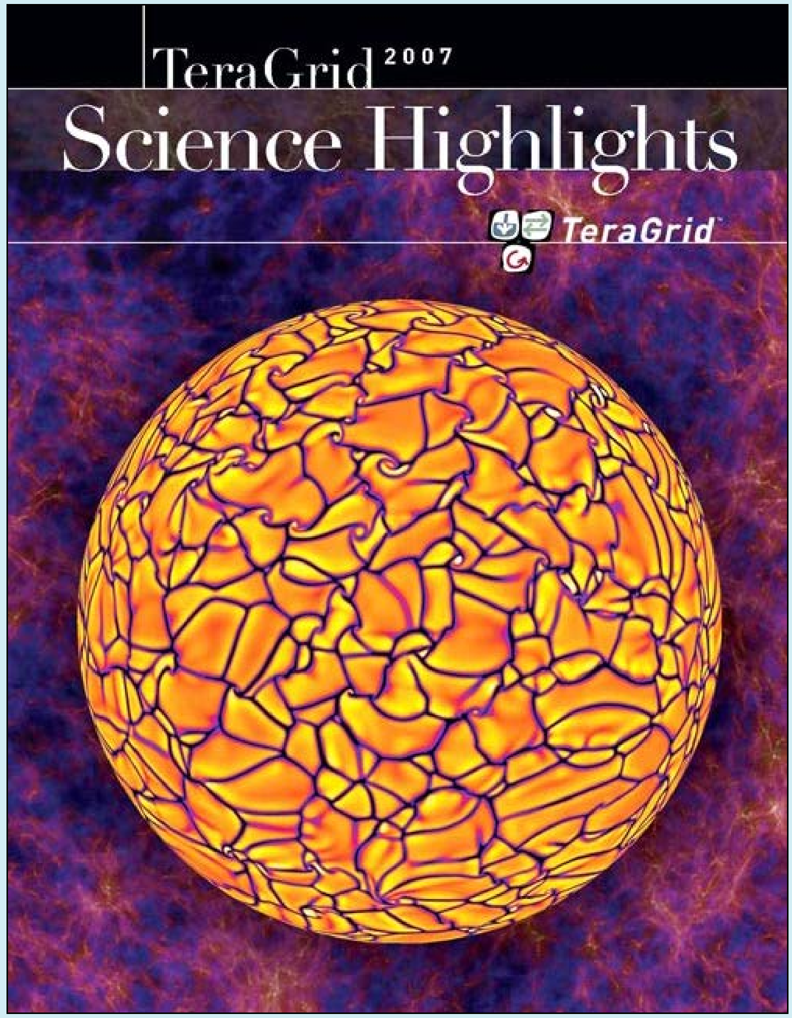
The National Center for Atmospheric Research (NCAR) has deployed a portion of its IBM Blue Gene/L (BG/L) supercomputer, named frost, on the TeraGrid. Frost has been an operational TeraGrid resource since August 1, 2007, and is expected to provide 4.5 million CPU hours annually to the TeraGrid research community.

The operational integration of the BG/L system frost with the TeraGrid involved extensive work by CISL. CISL engineers deployed frost outside the UCAR security perimeter after implementing extensive security measures, installing TeraGrid software, and automating the exchange of accounting data between NCAR's accounting system and the TeraGrid's.

In addition to the computational resources, NCAR is also testing experimental systems and services on the TeraGrid. These include the wide-area versions of parallel file systems from IBM and Cluster File Systems, as well as a remote data visualization capability based on the VAPOR tool, an open source application developed by NCAR, the University of California at Davis, and Ohio State University under the sponsorship of the National Science Foundation.

Operated in partnership with the University of Colorado, frost is the second BG/L system on the TeraGrid, joining the San Diego Supercomputer Center's 6,144-processor system. The NSF TeraGrid uses high-performance networks to integrate supercomputers, data archives, and data analysis facilities around the country. Its coordinated work environment enables researchers throughout the United States to collaborate on especially challenging scientific questions, and to process vast amounts of data that would not be manageable on smaller or isolated computing systems.

This effort supports NCAR's strategic priorities of "Developing and providing advanced services and tools" and "Engaging a broader and more diverse community." NCAR's participation in the TeraGrid is supported through NSF Core funds and UCAR Communications Pool indirect funds.




The cover of the 2007 TeraGrid Science Highlights brochure showcases a visualization of giant cell convection patterns beneath the surface of the sun. These processes, revealed by a recently developed model that allows scientists to examine inner workings of the sun that are hidden from any current observational technique, are being explored by researchers at the University of Colorado and NCAR using terabytes of data that reside at the Pittsburgh Supercomputing Center and the San Diego Supercomputer Center. Using NCAR's TeraGrid network node and VAPOR software, this new ability to explore remote data via the TeraGrid holds potential to significantly advance U.S. scientists' ability to rapidly pursue research questions that demand large-scale resources. (Image by Mark Miesch, NCAR.)

## TeraGrid 2007 detailed accomplishments

The NCAR TeraGrid integration effort in FY2007 shifted from the equipment acquisition and deployment phase that dominated FY2006 to a new phase characterized by security-hardening TeraGrid components, CTSS software deployment, testing, and migration, and integration of accounting software. During this period, testing of the storage cluster capabilities expanded to experimentation with the capabilities of grid technologies to support wide-area parallel file systems and distributed scientific visualization workflows. The effort culminated on August 1, 2007 with the successful deployment of 25% of the frost resource on the TeraGrid.

Frost is the 2,048-processor IBM Blue Gene/L system at NCAR. One quarter of this resource has been allocated to the TeraGrid, amounting to 4.5 million CPU hours of computer time annually. The system has been in production as a TeraGird resource since August 1, 2007. Frost is attached to a storage cluster, a visualization node, and has access to the multi-petabyte NCAR Mass Storage System. As a TeraGrid Resource Provider, NCAR is committed to offering a network of computational, data, and knowledge resources to multidisciplinary groups of researchers, students, educators, policy makers, and impact and assessment communities around the world.

### TeraGrid security

On October 22, 2006 frost was moved outside the UCAR security perimeter. Before this move could be contemplated, the operating system on the frost front-end login and service nodes had to be hardened, or configured to minimize computer security vulnerabilities to hacker exploits. Staff in CISL's Research Systems Evaluation Team (ReSET) also acquired equipment for setting up an intrusion-detection system.

### TeraGrid user support

The CISL Consulting Services Group integrated its NCAR-based trouble ticket system with the TeraGrid Ticket system. As early as May 11, 2007, NCAR began receiving and responding to user support requests. In FY2007 NCAR also integrated its documentation of the frost system with the overall TeraGrid documentation system.

### TeraGrid CTSS software

The integration of the Cobalt scheduler on frost with the GRAM resource management system was completed by March 2007. By April 2007 the NCAR TeraGrid team had completed the initial installation of all the most important CTSS-3 TeraGrid software stack components and began testing them. John White at SDSC was of great assistance installing and testing the INCA grid monitoring package. This CTSS installation and testing phase was complicated by the migration of CTSS-3 to CTSS-4 during the summer of 2007. CISL installed numerous CTSS independent subcomponents (kits), including Remote Login, Remote Compute, Data Transfer (e.g. gridftp), Data Management, Wide Area Parallel Filesystem (e.g. GPFS-WAN), Application Development and Runtime Support, and Science Workflow Support. The Parallel Application Support (e.g. MPI, MPICH-G2) kit was not supported because inherent limitations of the BG/L system precluded it.

### Integration of NCAR and TeraGrid accounting systems

Integration with the TeraGrid accounting system is a key requirement. The TeraGrid Connector Code (TGCC), a Java-based software application developed by CISL, integrates NCAR's allocation accounting database with the TeraGrid Central Database. TGCC has enabled NCAR to provide accounting information to the TeraGrid from its BG/L supercomputer and Mass Storage System.

TGCC accepts incoming packets from the TeraGrid that describe project and account requests and updates. TGCC then synchronizes these with NCAR's accounting database and relays the resulting data to frost and the MSS. This mechanism provides access to the system for authenticated TeraGrid users. The result is a virtually seamless ability for TeraGrid users to request NCAR's frost resource via the centralized TeraGrid User Portal and allocation panel, then be automatically set up with access. Their usage is reported back to the TeraGrid Central Database, which they can view on the TeraGrid User Portal.

### Visualization node deployment

The NCAR TeraGrid visualization resource named "twister" was procured, security hardened, and deployed in February 2007. Twister was used to provide VAPOR-based visualization services collaboration with researchers at the University of Colorado. Studies of the solar interior were run at SDSC. Hundreds of gigabytes of data were created there by CU astrophysicists running the Anelastic

Spherical Harmonic (ASH) model. These data were mounted at NCAR using GPFS-WAN and processed into a hierarchical storage format by VAPOR software running on twister. Data in this form could then be visually explored by CU astrophysicists using a simple laptop computer.

### Other infrastructure improvements

In late FY2007, CISL made infrastructure improvements to ensure enhanced security, redundancy, and fault tolerance in our TeraGrid cyberinfrastructure. These improvements include a 10 Gbps intrusion-detection system, additional disk to mirror critical system components, and redundant power supply systems.

### SRB connection and cross-archiving of priceless datasets

With the assistance of SDSC staff, NCAR installed the Storage Resource Broker (SRB) software necessary to begin backing up files to the SDSC mass storage file system. The archiving of a portion of NCAR's Research Data Archive began in April 2007. The average file size in these collections was just over 200 MB. To date 288,484 files have been transferred, amounting to 59.5 TB of valuable NCAR data now duplicated at SDSC.

## TeraGrid background

TeraGrid is an NSF-funded national facility that integrates computational and data resources and security, accounting, documentation, and educational outreach services from resource providers (RPs) to serve the nation's science and engineering community. Common services and integration processes and components are provided by, or in some cases coordinated by, the Grid Infrastructure Group (GIG). The GIG is responsible for architecture, planning, managing, and enhancing the TeraGrid facility, providing a core set of services, and coordinating RP staff through distributed service teams ranging from user support to security to education, outreach, and training.

The objective of the RPs and GIG is to enable scientific discovery by providing integrated access to the highest-performance resources available, integrated as a coordinated system that supports various use cases ranging from exploiting a single TeraGrid resource to combining resources in specialized workflow or cooperative computing modes. Resource integration and enhancement efforts are ranked through user input and evaluations of TeraGrid services as measured by operational, system, or service use metrics.

The set of long-term TeraGrid objectives toward providing cyberinfrastructure to national science and engineering researchers can be expressed in three interdependent sets of activities.

**TeraGrid *DEEP*** encompasses a set of initiatives aimed at fully exploiting the integrated capabilities of the TeraGrid facility to support scientific discovery that would not otherwise be possible. The GIG coordinates user support staff to provide both traditional user consulting support and a program called Advanced Support for TeraGrid Applications (ASTA). ASTA assigns user support staff to dedicate 25% of their time for 6-12 months assisting a science group to enable them to fully harness TeraGrid services and resources as an integrated facility.

**TeraGrid *WIDE*** recognizes that, traditionally, NSF's high-performance computing infrastructure has focused primarily on only a small fraction of the national science and engineering community. Thus, in addition to supporting a current and growing user community, the aim is to provide TeraGrid services to many more scientists and engineers over the coming years. Such scaling requires a new model for interacting with the community and for provisioning cyberinfrastructure: the creation of science gateways.

TeraGrid's broad-impact goals also extend to students and educators. TeraGrid's Education, Outreach, and Training (EOT) program is a coordinated effort to raise the awareness of the benefits of TeraGrid within research and education communities across all disciplines and all learning levels. The EOT team works closely with the science gateways to engage significantly larger numbers of scientists, educators, and students, with an emphasis on reaching out to under-represented groups.

**TeraGrid *OPEN*** involves the provision of a persistent, reliable national cyberinfrastructure. The TeraGrid facility is architected as a set of integrated services based on open standards wherever possible and embracing the heterogeneity represented by nearly 20 unique major resources operated by TeraGrid RPs. OPEN also describes the approach to presenting TeraGrid to NSF and the community as a truly extensible and adaptable facility.

## Strategic overview

Continued operation of TeraGrid cyberinfrastructure is a strategic and ongoing activity for CISL. Subsequent out-year upgrades of the TeraGrid infrastructure will be accomplished with CISL's research equipment budget. While modest, this investment should enable CISL and NCAR to continue deploying resources of a scale sufficient to develop Grid expertise and learn vital lessons about providing domain-specific Grid services to NCAR's scientific community.

In particular, plans are already in place to run a procurement process for a BG/L replacement system in FY2008. The procurement will be a two-stage process. In the first stage, an RFI will be run to establish the feasibility of a procurement of this size with the constraints on power, space, and cooling that will be available at NCAR's Mesa Lab facility after the deployment of the IBM POWER-6 system during the second phase of the ICESS procurement. Based on the information gathered in the RFI, the BG/L replacement RFP is scheduled to be run in spring 2008.

As new scientific collaborations and new services emerge on the TeraGrid, CISL will adapt the NCAR TeraGrid appropriately. A collateral goal will be to develop a cadre of NCAR users willing and able to use the TeraGrid, then to use their experiences to guide the development of both the NCAR node and the TeraGrid as a whole.

## Project plan evaluation measures

In FY2008, NCAR intends to continue to operate the NCAR TeraGrid resource, offering 4.5 million CPU hours to TeraGrid users during the year—25% of the resource. Accounting for these CPU hours is made in Service Units (SU) that are allocated by three committees: the Large Resource Allocations Committee (LRAC) makes awards larger than 500,000 SUs, the Medium Resource Allocations Committee (MRAC) makes awards of 0-500,000 SUs, and the Development Allocations Committee (DAC) makes awards of 0-30,000 SUs for new users and users investigating new architectures. NCAR's allocation plan for its BG/L during FY2008 is:

- LRAC: 2M SU/year, 1M SU/meeting x 2 times/year
- MRAC: 2M SU/year, 0.5M SU/meeting x 4 times/year
- DAC: 0.5M SU/year

Building a TeraGrid user base for the BG/L system at NCAR while procuring a replacement system for it will be CISL's primary goals for the TeraGrid activity in FY2008. Existing NCAR and University of Colorado users of the BG/L system will be encouraged to use it as TeraGrid users. We expect that additional allocation cycles will lead to new external users with large allocations. In FY2008 the following specific milestones will be met:

- CISL will resolve the incompatibilities between the UCAR and TeraGrid security models that have prevented TeraGrid access to the ESG data holding at NCAR.
- NCAR accounting services will implement support for a new storage accounting model currently being developed by TeraGrid working groups.
- ReSET will complete the integration of a TeraGrid queue wait time prediction system.

Also in FY2008, NCAR will continue to develop a portfolio of TeraGrid-based scientific and technical partnerships. In particular, NCAR has established partnerships with ORNL, PSC, and the University of Indiana for conducting Lustre-WAN testing with these TeraGrid resource providers. This testing and development is expected to continue. A similar working relationship exists with SDSC regarding GPFS-WAN and experimental pNFS filesystem deployment, development, and use.

NCAR will continue collaborating with SCEC and CU to leverage useful properties of VAPOR software. Once the security issues are resolved—allowing ESG transfers over the TeraGrid's 10 Gbps fabric—CISL will continue with its ESG-over-TeraGrid federation activities with ORNL, and will approach Purdue's Climate Center to develop new areas of collaboration in science gateway development. NCAR will also pursue the development of a new science gateway in astroseismology in collaboration with NCAR's High Altitude Observatory Division.

## Impacts

The impacts of integrating with the TeraGrid are already occurring. In particular:

- So far, both NCAR and the TeraGrid have learned from each other. For example, NCAR has provided important guidance for how to integrate new resources. The TeraGrid has introduced NCAR to wide-area parallel filesystems such as GPFS-WAN.
- Integration with TeraGrid has created new, and in many cases, unexpected opportunities for scientific collaboration. For example, current collaborations with SCEC and CU would not have happened.
- Domain-specific and multidisciplinary computing models can complement each other. This is illustrated through science gateways activities such as the Earth System Grid.
- The sum appears to be greater than the individual parts.

NCAR's access to and integration with TeraGrid resources will help ensure the consistency and integration of the NSF's cyberinfrastructure plans, particularly between the Office of Cyberinfrastructure (OCI) and the Geoscience Directorate. The connection itself is expected to increase the ability of NCAR scientists and geoscientists to collaborate using TeraGrid resources. The resulting collaborations will likely center around data exchanges at first, but will inevitably expand into other aspects of scientific workflows such as the sharing or coscheduling of HPC resources, like those demonstrated at SC06 in Tampa, Florida.

## Sponsorship

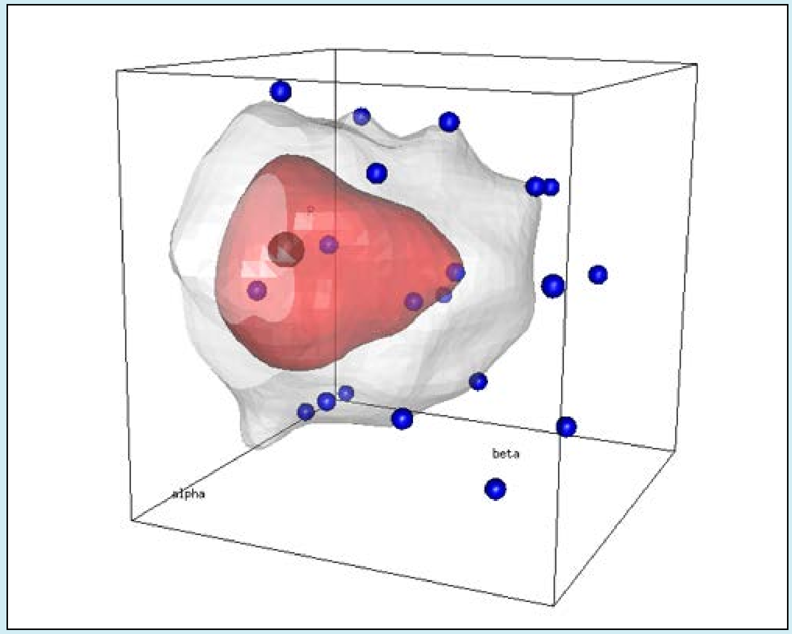
TeraGrid activities at NCAR are supported by NSF Core funding.

*Postal address: P.O. Box 3000, Boulder, CO 80307-3000 • Shipping address: 1850 Table Mesa Drive, Boulder, CO 80305 • Contact*

CISL Director's message
CISL annual report Table of contents
**Strategic goals**: science, facilities and technology
CISL research catalog

# IMAGe theme for 2007: Statistics for numerical models

IMAGe's vision is to bring mathematical models and tools to bear on fundamental problems in the geosciences, and be a center of activity for the mathematical and geophysical communities. A central activity in IMAGe is the Theme-of-the-Year (TOY)—an annual focus on a particular area of the geosciences or applied mathematics—that has an impact on NCAR's scientific mission. In FY2007, the TOY focused on statistics for numerical models. Statistical science in the past 20 years has advanced to handle the interpretation of complicated multivariate, spatial and temporal data sets, and it is well suited to tackle the massive outputs from numerical experiments that are now the norm in the geosciences. The FY2007 theme was undertaken with the goal of matching cutting-edge statistical methods to the needs of geophysical model development and to make statistical scientists aware of the particular scientific issues and research in the geophysical modeling community.




This figure displays contours of the posterior distribution of optimal calibration parameter values (alpha, beta, R) for the LFM model of the magnetosphere for a geomagnetic storm that occurred on January 10, 1997. A space-filling statistical design was used to choose a collection of values of the parameters (blue dots), and the resulting model runs were used to fit a statistical model to the surface representing the discrepancy between the LFM model output and satellite data from the date of the storm. The distribution of optimal calibration parameters in the figure was determined from this statistical representation of the discrepancy. The goal of this research is not only to improve the model and our understanding of the magnetosphere, but also to do so in a manner that uses computational resources most efficiently.

This effort supports the NCAR strategic priority of "Engaging a broader and more diverse community in the atmospheric and geosciences," and it leverages three others being advanced by IMAGe: "Improving prediction of weather, climate, and other atmospheric phenomena," "Conducting computer science, computational science, applied mathematics, statistics, and numerical methods R&D," and "Developing and providing advanced services and tools."

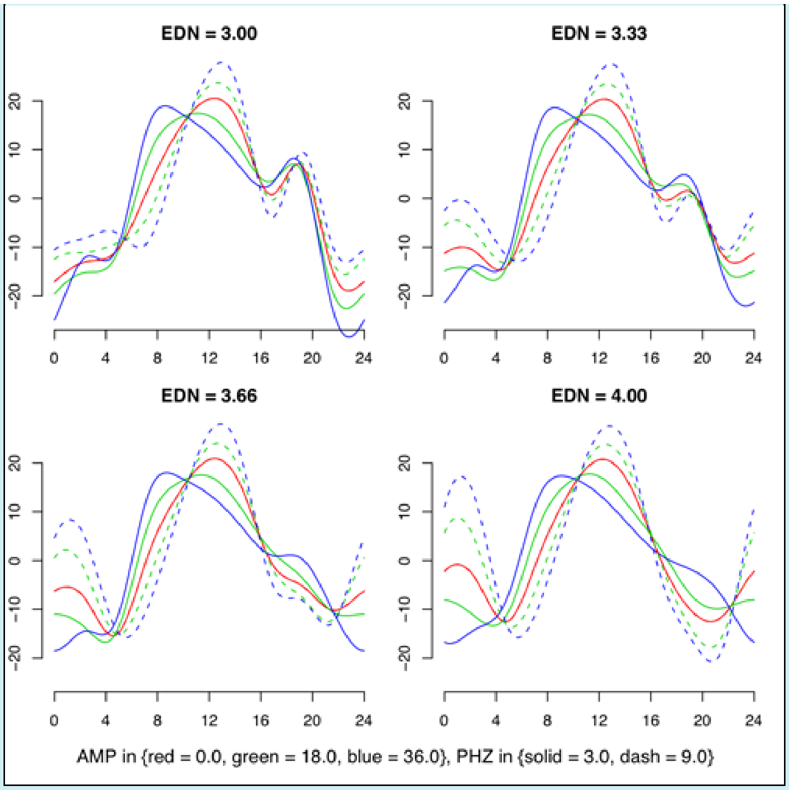
In cooperation and collaboration with the Statistical and Applied Mathematical Sciences Institute (SAMSI) and the Mathematical Sciences Research Institute (MSRI), the main activities of the 2007 TOY were a series of three workshops and a summer graduate workshop, all held at NCAR. These TOY workshops dovetailed with SAMSI programs on random matrices and computer models and with the MSRI summer school program.

Four modeling groups at NCAR were engaged to present their models and highlight potential statistical connections at the scoping workshop in November 2006. From that starting point, several collaborations between NCAR scientists and statisticians at SAMSI and the broader statistical community were begun, and the results of these efforts were presented at a follow-up workshop in May 2007. In addition, there was a workshop in May 2007 that focused on random matrices. Finally, a summer school program on the Carbon Cycle was hosted at NCAR during July

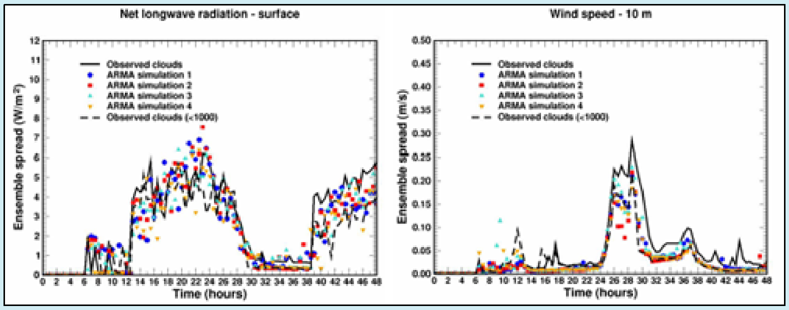
2007.

For FY2008, the TOY will focus on geophysical turbulence. Understanding turbulent processes at a fundamental level is essential to understanding the dynamics of the atmosphere, the oceans, the planetary boundary layer, and of the sun and solar-terrestrial interactions. The 2008 TOY will emphasize the fundamental aspects of turbulence, but also team with the experimental/observational and numerical/modeling communities. A series of three workshops and a summer school are planned that will serve to promote synergy and interaction between the different communities involved.

This project is made possible through NSF Core funding. Additional funds for FY2007 were supplied by NSF's Statistical and Applied Mathematical Sciences Institute (SAMSI).




This figure displays the response of the Thermosphere-Ionosphere Electrodynamics General Circulation Model (TIE-GCM) to three parameters that describe atmospheric tides at the lower boundary (AMP and PHZ) and variations of night-time ionization rates (EDN). These figures were produced using a statistical emulator of the model, constructed from an ensemble of only 30 model evaluations. This analysis has allowed scientists working with TIE-GCM to verify the underlying code and to quantify the effects of these three parameters on the model output, and, again, to do so in a manner that uses computational resources efficiently.




These figures show the results of using statistical models to capture the stochastic nature of cloud observations and to create a forcing time series to be used with a single column model (SCM) focusing on the planetary boundary layer (PBL). The figures show that the variability in wind speed (10 m above ground) and long-wave radiation emitted from the surface, as a function of time, are similar to the variability from observed clouds (solid curve). Several different statistical models are compared (colored markers). The results are also compared with the observations when very cloudy days are removed from the sample (dashed curve) showing the importance of outliers. This research is allowing scientists at NCAR to study the nature of the PBL response to clouds.

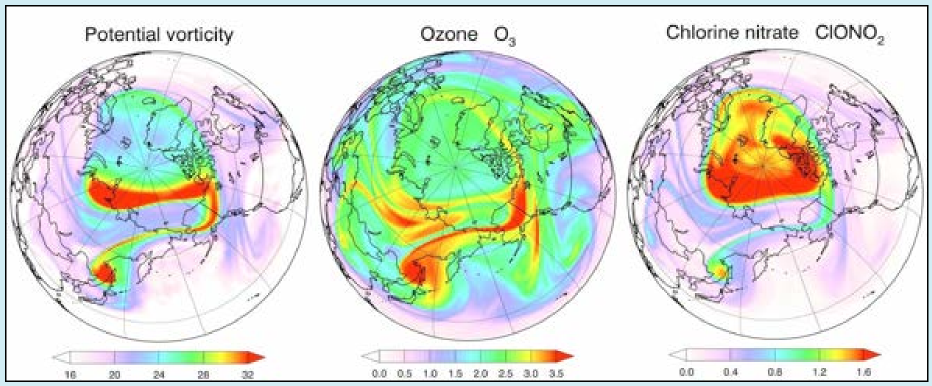

*Postal address: P.O. Box 3000, Boulder, CO 80307-3000 • Shipping address: 1850 Table Mesa Drive, Boulder, CO 80305 • Contact*

CISL Director's message
CISL annual report Table of contents
**Strategic goals**: science, facilities and technology
CISL research catalog

# Earth System Modeling Framework (ESMF) and ESMF-based initiatives

The Earth System Modeling Framework (ESMF) was motivated by the growing complexity of developing Earth system models. These are constructed of separate software components representing physical domains and processes; for example, atmosphere, ocean, and sea ice. The components, which are often developed at separate sites, are coupled into integrated systems to create realistic simulations. An additional complication is that the models are computationally intensive and must be designed to run on supercomputers with parallel processors. ESMF defines a set of standard software interfaces and a set of high-performance tools for common functions, such as grid interpolation. Now in its fifth year, it has transitioned from NASA funding to multi-agency support and is the technical basis for the DoD Battlespace Environments Institute, the NASA Modeling Analysis and Prediction Program, and a host of smaller projects. More information appears on the ESMF website.

By creating a common modeling infrastructure that serves the climate and weather domains and enables the integration of Earth systems with space weather models, hydrological components, and other related domains, ESMF is a full realization of the NCAR strategic priority of "Developing community models for weather, climate, atmospheric chemistry, and solar-terrestrial research." As it moves toward integrating the suite of scientific software at NCAR to better support science workflows, ESMF is fulfilling the NCAR strategic priority of "Creating an Earth system knowledge environment." Looking beyond NCAR, ESMF is a realization of the goals expressed by the broader community to develop cross-institutional and cross-agency infrastructure that enables them to collectively reuse software and exchange components.




This image shows some of the first ultra-high-resolution results (2/3-degree longitude by 1/2-degree latitude) from the GEOS-5 atmospheric general circulation model coupled via ESMF to a sophisticated NASA stratospheric chemistry package (STRAT-CHEM). The GEOS-5 modeling and data assimilation system developed at NASA's Global Modeling and Assimilation Office consists of over two dozen ESMF gridded components that can be coupled through the framework for a variety of applications, from atmospheric reanalysis and weather prediction to coupled climate modeling. The coupling of GEOS-5 and STRAT-CHEM enables scientists to perform calculations with a variety of interactions between the chemistry and the atmospheric radiation, large-scale dynamics, and sub-grid parameterizations. (Image courtesy of the GEOS-5 team at the NASA Global Modeling and Assimilation Office.)

## Project description

ESMF components are arranged in a hierarchical structure to form applications. Exchanges are facilitated both for large, composite components, such as an atmospheric model, and for smaller components such as particular physics parameterizations.

The current ESMF distribution contains:

- Tools for building scientific components and couplers, and a set of low-level utilities for common modeling functions such as calendar management and data redistribution
- Concurrent or sequential execution, single or multiple executable modes
- Support for configuring ensemble members sequentially or concurrently
- Fortran interfaces and complete documentation, some C++ interfaces

ESMF supports IBM, Cray X1, SGI, Linux, Mac, and other platforms.

## Timeframe for the project

ESMF is now in its fifth year and has started its second funding cycle under NOAA, NASA, DoD, and NSF sponsors. In the next three years, the ESMF group anticipates two major release increments: ESMF 4, focusing on rework and extensions to the grid representation and regridding software, and ESMF 5, focusing on consistency and standardization of interfaces.

## Accomplishments in brief for FY2007

The number of ESMF science components in the community is an important metric, since more standard components mean more options for researchers creating coupled systems. The adoption of ESMF grew steadily this year, with the number of available science components growing from 36 at end FY2006 to 58 at end FY2007.

One of the major accomplishments of the year was successful completion of a beta test of a coupled, ESMF-based COAMPS-NCOM application. The atmospheric portion of COAMPS (Coupled Ocean Atmosphere Mesoscale Prediction System) is in operational use at the Navy Fleet Numerical Meteorology and Oceanography Center (FNMOC) and Regional Centers. Coupling it to NCOM (NRL Coastal Ocean Model) improves the predictive capability of the system at high resolution. The coupling was accomplished within the ESMF component architecture, using the ESMF sparse matrix multiply for regridding. It is anticipated that the coupled system will be transitioned to FNMOC beginning in FY2008.

Another application milestone for FY2007 was that ESMF successfully passed Stage 1 of its Community Climate System Model (CCSM) evaluation in May 2007, demonstrating minimal component changes relative to the base code, less than 5% overhead in time to solution, and comparable memory usage for standard configurations. The Stage 2 plan was approved by the CCSM Scientific Steering Committee in Septemmber 2007.

An initial implementation of a more general Grid class, capable of representing curvilinear and (with effort) multi-tile grids, was included in ESMF beta version 3.0.3, released in July 2007. Designs for unstructured grids and a generalized regrid operation have been through their first reviews and have been successfully prototyped. Many elements across the framework were standardized, including treatment of datatypes, aspects of error handling, and initializations. The team removed extraneous files and documentation files from the distribution, which made it significantly more compact (about 1/10 its previous size).

On the programmatic front, NOAA joined NASA, DoD, and NSF as a sponsor of the ESMF Core Team. A proposal funding a NOAA ESMF-based Modeling Architecture (NEMA), with support for both development and applications, was awarded in June 2007 with $600K over three years for the development team. The DoD High Performance Computing Modernization Office, sponsors of the Battlespace Environments Institute (BEI), has provided $1.5M in additional funding over the next three years for the ESMF team through BEI. Efforts will initially focus on developing C interfaces and integrating newly redesigned, more general grid and array classes with higher-level classes in the framework.

## Plans in brief for FY2008

ESMF will continue to track adoption efforts carefully and will put user surveys online so information can be easily and regularly collected from customers. Progress is expected on the CCSM Stage 2 evaluation plan, but it is unlikely to be completed during FY2008.

The ESMF team will focus on completing the implementation of structured grids, releasing a general, parallel, online regridding capability, and delivering software for the representation of unstructured grids. The location stream (observational data stream) software contributed by NASA Goddard will be integrated into the new ESMF grid software. Usability goals include decreasing the number of open bugs by half and developing C interfaces.

## Detailed accomplishments for FY2007

During FY2007, the ESMF team made significant advances in community adoption; training, support, and outreach; software development; and organizational maturity.

### Advance community adoption

Means, strategies, and actions:
Assist in the development of new, coupled ESMF applications and the transition of these applications to routine use and operations.

Measures of success:
Number of ESMF components available.
Number of ESMF applications in routine use or operations.

Actual performance, outputs, and outcomes:
There are now more than 58 ESMF components available, a significant increase over the 36 available at last reporting. Components are listed on the ESMF website at ESMF components.

There are now four major coupled codes that have put ESMF into extensive and routine use:

- The NASA GEOS-5 atmospheric general circulation model based on ESMF has been in production since FY2005, and it has added numerous components including a set of chemistry package options.
- The NCEP Global Forecasting System using ESMF was put into operation on August 22, 2006.
- The coupled HYCOM and CICE model using ESMF is now in routine use at the Naval Research Laboratory.
- The coupled COAMPS and NCOM application using ESMF components and coupling passed its beta test in September 2007 (identified as an adoption goal last year).

ESMF passed the CCSM Stage 1 Evaluation Plan in May 2007, identified as a goal last year. Relative to the base code, the evaluation demonstrated minimal component changes, less than 5% overhead in time to solution, and comparable memory usage for standard configurations. The Stage 2 plan was approved by the CCSM Scientific Steering Committee in September 2007.

Progress was made on a coupled ADCIRC-pWASH123 application, but an alpha test was not completed. It is expected to be completed in 1Q FY2008. A coupled SWAN-ADCIRC application identified as a goal last year was replaced by a different application and shifted to a later delivery date.

### Provide ESMF training and support

Means, strategies, and actions:
Continue development of ESMF tutorials and documentation. Improve presentation of introductory and "big-picture" concepts in the ESMF documentation. Develop system tests and/or demos showing a variety of configurations of ESMF applications, including ensembles and alternative methods of time management and sequencing. Update the ESMF Developer's Guide, which outlines conventions and processes used in framework development. It was initially written when ESMF was a NASA project, and parts of it still treat ESMF as a single-sponsor, milestone-driven activity.

Measures of success:
Number of training classes.
Number of individuals trained.

Actual performance, outputs, and outcomes:
The ESMF Core Team presented one framework training classes during FY2007: NCAR, June 1, 2007, Boulder, Colorado. This class contained about 30 students. A total of about 160 students have been trained since project inception.

The ESMF website was thoroughly reworked and now includes additional introductory material, including a Frequently Asked Questions section useful for beginners. New big-picture sections include project vision, feature overview, metrics, and science impacts. An ensemble system test was started but is not yet complete; it is expected to be in an early FY2008 release. The team did not complete examples showing alternative methods of time sequencing. The Developer's Guide was updated to reflect the current status of the project.

### Software development

Goal: **Further implementation of data structures that represent unstructured grids, grids with curvilinear coordinates, and observational data streams.**

Means, strategies, and actions:
Complete the implementation of classes that represent data blocks and their distribution (array and distributed grid classes). These classes were redesigned in FY2006 to support unstructured grids, multi-patch curvilinear coordinate grids, and observational data streams. Methods to be implemented include additional communication operations. Rework the grid and field classes to provide better support for the representation and manipulation of these more complex grids. Key abilities to be developed are the ability to read in a grid specification from a file and to generate interpolation weights for regridding within ESMF. ESMF can currently only generate interpolation weights internally for single-patch rectilinear grids.

Measures of success:
Delivery of an ESMF release with a full implementation of the data block and distribution class interface, the ability to read in grid specifications for unstructured and multi-patch curvilinear coordinate grids, and the ability to generate interpolation weights for regridding such grids.

Actual performance, outputs and outcomes:
Most methods for data block and distribution classes were completed. A completely redesigned grid class capable of representing curvilinear grids and, in index space, multi-patch grids, was released in July 2007. Work began on integrating these new capabilities into fields, bundles of fields, and components, and the first release with this improvement is expected in November 2007. No file specification capability was completed, since users indicated that they preferred an argument list interface for grid creation to a grid specification from file. A design for the comprehensive support of unstructured grids began review, and a prototype was completed. Code for the representation and manipulation of observational data streams was contributed by staff at NASA GMAO.

Methods were added and extended to provide better support for regridding unstructured grids with arbitrary distributions in index space. Optimizations for memory and performance of the array sparse matrix multiply used in these operations were introduced.

A general regridding strategy for the internal generation of regridding weights, in 2D and 3D, based on a parallel rendezvous method, was successfully prototyped. These results were presented at the ESMF Annual Community Meeting on May 30-31, 2007 and at the CCSM Annual Workshop on June 19-21, 2007. A release is expected in FY2008.

Goal: **Improve usability.**

Means, strategies, and actions:
ESMF has many unaddressed bug reports and feature requests, gaps in testing, and inconsistencies in interface and implementation. These issues make it harder for users to adopt the framework, and can hinder and confuse developers. In FY2007 the ESMF team worked to address these concerns.

Measures of success:
Substantial reduction in the number of open bug reports, support requests, and untested interfaces and features. Delivery of a release that includes improvements in consistency in the treatment of basic data types, method argument conventions, and inter-language interfaces.

Actual performance, outputs, and outcomes:
The ESMF team achieved a substantial reduction in the number of open bug reports and support requests. As of September 2007, about 30% of open bug reports were closed, from a high of 229 down to 169. More than half of the open support requests were

closed, from a high of 62 to 15. Resolving these issues represents a substantial increase in the robustness of the ESMF software and the ability of users to make progress.

The ESMF team did not reduce the number of feature requests—these continued to come in faster than they can be resolved. The number of open feature requests stands at 86.

To improve usability, this year the ESMF team also improved consistency across the framework by implementing the following:

- Standard treatment of real and integer data types in framework internal code and in method arguments
- A policy and standard to address auto-promotion of data types via compiler directives
- Standard code for initialization of variables across the framework, for consistent behavior across platforms that do/do not support automatic initialization
- Standard error handling across the framework (partly complete)
- A convention for standard treatment of optional arguments in the C interface, contributed by NRL Stennis

New standards were documented in the ESMF Developer's Guide. The first four of these standards were included in FY2007 releases. The last requires significant development effort to propagate C interfaces across the whole framework.

Goal: **Development of frequently used utilities.**

Means, strategies, and actions:
The implementation of more complex grids will require improvements to or replacement of the current I/O system. This was scheduled for FY2006 and not delivered. It was rescheduled for FY2007. Ongoing improvements are expected in low-level utilities such as the time manager, configuration attributes, and message logging.

Measures of success:
Delivery of an I/O system to support complex grid implementation.
Delivery of a public ESMF release that includes new features for existing utilities. These will be prioritized in response to user input.

Actual performance, outputs, and outcomes:
An I/O system was not delivered this year. The ESMF Change Review Board, which sets project priorities, did not allocate resources for this, and instead channeled available resources to grid development and addressing usability issues. The rationale was that I/O capabilities are secondary in importance to the central concerns of grids and user progress.

Several utilities in the framework, including LogErr and Config, had minor new features implemented (ability to mask specific errors; ability to turn off Log completely at the ESMF Initialization call; addition of a Config Set method). There was substantial makefile rework this year to improve ease of compiling and linking the ESMF software.

Goal: **Framework optimization and porting.**

Means, strategies, and actions:
Benchmark component overhead, regridding methods, redistribution, and middle- and low-level communications on a number of platforms. Include some evaluations at high processor counts (1,000-5,000 processors).

Measures of success:
Minimal performance burden for working code. (Target <5% overhead in component overhead and regridding methods.)

Actual performance, outputs, and outcomes:
The ESMF team benchmarked framework component overhead and its redistribution method on large processor counts. Performance results are posted on the ESMF website under the Metrics tab. Component overhead was shown to be small even for high processor counts ( 30 microseconds at 2,000 processors on a Cray XT3). Redistribution results for up to 256 processors showed comparable performance (<5%) between ESMF and a native package (from the Community Climate System Model) on an IBM POWER5 and a Cray X1. At larger processor counts the results for redistribution are still ambiguous. The XT3 that was used to time performance overhead on 2,000 processors was upgraded to an XT3/4. Multiple processors with different speeds on that machine and hardware instability have led to a wide range of measurements for time to solution for the same configuration. ESMF staff will continue to try to obtain conclusive measurements.

## Organizational maturity

Means, strategies, and actions:
Continue to monitor processes and effectiveness of the Change Review Board and other project bodies. Establish a mechanism for tracking and reporting sponsorship and progress of application projects adopting ESMF. The number of these has multiplied quickly, and they have proven difficult to track.

Promote a paradigm for community development in which stakeholders have direct input into priorities and schedules.

Measures of success:
Broad sponsorship.
Broad representation.

Continuity and regular project meetings.

Actual performance, outputs, and outcomes:
NOAA became a new sponsor of ESMF during FY2007, with the initiation of the NOAA ESMF-Based Modeling Architecture (NEMA) and a $600K three-year award. ESMF also received a $1.5M, three-year supplement from DoD in FY2007 to its Battlespace Environments Institute effort. The ESMF Change Review Board, the multi-agency group that sets priorities and schedules, has met regularly with full or close-to-full attendance. New members have been added to the ESMF Boards representing COLA, the Air Force Weather Agency, the NASA Land Information System project, and NCAR. ESMF held a well-attended annual meeting at NCAR in May-June 2007. A database for tracking ESMF sponsorship, application projects, and level of adoption was established and customers are being surveyed about their level of framework use (through email contact) twice yearly, with results entered into the database.

## Project plan evaluation measures for FY2008

### Advance community adoption

Means, strategies, and actions:
Continue to focus on development of new, coupled ESMF applications and the transition of these applications to routine use and operations.

Measures of success:
Number of ESMF components available.
Number of ESMF applications in routine use or operations.

### Provide ESMF training and support

Means, strategies, and actions:
Continue development of ESMF tutorials and documentation. Bring ESMF documentation up to date with new grid development. Improve presentation of code examples and demos in the ESMF written documentation and the website. Develop system tests and/or demos showing a variety of configurations of ESMF applications, including ensembles and alternative methods of time management and sequencing. Develop an online survey to assess, on an ongoing basis, user satisfaction with the ESMF software, documentation, and instructional materials. Submit a journal paper on the ESMF design or processes.

Measures of success:
Number of training classes. (Goal is two for FY2008.)
Number of individuals trained.
User comments, surveys, and/or evaluations showing that ESMF customers are satisfied with support, training, and documentation.
Produce a journal paper on ESMF.

### Software development

Goal: **Further implementation of data structures that represent unstructured grids, grids with curvilinear coordinates, and observational data streams.**

Means, strategies, and actions:
Continue rework of structured grids and development of unstructured grids. The goal for this year, carried over from last year, is to enable users to represent single and multi-patch structured grids, to generate regridding weights internally, and to perform regridding operations using those weights. In addition, the ESMF team plans to provide a natural representation of unstructured grids using ESMF data structures. NASA-contributed code that supports manipulation of observational data streams will be updated so that it works with the new grid software.

Measures of success:
Delivery of an ESMF release with the capability to represent and regrid structured grids, to represent unstructured grids, and to support the manipulation of observational data streams.

Goal: **Improve usability.**

Means, strategies, and actions:
Reduce the number of outstanding bug reports by half, and achieve 100% test coverage of public interfaces. The standardization work that began in FY2007 will continue. Anticipated work will address internal inter-language interfaces, error handling, public C/C++ interfaces, and logical data types.

Measures of success:
Reduction by half of outstanding bug reports.
Delivery of a release that further improves consistency of behavior and interfaces.
Development of C interfaces.

Goal: **Develop frequently used utilities.**

Means, strategies, and actions:
Delivery of a public ESMF release that includes new features for existing utilities. These will be prioritized in response to user input and grid development requirements.

Measures of success:
Ongoing improvements are expected in low-level utilities such as the time manager, configuration attributes, and message logging. I/O capabilities will be developed as they are required to support grid development.

Goal: **Framework optimization and porting.**

Means, strategies, and actions:
Benchmark regridding methods for a range of processor counts (1,000-5,000 processors). Ensure that continued framework development does not degrade redistribution performance or increase component overhead.

Measures of success:
Minimal performance burden for working code. (Target <5% overhead for regridding methods vs native packages.)

### Organizational maturity

Means, strategies, and actions:
Establish consistency and routine in the management structures and administration of the ESMF project throughout rapid growth periods. Work with the operational community to help establish effective communications among their members and effective communications between their community and others who are working with and are invested in ESMF.

Measures of success:
Broad sponsorship.
Broad representation and participation in project bodies.
Continuity and regular project meetings.

## Impact of the project

Widespread use of ESMF indicates a paradigm shift in the way weather and climate models are constructed. ESMF is beginning to make model development easier through building model codes using components, increased code interoperability, community building, and standard tools. This approach is also facilitating new, multi-agency science collaborations.

This is producing an Earth science community better equipped to explore basic research issues and to answer questions about the impacts of Earth science on society.

## Sponsors

Core ESMF development is sponsored by the National Science Foundation, the National Aeronautics and Space Agency, the National Oceanic and Atmospheric Administration, and the Department of Defense. In addition, a variety of ESMF-based application adoption projects have been sponsored by NASA, NOAA, the U.S. Geological Survey/Department of the Interior, and other agencies and institutions.


*Postal address: P.O. Box 3000, Boulder, CO 80307-3000 • Shipping address: 1850 Table Mesa Drive, Boulder, CO 80305 • Contact*

# Summer Internships in Parallel Computational Science (SIParCS) program

The Summer Internships in Parallel Computational Science (SIParCS) program is a prototype partnership between NCAR's Computational and Information Systems Laboratory (CISL) and selected universities. SIParCS is sponsored and administered by CISL to provide opportunities for exceptional students with backgrounds in computational science, applied mathematics, computer science, or the computational geosciences. SIParCS is designed to broaden their experience by working on projects with mentors from CISL's staff.

These interns worked at NCAR in the mutually beneficial SIParCS program. The CISL-based SIParCS program challenges students in applied mathematics and computational science to help solve real-world problems associated with CISL's mission to support the atmospheric and related sciences. The students gain valuable work experience, and CISL is cultivating a skilled workforce for future supercomputing centers.

From left to right are Ryan O. Kuinghttons, Colorado School of Mines; Victor Snyder, Colorado School of Mines; Kenny Gruchalla, University of Colorado; Michael Levy, University of Colorado; Arunasalam Rahuynanthan, University of Wyoming; Matthew Norman, North Carolina State University; Robert House, University of Colorado.

The program represents a formalization of CISL's summer internship efforts, and it offers a significant opportunity to make a positive impact on the quality and diversity of the workforce needed to use and operate 21st century supercomputers. Ultimately, SIParCS aspires to help address shortages of trained scientists and engineers capable of using and maintaining high-end computer and data systems—people desperately needed to achieve the goals of future computational geoscience research. In return, SIParCS provides a framework for interns to gain practical experience with a wide variety of parallel computational science problems by working with the HPC systems and applications relevant to NCAR's Earth System science mission.

SIParCS supports NCAR's strategic priorities of "Supporting and enhancing formal science education," "Maintaining an innovative and creative workplace," and "Conducting computer science, computational science, applied mathematics, statistics, and numerical methods R&D."

In 2007, seven interns were invited based on recommendations from selected academic advisors. The students come from the University of Colorado, Colorado School of Mines, the University of Wyoming, and North Carolina State University. Each student's skill set was matched with an appropriate project within the lab. During the summer, the students worked one-on-one with volunteer mentors from across CISL, including the Operations and Services Division, Technology Development Division, and the Institute for Mathematics Applied to Geosciences (IMAGe). One student was mentored by a scientist in NCAR's Climate and Global Dynamics Division.

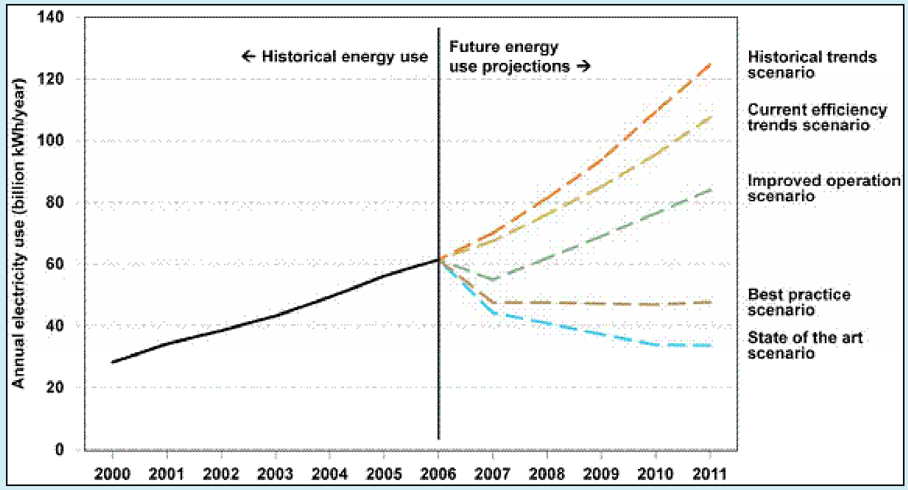
The summer program lasted for 10 to 12 weeks. The internship includes a stipend, and out-of-state interns receive travel and housing assistance as well.

CISL places a high priority on these summer internships and will continue to develop the program in coming years. In 2008, CISL plans to further broaden the candidate pool by running an open solicitation for all positions.

SIParCS is made possible by NSF Core funding.


*Postal address: P.O. Box 3000, Boulder, CO 80307-3000 • Shipping address: 1850 Table Mesa Drive, Boulder, CO 80305 • Contact*

# Expand the capability and capacity of NCAR supercomputing facilities




These scenarios show annual savings of approximately 23 to 74 billion kilowatt-hours in 2011 compared to current electricity efficiency trends in U.S. data centers. These savings reduce the peak load from data centers by the equivalent of up to 15 new power plants and reduce annual electricity costs by $1.6 billion to $5.1 billion. The projected savings in electricity usage correspond to reductions in nationwide carbon dioxide ($CO_2$) emissions of 15 to 47 million metric tons (MMT) in 2011. The best-practice scenario shows that electricity use in servers and data centers can be reduced below its 2006 level during the next five years rather than almost doubling, which would result if current efficiency trends continue.

Identified by CISL staff nearly five years ago, the trend of dramatic increases in power and cooling requirements for replacement computing systems garnered industry-wide attention in 2007. In response to research by Dr. John Koomey at Lawrence Berkley National Labs, Congress directed the EPA to study data center efficiency. The study recommends three sets of guidelines for computing facilities to implement: "improved," "best practice," and "state of the art." CISL continues to be actively engaged with the management of high-end facilities and has implemented many of the recommendations from all three categories in the Mesa Lab computer room. CISL is planning a new supercomputing facility that will fully meet "state of the art" specifications.

Providing computing facilities to meet NCAR's needs is fundamental to NCAR's strategic goal to "Provide robust, accessible, and innovative information services and tools," and to the related strategic priority of "Enhancing capability and capacity of NCAR supercomputing." We continue a two-pronged approach to meeting this challenge.

First, we have solidified and prepared the NCAR Mesa Lab computing facility infrastructure to operate at or near capacity for the next three years. With the installation of the POWER5+ system blueice, the Mesa Lab computing facility operated successfully at nearly 100% capacity for over four months. Blueice also represented the return of liquid-based cooling, one of the EPA's "state of the art" recommendations. Preparation is also underway to utilize more aggressive direct water cooling methods for the installation the POWER6 system, which is the second phase of NCAR's ICESS supercomputing procurement. The Mesa Lab facility will then be run at full capacity until a new facility goes into operation.

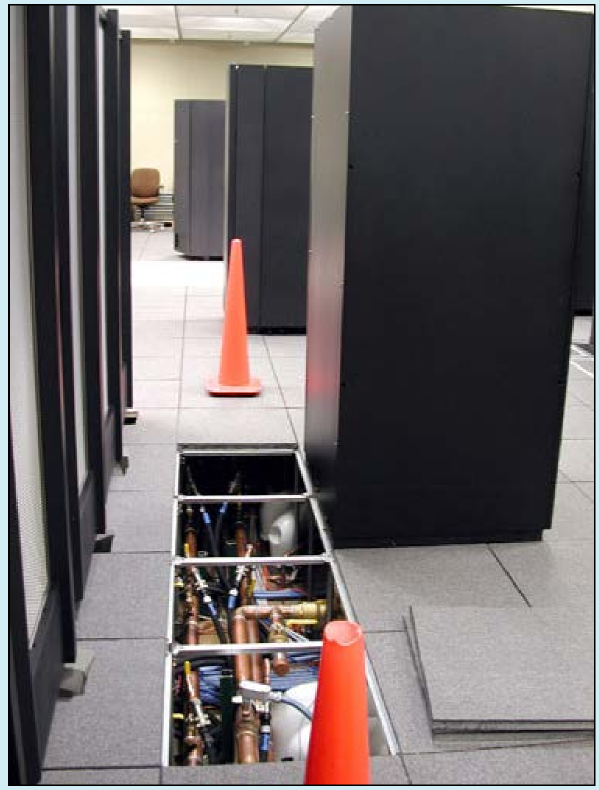
Having already implemented many of the EPA recommendations and still seeing significant constraints on both electrical and cooling capacity, CISL continues planning the construction of a new facility. A partner selection process was completed, and an announcement was made in January 2007 that the University of Wyoming was selected and that a site was identified in Cheyenne, Wyoming. Over the spring and summer of 2007, NCAR and Wyoming further developed the proposed partnership and are working with NSF toward final approval. Upon approval, the full design of the facility is scheduled for 2008.

This work is supported by NSF Core funding.


*Postal address: P.O. Box 3000, Boulder, CO 80307-3000 • Shipping address: 1850 Table Mesa Drive, Boulder, CO 80305 •* *Contact*

# Reintroduction of liquid cooling for high performance computing

With the installation of the IBM POWER5+ computer, the technology of cooling supercomputer-class systems comes full circle. Just under one decade ago the last liquid-cooled Cray system was decommissioned and removed from the Mesa Lab computing facility. During FY2007, CISL staff and members of UCAR Physical Plant Services planned and installed water cooling infrastructure to cool blueice, the first phase of the ICESS procurement.



Piping, hoses, connectors, valves, temperature sensors, and a heat-exchange system are necessary to capture the waste heat from blueice. Chilled water flows from the insulated white piping to the heat exchanger where warm water is transferred back to the large-scale chilled water system. The manifold directs cool water to the rear doors of the computer cabinets on the left. This cooling technology increases the complexity of the facility required to operate increasingly high-performance supercomputers. CISL is developing valuable experience with this technology that will be critical for managing future supercomputing facilities.

The blueice system utilizes IBM's "coolblue" technology. This system captures the hot air expelled from the back of the computer and directs it across a large coil built into the rear door of each computer cabinet. This system captures nearly 60% of the waste heat before it enters the air in the computer room and transfers it into the chilled water system. Water cooling is significantly more efficient and is identified as a state-of-the-art practice by the recently published EPA guidelines for data centers. There is a certain amount of irony in this guideline given the lengthy history of liquid-cooled systems at the Mesa Lab.

While the system is much more efficient, water cooling does present certain challenges. Clearly, top-quality installations must be followed as water is moving much closer to the computers, and leaks are a risk that must be rigorously controlled. CISL has been very successful using in-house expertise to perform this rigorous level of installation. One additional risk is introduced with this technology specifically because it is more efficient. Because heat is captured directly, there is less time for staff to react to a failure of the cooling system. Chillers, pumps, and other mechanical devices take some time to restart after even momentary power anomalies. This issue becomes even more critical as we prepare to install the IBM POWER6 system for the second phase of the ICESS procurement. This system uses direct methods of heat transfer and further reduces the reaction time for cooling systems. Planning is already underway to add thermal storage to the Mesa Lab systems.

The concept of thermal storage is analogous to Uninterruptible Power Supplies (UPS) for the electrical systems. For mechanical systems, a reservoir of water, ice, or other liquid is stored in the system and works just like the batteries in a UPS system.

This advancement in computing facility technology fulfills NCAR's strategic goal to "Provide robust, accessible, and innovative information services and tools," and the related strategic priority of "Enhancing capability and capacity of NCAR supercomputing." This work is supported by NSF Core funding.


*Postal address: P.O. Box 3000, Boulder, CO 80307-3000 • Shipping address: 1850 Table Mesa Drive, Boulder, CO 80305 • Contact*

CISL Director's message
CISL annual report Table of contents
**Strategic goals**: science, facilities and technology
CISL research catalog

# Continuation of cyberinfrastruture reports from FY2006

## Workshop on High Performance Computing for Geosciences Research

For several years, NCAR has been contributing to efforts to define the future requirements for both the science and the cyberinfrastructure of the geosciences. The findings of the High Performance Computing in the Geosciences workshop are published in the report issued in FY2007. Its recommendations included:

- In general, there was consensus across the various disciplines that the geosciences community as a whole has problems suitable for petascale computing resources and that a need exists for access to large-scale computing resources.
- Many of the discipline areas cited a need for the collaboratory to provide access to a spectrum of small- to large-scale computing facilities to handle a broad range of computations.
- A number of the disciplinary breakout groups emphasized the need for both end-to-end community models and community data sets to be made available within the geosciences collaboratory.
- The need for the collaboratory to provide end-to-end HPC research support was emphasized by the majority of workshop participants.

CISL's work on this effort aligns with NCAR's strategic goal to "Provide robust, accessible, and innovative information services and tools." This workshop series was based on work supported by the National Science Foundation under grant number 0631272.

## Workshop on Geoscience Application Requirements for Petascale Architectures

The second and final workshop on Geoscience Applications Requirements for Petascale Architectures was held in San Diego, California on February 21-22, 2007 at the San Diego Supercomputing Center in La Jolla, California. This NSF-funded workshop brought together 35 computer scientists, application experts, and vendors to discuss a broad set of problems related to tackling petascale geoscience problems on the NSF's Track-1 and Track-2 systems.

The workshop series was centered around these broad questions:

1. What are examples of important questions and conceptual challenges in the geosciences that illustrate the potential impact of access to a petascale computational facility?
2. What strategies will ensure that the geoscience community is in position to take advantage of petascale computational capabilities?
3. What resources are needed to get teams of geoscientists and computer scientists working together on petascale applications development, with the goal of having operational packages ready by 2011 when petascale resources will come on line?

The workshop series resulted in a final report with two general recommendations:

1. A portfolio of candidate petascale applications should be established, and development funding should be provided for collaborative teams of geoscientists and computer scientists to prepare calculations that can both advance scientific discovery and run at petascale.

   Specifically, the following five application areas were identified at the workshop as candidates for that petascale applications portfolio:

   - Mantle dynamics (for example earthquake ground motion prediction using PetaShake at 25 meter, 2 Hz)
   - Climate (for example hemispheric "nature" runs to study energy spectrum in the atmosphere at the $k^{-3}$ to $k^{-5/3}$ kinetic energy spectral transitions)
   - Coupled ocean and weather (for example a hurricane eyewall calculation with turbulence and mixing at sub-10-

meter resolution)

- Space weather (for example a full-hemisphere coronal model to resolve and improve understanding of loop structure in a constrained coronal heating with loop structures model)
- Ecological component of earth system modeling (for example adding plant cover to climate models)

2. Suitable selection criteria should be applied to choose which specific calculations and teams from the above areas to invest effort and money into for the purpose of enabling viable petascale applications (via several years of effort starting as soon as possible).

   The following selection criteria were proposed in the workshop report:

   - Science impact
   - Strength and interdisciplinary nature of proposed team
   - Demonstrated plausibility for petascale
   - Needed investment in algorithms and model development
   - Risk of failure

CISL's work on this effort aligns with NCAR's strategic goal to "Provide robust, accessible, and innovative information services and tools." Funding was provided by NSF-ATM award 0540688 received through subcontract 2005-006559-01 with the University of Illinois.

## Data center expansion advanced conceptual design

Two further revisions to the conceptual design were completed in FY2007. A warehouse facility located in Longmont, Colorado was further analyzed, and the base concept design was modified to fit this existing facility. The total cost of modifying an existing facility was found to have so many constraints that it was likely to cost more than constructing a new facility. In addition, a study was completed to compare the original site identified in the conceptual design with sites at the University of Colorado and at the Front Range Business Park in Cheyenne, Wyoming. The study found all three sites to be suitable from a technical perspective. The Wyoming site offered some additional flexibility.

The conceptual studies are complete, and NCAR is preparing to start detailed construction design work when approval is received from NSF. The conceptual design work was made possible through NSF Core funding.

## Chilled water system upgrade

The chilled water system installation and testing have been completed, and it is now serving the blueice supercomputer in production usage. Water-cooled supercomputers are becoming necessary because of rapidly advancing transistor densities and processor speeds. Controlling ongoing increases in supercomputer heat output continues to challenge the chilled water system at NCAR's Mesa Lab facility.

This facility upgrade was made possible through NSF Core funding.


*Postal address: P.O. Box 3000, Boulder, CO 80307-3000 • Shipping address: 1850 Table Mesa Drive, Boulder, CO 80305 • Contact*

CISL Director's message
CISL annual report Table of contents
**Strategic goals**: science, facilities and technology
CISL research catalog

# Cyberinfrastructure procurement and deployment

Historically, NCAR has provided a computational environment to satisfy the center's strategic goal to "Provide robust, accessible, and innovative information services and tools" to universities and the broader scientific community. CISL fulfills this responsibility within the context of the NCAR Strategic Plan, and it continues to provide robust computational and scientific data services including:

- High performance computing production environment
- Mass storage
- Network connectivity
- Data analysis and visualization
- Cultivation of the research data archive
- Data distribution


Blueice is a supercomputer based on the IBM POWER5+ processor and the High Performance Switch communication technology. When it was installed, it effectively doubled the high-end computing resources available at NCAR. CISL bears the ongoing responsibility to provide the numerical simulation community with resources that offer the optimal combination of computational capability and capacity that can be used effectively. This facility supports the NCAR strategic priority of "Enhancing capability and capacity of NCAR supercomputing."

Further, CISL continually evaluates opportunities to provide advanced services and tools designed to enable Earth system science for the entire community of users:

- TeraGrid integration
- Experimental computing systems
- Earth System Knowledge Environment

The deployment during FY2007 of the IBM POWER5+ supercomputer blueice was the next step in CISL's five-year strategic plan goal to provide a 25-fold increase in sustained computing capacity (over 2004 levels) by 2009. The introduction of blueice represented the first-phase deployment of the Integrated Computing Environment for Scientific Simulation (ICESS) contract with IBM, and more than doubled, over FY2006 levels, the compute capacity available to scientists. During FY2008 the second phase of the ICESS procurement, an IBM POWER6, will be installed and available to the user community. The computing capacity at NCAR will again increase by at least two-fold, and will keep CISL in alignment with its strategic goals.

NCAR's supercomputers are managed by CISL under the UCAR/NSF Cooperative Agreement and are supported by NSF Core funds including CSL funding.


*Postal address: P.O. Box 3000, Boulder, CO 80307-3000 • Shipping address: 1850 Table Mesa Drive, Boulder, CO 80305 • Contact*

CISL Director's message

CISL annual report table of contents

**Strategic goals**: science, facilities and technology

CISL research catalog

# Production supercomputing

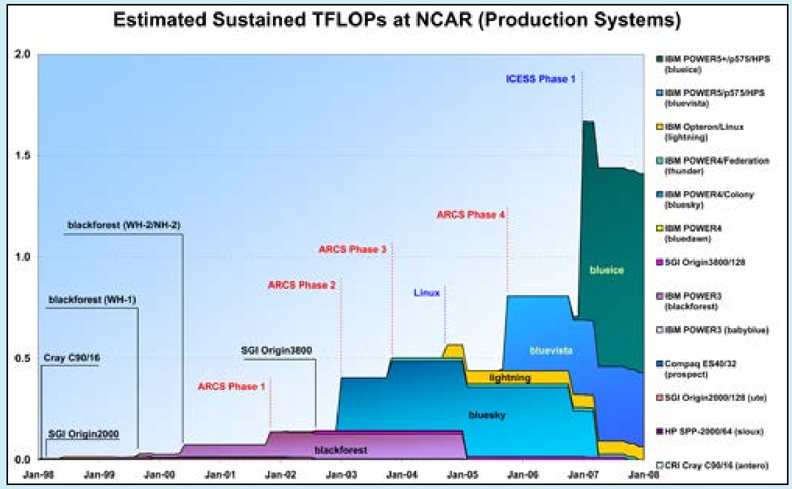
To fulfill its mission, CISL provides robust, reliable, effective, and efficient production supercomputing, coupled with state-of-the-art storage, data analysis, and data visualization services and tools for its community of users.

CISL's goals are to provide equitable access to reliable computing resources with minimal user wait times, while maximizing resource utilization. These goals are achieved by balancing the allocation and scheduling of resources with a well-tuned queue structure and prescribing single-job resource limits.

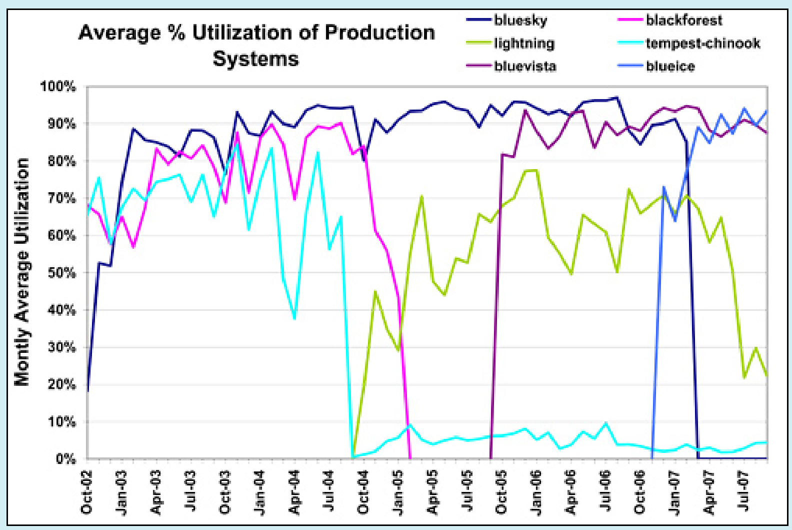
CISL works to increase the computational capacity available to the community on a regular basis. Deploying the IBM POWER5+ system blueice during FY2007 is another example of such an increase. Peripheral resources, which complement and supplement the high-end computing environment, are upgraded and enhanced as appropriate to match the growth in compute capacity.

In FY2008, CISL will install an IBM POWER6 system as the second phase of the ICESS procurement. The power and cooling demands of this new system will require the removal of both the POWER5 system bluevista and the POWER5+ system blueice. Despite the removal of these two large systems, both computational capacity and capability available to users will increase significantly.

This work fulfills NCAR's strategic priority of "Enhancing capability and capacity of NCAR supercomputing" and is supported by NSF Core funds, including CSL funding.




Estimated sustained computing capacity (in teraflops) available to the NCAR community over the past 10 years. On average CISL provides substantial capacity increases every 16 months to meet the scientific research demands of the community.




Average utilization (defined as the percent of compute nodes assigned to users at any one time) of the production computing platforms provided by CISL. During the time period shown, the major IBM systems (blackforest, bluesky, bluevista, and blueice) were delivered on time and reached nearly 90% utilization within a few months. Keeping scientific production at a high level meets NCAR's goal of providing reliable and robust computational services to the community.

Find People | Contact/Visit

NCAR Annual Report | CISL report | EOL report | ESSL report | RAL report | SERE report

The National Center for Atmospheric Research sponsored by NSF

NCAR

CISL Annual Report 2007

Search

CISL Director's message

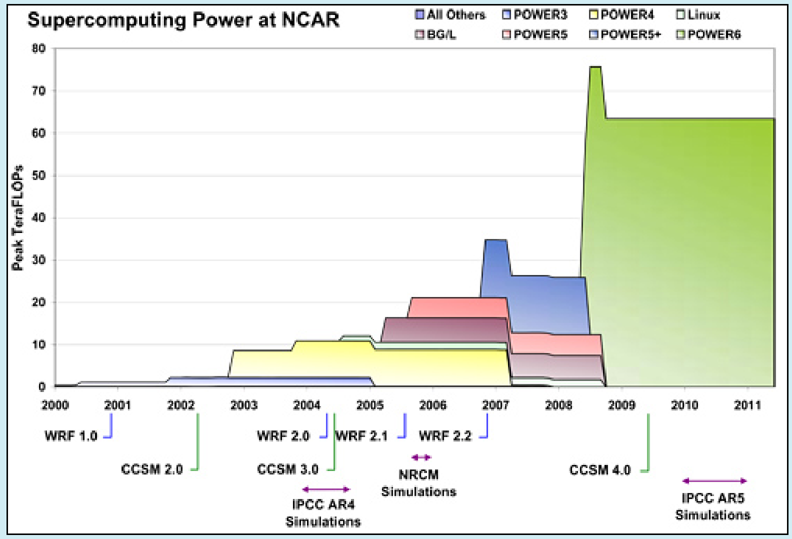
CISL annual report Table of contents

**Strategic goals**: science, facilities and technology

CISL research catalog

# Supercomputer status

During the first quarter of FY2007, CISL deployed the first phase of hardware of the Integrated Computing Environment for Scientific Simulation (ICESS) contract with IBM. The new supercomputer blueice is based on the IBM POWER5+ dual-core processor and the High Performance Switch communication technology. It offers over twice the computing capacity as NCAR's IBM POWER5 system bluevista.




The computing capability at NCAR, as shown by recent increases in the center's peak capability (in teraflops), allows NCAR scientists to develop, test, and release updated versions of the WRF and CCSM models. CCSM version 3 was used to provide climate simulations to the IPCC AR4, which was awarded the Nobel Peace Prize in October 2007. With anticipated increases in computational capability at NCAR, activities are under way to build and test CCSM version 4 for participation in the 2010-2011 IPCC AR5.

The deployment of blueice more than doubled the high-end computing resources available at NCAR. The IBM POWER4 system bluesky, which had been in operation since early FY2003, was decommissioned in March 2007. The deployment of blueice is consistent with CISL's strategic plan to significantly enhance the high-end computational environment at NCAR during FY2007, and it upgraded the production cyberinfrastructure available to the university, NCAR, and Climate Systems Laboratory (CSL) communities served by CISL.

During the first four months of blueice availability, CISL provided priority access to eight Breakthrough Science projects that required large numbers of processors and long periods of computational residency time to satisfy ambitious scientific goals. A large portion of blueice (1,200 processors) was reserved for four months to provide this opportunity to projects selected from the NSF GEO/ATM community and the overall NSF GEO community. Access to this amount of computing capability and capacity devoted to several grand challenge problems was unprecedented and allowed scientists to simulate and analyze problems never before addressed.

In June 2007, blueice was made available to the general user communities. Utilization of the resources provided by both bluevista and blueice then reached saturation quickly.

The second phase of ICESS hardware is scheduled to be delivered in April 2008. An IBM POWER6 supercomputer, to be named bluefire, will increase the computational capacity available to users by yet another significant factor. Due to electrical power constraints within the NCAR computing facility, both blueice and bluevista will be removed to provide the physical infrastructure headroom needed for the powerful IBM POWER6. This second phase of ICESS is designed to meet the continuing needs and requirements of the scientific community for computationally expensive endeavors, such as preparation for the IPCC AR-5 climate simulations with the Community Climate System Model Version 4 (CCSM4), which is currently under development.

This work aligns with the NCAR strategic priority of "Enhancing capability and capacity of NCAR supercomputing" and is supported by NSF Core funds, including CSL funding."



*Postal address: P.O. Box 3000, Boulder, CO 80307-3000 • Shipping address: 1850 Table Mesa Drive, Boulder, CO 80305 • Contact*

CISL Director's message
CISL annual report Table of contents
**Strategic goals**: science, facilities and technology
CISL research catalog

# Production deployment of blueice supercomputer

The blueice cluster represents the first phase of the Integrated Computing Environment for Scientific Simulation (ICESS) procurement. It is a 112-node IBM POWER5+ Cluster 1600 with a peak speed of 12 teraflops. The system successfully completed its Acceptance Test Phase at 11:00 am on December 15, 2006. From that time through January, the system was dedicated to code qualification for the Breakthrough Science special computing campaign and some miscellaneous benchmark runs. It began full production on February 1, 2007.

The 112-node IBM POWER5+ supercomputer blueice provides the scientific community with additional computation resources for both capacity and on-demand capability computing. The blueice cluster provides the platform for scientists to scale their codes into larger problem sizes and to increase the complexity of the physics within their simulations.

The ICESS project in general and blueice in particular advance NCAR's strategic goal to "Provide robust, accessible, and innovative information services and tools" and NCAR's strategic priority of "Enhancing capability and capacity of NCAR supercomputing." Notably, blueice expands and extends the CISL-developed on-demand capability computing model that enables the entire cluster or portions of it to support dedicated or shared special computing campaigns, such as the Breakthrough Science campaign or this year's High Resolution Hurricane Simulation Special Computing Campaign.

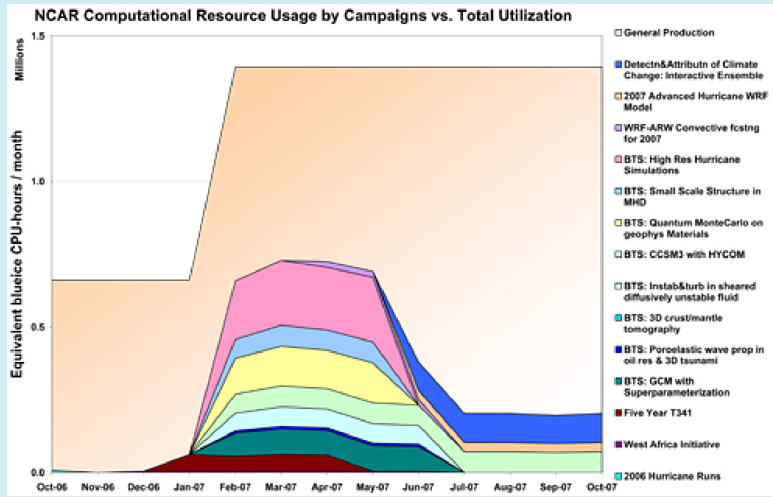
Since entering production, the blueice cluster has serviced over 210,000 jobs, a 91% utilization rate, and a sustained rate of just over 600 gigaflops (four times that of the previous bluesky system). Of the approximately 210,000 jobs, just over 5% represent capability and/or special-campaign runs, with the other 95% representing capacity runs split in the ratio of 20/60/20 between the economy, regular, and premium classes of service.

In late FY2008, blueice will be phased out to make room for bluefire, the ICESS Phase 2 system. The bluefire cluster will be an IBM POWER6 Cluster 1600, and it will continue to provide capacity and on-demand capability to the scientific community for even larger and more complex simulations.

This project is made possible through NSF Core funds, including CSL funding.

# Supercomputer special campaigns

This year, CISL supported four major and several minor on-demand computing campaigns on the production supercomputer clusters, in addition to the eight Breakthrough Science projects that were hosted on the new IBM POWER5+ system blueice. These campaigns, and the provision of special queues and pre-emptive scheduling to support on-demand and real-time computing, are a regular feature of the services provided by CISL to the NCAR, university, and CSL scientific user communities. Some computational campaigns recur annually, such as the WRF hurricane real-time forecasts, while others are either a one-time event or are accommodated on an as-needed basis. A common CISL-developed Special Campaign Software Tool Suite is used to manage the computer systems and the scheduling of special campaign job runs.




This chart tracks the usage of NCAR computational resources by special computing campaigns (on-demand and Breakthrough Science) during FY2007. This shows the significant increase in support for special campaigns made possible by blueice, the first computer acquired through the ICESS procurement. Outcomes from work accomplished with the significantly larger computing resources available to special campaigns are changing researchers' expectations for the pace of scientific progress that can be made through numerical simulations. (See larger image.)

While the NCAR production supercomputing environment provides capacity computing to the scientific end-user community, the special campaign mechanism supports ongoing computational projects and campaigns and on-demand capability computing for the scientific end-user community. CISL software engineers and system administrators have tuned and enhanced Platform Computing, Inc.'s LSF-HPC job scheduler to manage the supercomputer workload to accommodate these diverse needs, while continuing to maintain high system utilization and short wait times for jobs submitted for production computing.

CISL staff will continue to provide full 24x7 support for the special campaigns and on-demand, real-time computing during FY2008. Additionally, CISL software engineers and administrators will continue to enhance the CISL-developed Special Campaign Software Tool Suite and tune LSF-HPC to maximize system resource utilization, minimize job wait times, and to facilitate the use of NCAR computational resources.

The special computing campaigns and provision of on-demand and real-time computing support the NCAR strategic priority of "Developing and providing advanced services and tools." This work is made possible through NSF Core funds, including CSL funding.



*Postal address: P.O. Box 3000, Boulder, CO 80307-3000 • Shipping address: 1850 Table Mesa Drive, Boulder, CO 80305 • Contact*

# Supporting supercomputer users

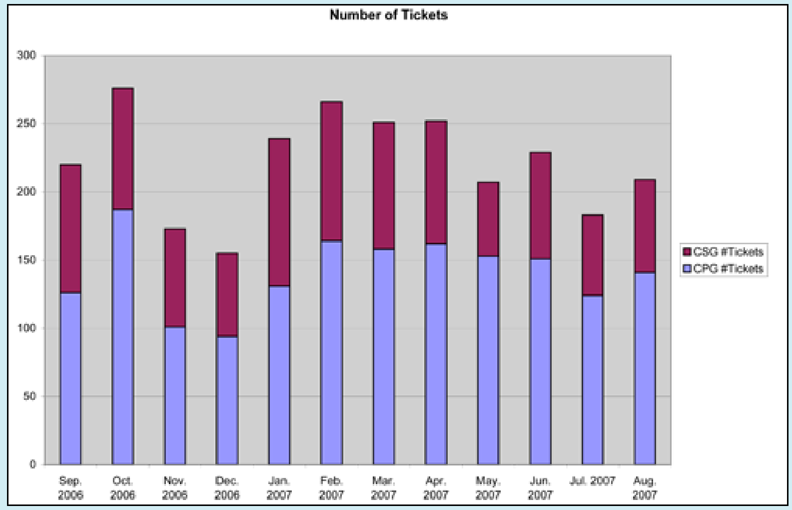
In today's challenging computational environment, excellent customer support is essential to making progress in computational and scientific research. That support begins the moment an investigator decides to use NCAR resources, and the collaboration may continue over months or years until results are achieved. This work supports NCAR's strategic goal to "Provide robust, accessible, and innovative information services and tools" to our customers. CISL provides end-to-end service using the full capability of the divisional staff.

In FY2007, CISL further enhanced a new tiered customer support system. The key to making this project succeed was expansion of the consulting service to include other groups within CISL who could provide frontline assistance as well as in-depth expertise. Contacts are tracked using an ExtraView HelpDesk trouble ticket system.

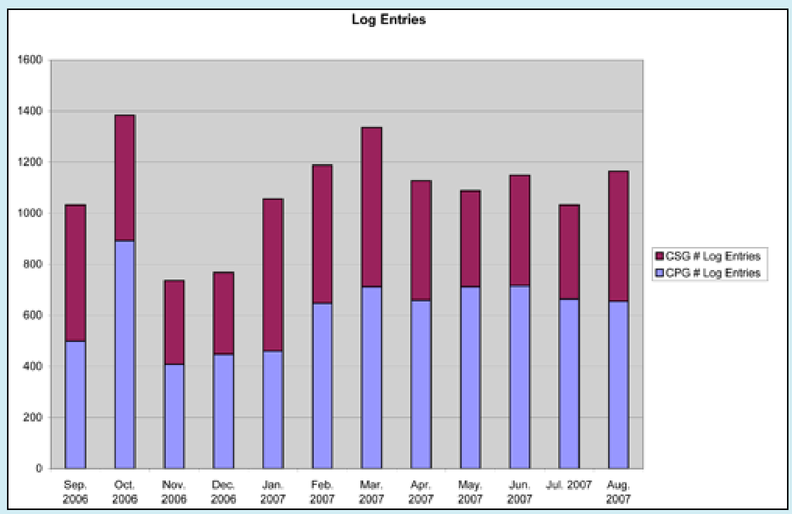
A benefit of tiered customer support has been greater efficiency, freeing CISL staff to begin supplying customized, one-on-one service for special projects such as 2007's innovative Breakthrough Science program, which provided opportunities for capability computing projects requiring hundreds of thousands of processor hours. We also began preparing consulting and documentation support for users joining the TeraGrid via NCAR.

In FY2008, we anticipate further growth in this type of scientific support and plan to begin logging these using ExtraView.

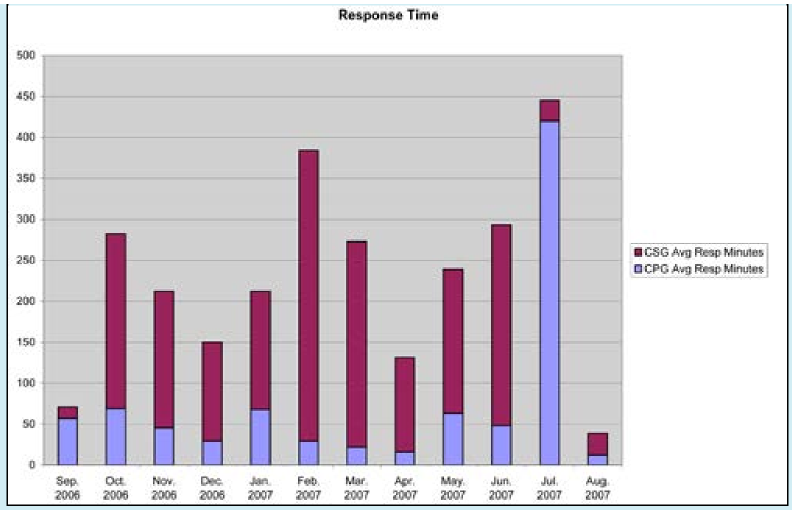
This ongoing service is supported by NSF Core funds, including CSL funding.



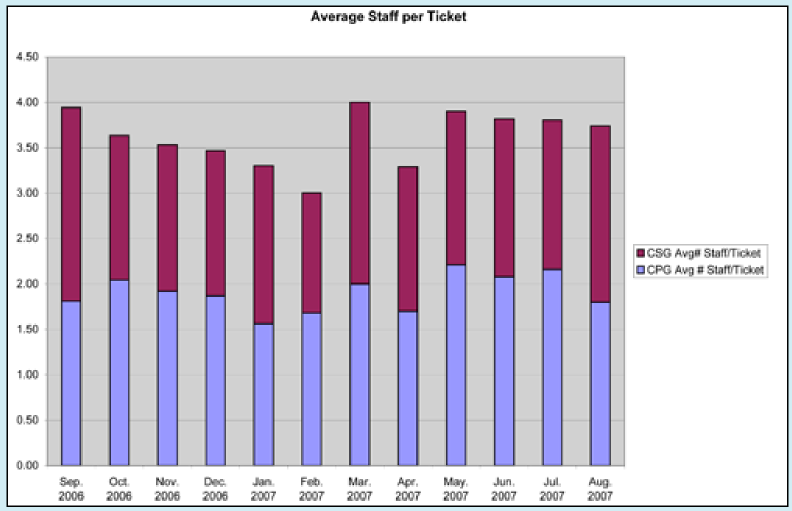

These graphs show CISL support statistics from a new tiered customer support system. Blue bars show frontline customer support, while red indicates advanced consulting. Frontline support resolved 1,692 tickets between September 2006 and August 2007. In that same time, advanced support resolved an additional 968 contacts, for a total of 2,660.




The average number of log entries per ticket was 4.9; communication was highest with users on complex cases.




Average response time for frontline support was about 70 minutes, while a longer average response time of about 3.3 hours was required for more complex issues. Unusually long frontline response times seen in July-August were due to a larger-than-usual number of tickets for which resolution stalled.




The average number of staff who worked on tickets was 1.81, demonstrating cross-team cooperation in resolving issues. Use of tiered consulting has made 24x7 customer response feasible, while a tracking system has made it easier to route questions and deal with them efficiently.


*Postal address: P.O. Box 3000, Boulder, CO 80307-3000 • Shipping address: 1850 Table Mesa Drive, Boulder, CO 80305 • Contact*

CISL Director's message
CISL annual report Table of contents
**Strategic goals**: science, facilities and technology
CISL research catalog

# Cybersecurity enhancement

UCAR manages and maintains a large and diverse set of compute, data, data storage, email, web, and network servers that form the core information technology within the institution. Not only are these systems valuable monetarily, they comprise vital scientific research tools and business continuation systems used by the UCAR organization and university communities. To pursue the scientific mission of the organization in an unobstructed manner, CISL is committed to maintaining a security posture that represents an enterprise to the community and adheres to NSF security best practices and recommendations.

Providing secure information technology systems within CISL and across UCAR supports the NCAR strategic priority of "Developing and providing advanced services and tools." It is vital to the organization that we protect systems, data, and intellectual property at the highest level possible that keeps usability and security in balance. This work is supported by UCAR Communications Pool indirect funds.

During FY2007, these factors are vital to the continued security of IT systems at UCAR:

- Coordinated consistent security policies and procedures across UCAR by the Computer Security Advisory Committee (CSAC), with a goal of achieving the appropriate balance between reasonable protection and pursuit of the scientific mission of the institution
- Staff participation in the community-wide, NSF-sponsored Cybersecurity Summit 2006 held in December 2006
- Initiating a redesign of the UCAR-wide token authentication service
- Placing increased importance on computer and network security when acquiring and configuring new equipment (computers, storage, network routers, etc.)
- Coordinating security training for system administrators throughout UCAR

To maintain a meaningful security posture and to fulfill the near-term security objectives of CISL, the following plans for FY2008 are in place:

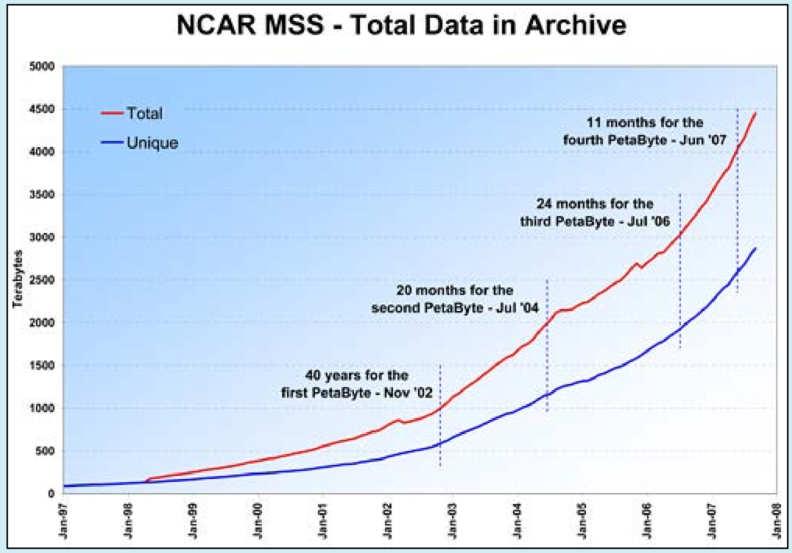
- Produce a UCAR/NCAR Cybersecurity Strategic Plan for 2007-2012
- Perform in a leadership role at the NSF-sponsored Cybersecurity Summit 2007
- Complete implementating one-time password (OTP) technology across UCAR
- Upgrade our aggressive network and host monitoring tools; augment current intrusion detection system (IDS) software
- Engage in collaborative efforts with peer and TeraGrid centers to share cybersecurity information, best practices, and incident notification
- Optimize our central logging system to incorporate all of UCAR

Cybersecurity at NCAR is supported by a combination of NSF Core funding and UCAR Communications Pool indirect funds.

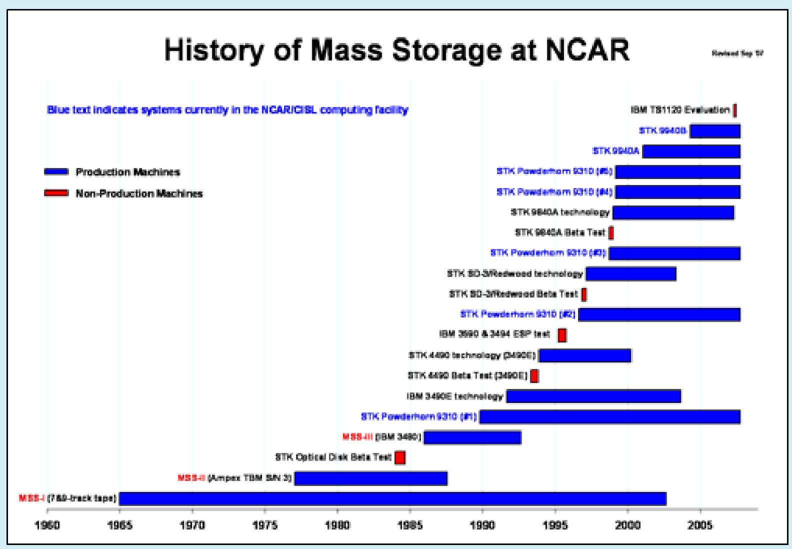

*Postal address: P.O. Box 3000, Boulder, CO 80307-3000 • Shipping address: 1850 Table Mesa Drive, Boulder, CO 80305 •* Contact

# Mass Storage System (MSS) improvement

The NCAR Mass Storage System (MSS) has been a high performance, reliable, and scalable system over the past 20 years. It has demonstrated high availability and accessibility and proven its cost effectiveness.




The growth of the NCAR MSS continues to follow an exponential curve. The MSS has successfully scaled up for decades. CISL continues to make system enhancements and deploy state-of-the-art storage solutions to maintain the NCAR MSS' leadership position in high-volume data management technology.




These are the storage technologies tested and used in the MSS since 1964. The NCAR MSS Group has evaluated and deployed many cutting-edge storage technologies during the life of the MSS. These carefully chosen solutions have enabled and enhanced MSS scalability, reliability, and availability at affordable levels throughout the life of the system.

The MSS in many ways has been what has distinguished computing at NCAR from computing elsewhere, and the system continues to be highly regarded by users and by peers at other centers. MSS maintenance and development supports the NCAR strategic priority of "Enhancing capability and capacity of NCAR supercomputing."

Today, the NCAR MSS remains one of the most capacious archives. In June 2007 the NCAR MSS surpassed its fourth petabyte of data. At the end of FY2007, it stores more than 4.5 petabytes (PB) of total data (2.7 PB of unique data), transfers more than 10 terabytes (TB) of data per day in response to user requests, and transfers another 6.7 TB of data per day for internal data migration and data movement to new media. The MSS is growing at a net rate of more than 100 TB per month.

Traditionally, MSS users access MSS data within the confines of the NCAR computer room where the highest possible data performance, reliability, and availability are provided. However, the computing environment is shifting from the traditional "glass house" paradigm, where the end user comes to a central site via remote data access interfaces, to a Grid-based infrastructure that supports more sophisticated work and data flows. The NCAR MSS is adapting to these changes.

The first step in adapting to this emerging landscape occurred in FY2007 when CISL joined the NSF TeraGrid and offered the NCAR MSS as an available resource. The NCAR MSS also embarked on a collaborative effort with the San Diego Supercomputing Center (SDSC) to provide mutual dark storage for disaster recovery, wherein each site serves as a remote backup site for the other. The NCAR MSS must continue to adapt to the evolving needs of the TeraGrid, including accommodating new areas of science and new classes of scientific users, while maintaining the high-performance characteristics of the glass house environment to traditional users.

The future development and deployment of the NCAR Mass Storage System is constrained by both the need to continue providing traditional file storage and access to Mass Storage services in the context of a full 7 by 24 production environment, as well as adopting new roles as an integrated component of larger UCAR-wide data management efforts. The MSS's traditional role will continue: to reliably preserve UCAR, NCAR, and university community data while serving a wide client base on multiple levels.

The MSS must scale up to meet an ever-growing demand for secure, reliable data storage and high-performance access. This requires the constant evaluation and periodic deployment of the latest, highest-performance, and most cost-effective hardware and software technologies available. Plans for FY2008 include upgrading the current MSS tape subsystem midyear and launching a project to prepare for replacing the tape library technology within the next few years. The NCAR MSS must also be ready to handle the anticipated increase in traffic from the ICESS computing upgrade in FY2008.

The NCAR MSS is managed by CISL under the UCAR/NSF Cooperative Agreement and is supported by NSF Core funds including CSL funding.


*Postal address: P.O. Box 3000, Boulder, CO 80307-3000 • Shipping address: 1850 Table Mesa Drive, Boulder, CO 80305 • Contact*

CISL Director's message
CISL annual report Table of contents
**Strategic goals**: science, facilities and technology
CISL research catalog

# Network engineering and telecommunications

The Network Engineering and Telecommunications Section (NETS) is responsible for the planning, engineering, installation, operation, maintenance, strategy, and research regarding the state-of-the-art data networking and telecommunications facilities for NCAR/UCAR. NETS provides a vital service to the atmospheric and oceanographic research communities by ensuring supercomputing resources are linked to scientists at NCAR and throughout the university research community. These activities are essential to the effective use of NCAR/UCAR's scientific resources, and they foster the overall advancement of scientific inquiry. This work supports NCAR's strategic priority of "Developing and providing advanced services and tools."

NETS pursued these LAN projects in FY2007:

- UCAR network infrastructure recabling
- Network monitoring
- Multicast support activities
- UPS, grounding, wireless networking, Voice over IP
- SCD LAN projects

NETS pursued these MAN projects in FY2007:

- Boulder Point-Of-Presence (BPOP)
- Boulder Research and Administration Network (BRAN)
- Remote-working and home-access

NETS pursued these WAN projects in FY2007:

- Front Range GigaPOP (FRGP)
- UCAR Point of Presence (UPoP)
- National LambdaRail (NLR)
- Internet2/Abilene
- Bi-State Optical Network (BiSON)
- TeraGrid

In FY2008, NETS will continue to provide support and enhancements for these essential networking services.

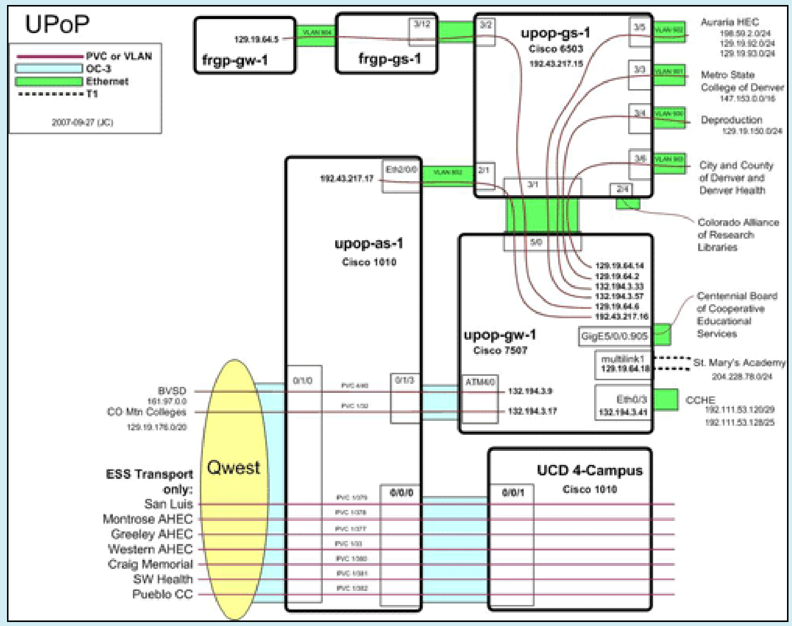
NETS activities are supported through UCAR Communications Pool indirect funds.


*Postal address: P.O. Box 3000, Boulder, CO 80307-3000 • Shipping address: 1850 Table Mesa Drive, Boulder, CO 80305 • Contact*

CISL Director's message
CISL annual report Table of contents
**Strategic goals**: science, facilities and technology
CISL research catalog

# UCAR Point of Presence (UPoP)

NETS undertook the development and construction of a new entity called the UCAR Point of Presence (UPoP). The UPoP is a consortium of universities, K-20s, non-profit corporations, and government agencies that cooperate in an aggregation point (the UPoP) to share Wide Area Networking (WAN) services, access to the commodity Internet, access to the Abilene (I2) research network, and access to the National LambdaRail (NLR). The current members include:




This diagram shows the current network configuration of the UPoP. This is a multi-faceted facility that integrates many networking technologies to serve a broad research and education community.

- Auraria Higher Education Center (AHEC)
- Boulder Valley School District (BVSD)
- Centennial Board of Cooperative Educational Services (CBOCES)
- City of Boulder
- City and County of Denver
- Colorado Alliance of Research Libraries (CARL)
- Colorado Mountain College (CMC)
- Deproduction
- Denver Health and Hospital Authority (DHHA)
- Educational Support Services (ESS)
  - San Luis
  - Montrose-AHEC
  - Greeley-AHEC
  - Western-AHEC
  - Craig Memorial-AHEC
  - SW Health Hospital
  - Pueblo CC
- Metropolitan State College of Denver (MSCD)
- St. Mary's Academy

Pending members at end-FY2007 include:

- Regis High School
- Colorado Springs K-12s
- Continuing expansion of CBOCES

This project required the vision to see a role for UCAR, the approval of UCAR to proceed, the development of policies, procedures, agreements, invoicing techniques, then undertaking the education of the users as well as encouraging their commitment to the new enterprise.

There are a number of advantages gained by sharing services through such a consortium. Costs for WAN services are reduced for each partner, expertise among partners can be shared, a higher level of services can be purchased than individual institutions could afford, there is more buying power among a consortium, and there are great economies of scale. All of this leads to much better wide area networking than what individual members could provide to their users on their own. NCAR/UCAR has agreed to provide the engineering, administrative, and NOC support for the UPoP. The service costs incurred by NCAR/UCAR are shared by all members. NETS believes that the greater service and bandwidth provided through the UPoP are important enough for NCAR/UCAR to both participate and provide the engineering, administrative, and NOC services.

From the early stages of planning the UPoP, the administrative team has been involved in determining the appropriateness of NCAR/UCAR's involvement in administering this effort. Once it was deemed appropriate for NCAR/UCAR to administer the UPoP, it required many hours of meetings with the UPoP members to finalize the agreement details, and still more hours settling the financial specifics. Setting up the agreements, the financial spreadsheets, and the accounting system were all major efforts that required extensive time, commitment, and expertise.

The UPoP is expected to continue to grow with new members in FY2008. NETS also plans to reconfigure the hardware to more current equipment.

The shared funding arrangement for the UPoP is indicated above and is managed through the UCAR Communications Pool indirect funds. This work supports NCAR's strategic priority of "Developing and providing advanced services and tools."

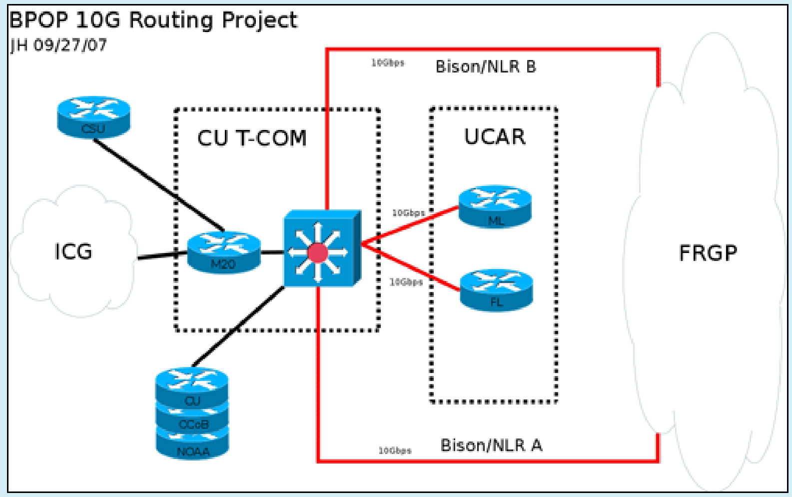

*Postal address: P.O. Box 3000, Boulder, CO 80307-3000 • Shipping address: 1850 Table Mesa Drive, Boulder, CO 80305 • Contact*

CISL Director's message
CISL annual report Table of contents
**Strategic goals**: science, facilities and technology
CISL research catalog

# 10 Gbps end-to-end technology implemented at NCAR

NETS has achieved its goal to complete the configuration of 10 Gbps network service from UCARnet to the wide area. This goal was accomplished in FY2007 with the reconfiguration of the routers at the Telecommunications Building on the CU-Boulder campus (T-COM). They now route all traffic through our 10 Gbps-capable Cisco router. This has improved and will continue to improve network service including data transport, especially to the Internet2 and NLR research networks.

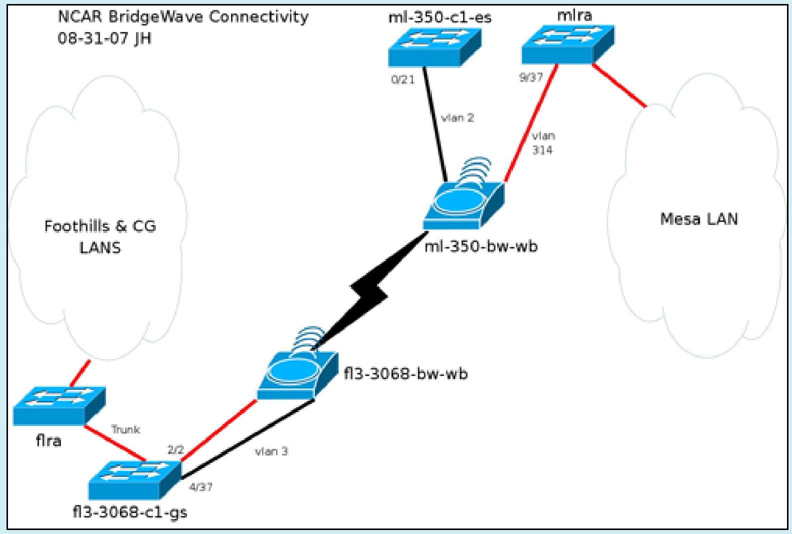
This work addresses NCAR's strategic priority of "Developing and providing advanced services and tools" and is supported through UCAR Communications Pool indirect funds.




The final configuration of the Boulder Point of Presence wide area router that enables 10 Gbps end-to-end from UCARnet to the wide area including Internet2 and National LambdaRail (NLR). This has improved and will continue to improve network service including data transport, especially to the Internet2 and NLR research networks.

# ML/FL WAN wireless upgrade

NETS initiated a project this year to replace the unlicensed Proxim wireless system that operated between the Mesa Lab and Foothills Lab. This system was experiencing interference that affected its performance with a licensed wireless system. A NETS team performed extensive research on options, presented a solution, then installed, deployed, and tested the system. This new licensed-spectrum 1-Gbps BridgeWave wireless system has now been formally accepted.




This diagram illustrates the new licensed-spectrum 1-Gbps BridgeWave wireless system that was installed at NCAR/UCAR during FY2007. This system backs up our fiber optic facilities in Boulder. This alternate-technology system provides a new level of high-availability network service for NCAR/UCAR staff.

The goal of this system is to provide backup should the fiber optic system be damaged between the Mesa Lab and Foothills. It will ensure that network and phone service remains operational while the fiber is repaired. This project is part of NETS ongoing business continuity efforts. The Mesa Lab is at particular risk of a fiber cut since we are on a BRAN fiber spur from the University of Colorado to the Mesa Lab.

Providing robust networking services is critical to NCAR's strategic priority of "Developing and providing advanced services and tools." This work is supported by UCAR Communications Pool indirect funds.

CISL Director's message
CISL annual report Table of contents
**Strategic goals**: science, facilities and technology
CISL research catalog

# LAN wireless upgrade

NETS initiated a project in FY2007 to upgrade NCAR/UCAR's local area network wireless system. We resurveyed the wireless coverage in all NCAR/UCAR facilities and decided on the best way to improve this service. We upgraded 123 wireless access points over seven months using IEEE 802.11g technology.

The new access points provide broader coverage and IEEE-standard 802.11g service that provides more than five times the bandwidth available before. The new system operates at a shared 54 Mbps versus the previous shared 10 Mbps.

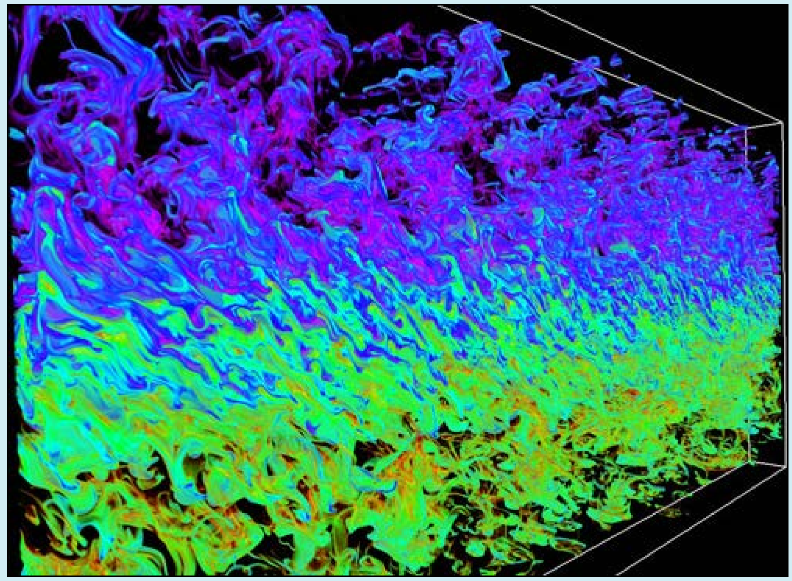
Providing robust networking services addresses NCAR's strategic priority of "Developing and providing advanced services and tools." This work is supported by UCAR Communications Pool indirect funds.

Bryan Anderson, a Network Technician with NETS, installs and configures one of the Cisco wireless access points to upgrade the Local Area Wireless (LAN) system for all UCAR campuses. This upgrade gives NCAR/UCAR staff broader, faster, and more reliable wireless connectivity to local networks and the internet.


*Postal address: P.O. Box 3000, Boulder, CO 80307-3000 • Shipping address: 1850 Table Mesa Drive, Boulder, CO 80305 • Contact*

# Data analysis and visualization

The Data Analysis and Visualization Lab enhances scientific workflow by providing UCAR's research community with a highly advanced computing environment tailored for the specialized needs of interactive data post-processing, analysis, and visualization. This evolving environment provides a unified state-of-the-art computing environment comprised of powerful, closely coupled, interactive processing and visualization engines and large-capacity high-performance global file systems. We provide direct support to the research community by developing algorithms for relevant visualization and analysis methods and by producing animations and imagery on behalf of the scientific staff.



Generated by Bill Smyth, University of Oregon, as part of CISL's Breakthrough Science (BTS) campaign. The image, which depicts the turbulent mixing of fresh water and seawater, was produced with VAPOR utilizing DASG's new remote visualization service, HPRGS. The CISL Data Analysis and Visualization Lab provides computing resources and consulting expertise to meet the interactive data exploration needs of the entire NCAR/UCAR scientific community. CISL's state-of-the-art data analysis capabilities play an integral role in the scientific discovery process for groundbreaking research in the geosciences.

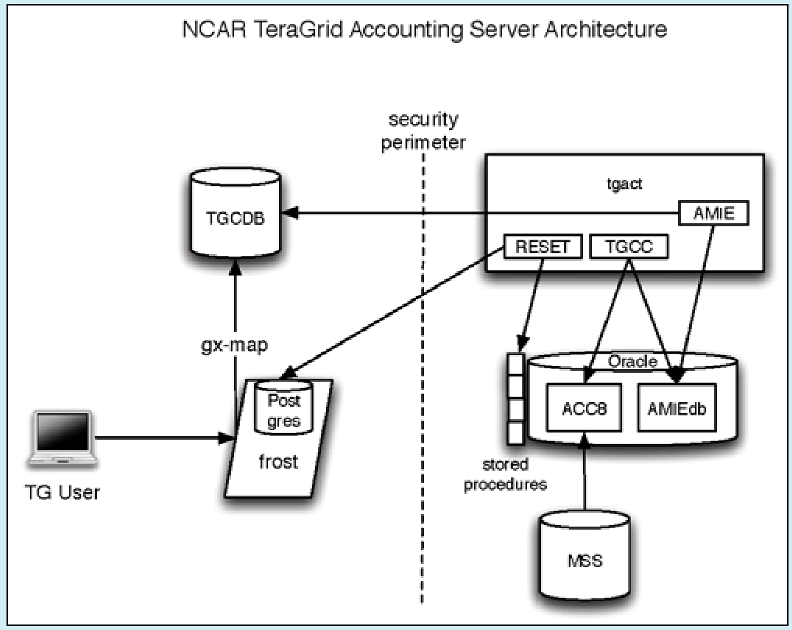
The goals of this effort are focused on addressing the growing sizes and complexity of scientific problems being researched at UCAR. We have seen a significant increase in resolution and data set sizes that require not only the enhancement of NCAR computational resource capability and capacity, but that also challenge us to provide advanced services and tools. The Data Analysis Services Group works not only to provide a suitable computational environment but also works directly with users to help develop new techniques and algorithms that allow scientists to push the boundaries of discovery. This work supports NCAR's strategic priorities of "Developing and providing advanced services and tools" and "Maintaining an innovative and creative workplace."

The evolution of this facility from a collection of dedicated standalone resources into a tightly coupled unified computing environment is a multi-year process. In FY2007 we made great strides in acquiring and integrating a large-scale shared storage solution and powerful computational and graphics resources. We have enhanced the visualization capabilites through the use of remote desktop graphics software and powerful servers capable of handling today's large data sets. The completion of this integration with an additional computational and visualization enhancement in FY2008 will offer the data post-processing, analysis, and visualization community an entirely new and well-designed facility to tackle today's larger challenges. FY2008 will see additional research into higher-performance storage and file system solutions that are more tightly coupled with UCAR's supercomputing resources.

This ongoing service is supported by NSF Core funds including CSL funding.

# TeraGrid Connector Code (TGCC)

TeraGrid Connector Code (TGCC) is a Java-based software application that was developed by CISL in FY2007 to integrate NCAR's allocation accounting database with the TeraGrid Central Database. This has enabled NCAR to provide its IBM Blue Gene/L supercomputer (frost) and Mass Storage System (MSS) as TeraGrid resources.




This diagram of NCAR's overall TeraGrid server architecture shows how the TeraGrid Connector Code (TGCC) is a key link in synchronizing TeraGrid project, user, and account information in the AMIEdb with NCAR's ACC8 accounting database. All account and supercomputing usage data flows through TGCC, effectively integrating the TeraGrid Central Database with NCAR's accounting database.

TGCC accepts incoming TeraGrid packets that describe project and account requests and updates. TGCC then synchronizes these with NCAR's accounting database and relays the resulting data to frost and the MSS. This mechanism provides access to the system for authenticated TeraGrid users. The result is a virtually seamless ability for TeraGrid users to request NCAR's frost resource via the centralized TeraGrid User Portal and allocation panel, then be automatically set up with access. Their usage is reported back to the TeraGrid Central Database, which they can view on the TeraGrid User Portal.

In 2008, NCAR will implement support for the storage accounting model currently being developed by TeraGrid working groups.

This work supports NCAR's strategic priority of "Developing and providing advanced services and tools." TGCC is supported by NSF Core funds.


*Postal address: P.O. Box 3000, Boulder, CO 80307-3000 • Shipping address: 1850 Table Mesa Drive, Boulder, CO 80305 • Contact*

CISL Director's message
CISL annual report Table of contents
**Strategic goals**: science, facilities and technology
CISL research catalog

# Experimental computing systems: Blue Gene/L


The IBM Blue Gene/L computer "frost" at NCAR was innovative in more ways than just the shape of its cabinet when it was installed in 2005. Its high-performance, low-power-consumption design had great potential, but the system required R&D to become a useful tool for geosciences research. That work has been very successful, and frost is now performing at a high level in multiple roles for universities, NCAR, and the TeraGrid.

In March 2005, NCAR became one of the first sites in the world to receive an IBM Blue Gene/L (BG/L) supercomputing system. The system, named frost, consists of a single BG/L rack (2,048 compute processors, 64 I/O processors, 5.73 teraflops peak) and appeared as the 61st fastest computer in the world in the 25th Top500 List (released in June 2005). Frost was an experimental system to support researchers from NCAR, the University of Colorado at Boulder, and the University of Colorado at Denver who are investigating and addressing the technical obstacles to achieving practical petascale computing in geoscience, aerospace engineering, and mathematical applications. The opportunity to experiment with systems like BG/L is absolutely essential for NCAR to maintain its ability to provide capability and capacity supercomputing to the community. Moreover, low-power systems like BG/L (only 25 KW for 5.73 teraflops) offer the promise of significantly reducing the strain on the NCAR Mesa Lab's computing facility.

To consolidate experimental coumputer system research in CISL, the Research Systems Evaluation Team (ReSET) was formed in late 2005. The mission of ReSET is to administer and evaluate strategically selected experimental systems for CISL to gain maximum knowledge of and impact from emerging technologies. ReSET is housed in CISL's Computer Science Section, but it collaborates with staff members from other sections and groups across CISL to accomplish its mission. In mid-November 2005, frost became the first experimental system managed by ReSET.

During FY2007, members of ReSET continued working with the frost user community to significantly increase both the number and breadth of applications that can be run on frost. One example of this effort's impact is the development of a version of CCSM capable of exploiting massively parallel computing platforms like BG/L. While frost was an experimental system, ReSET's success in expanding the user and application code base produced system usage levels that are similar to those of the production supercomputing systems managed by CISL.

In addition to providing user support, the ReSET team continues to work through the Blue Gene consortium and SP-XXL to improve the BG/L system software stack and influence development of the software stack for the follow-on system, Blue Gene/P. One example of this effort is the collaboration with Argonne National Laboratory to further develop Cobalt, the queuing system currently being used on frost, by incorporating alternate scheduling strategies and interfacing it with the Coordinated TeraGrid Software and Services software stack.

Frost became a production TeraGrid resource on August 1, 2007: 25% of its cycles are devoted to supporting NSF TeraGrid science activities. In FY2008, frost will continue to be used both as an experimental research system for university and NCAR users and as a production computing resource on the TeraGrid.

The role frost plays for the research commmunity now addresses three of NCAR's strategic priorities: "Conducting computer science, computational science, applied mathematics, statistics, and numerical methods R&D," "Developing and providing advanced services

and tools," and "Enhancing capability and capacity of NCAR supercomputing." This work is made possible through NSF MRI Grants CNS-0421498, CNS-0420873, and CNS-0420985, and through the IBM Shared University Research (SUR) program with the University of Colorado. NSF Core funding also supports this system.



*Postal address: P.O. Box 3000, Boulder, CO 80307-3000 • Shipping address: 1850 Table Mesa Drive, Boulder, CO 80305 • Contact*

CISL Director's message
CISL annual report Table of contents
**Strategic goals**: science, facilities and technology
CISL research catalog

# Continuation of cyberinfrastruture reports from FY2006

## Antarctic Mesoscale Prediction System (AMPS) on pegasus

In FY2007, CISL successfully negotiated with IBM to extend the support contracts for its two Linux cluster systems pegasus and lightning (lightning provides warm failover for pegasus) through the end of FY2008. The pegasus cluster runs two mesoscale forecast models in the Antarctic Mesoscale Prediction System (AMPS)—MM5 and WRF—as well as testing a polar version of WRF. The latter, Polar WRF, contains modifications to better represent conditions over the high latitudes and extensive ice sheets, and testing on pegasus has shown it to be an improvement over the regular WRF in Antarctica. Over the past year, Polar WRF has been implemented in AMPS.

CISL staff will continue to operate pegasus in normal operational mode through the end of FY2008.

This project is made possible through funding from the NSF Office of Polar Programs in collaboration with the Byrd Polar Research Center of the Ohio State University.

## LSF deployment

In FY2007, CISL staff completed work on the new batch system accounting database. This centralized MySQL database provides a consolidated repository of all production supercomputer batch system accounting data generated by Platform Computing's Load Sharing Facility (LSF). In addition to designing and creating the new database, CISL software engineers developed new tools and processes to automatically clean and load the accounting data into the database at multiple intervals throughout the day.

During this year's blueice Breakthrough Science (BTS) campaign, CISL staff mined the database to produce daily usage reports. These reports were then used to identify and provide assistance to the scientific researchers who were having difficulty getting their code to run properly on the new supercomputer. Also in FY2007, CISL has also configured a direct interface from the statistical package R to the database to further facilitate complex problem resolution, scheduler optimization, and data analysis.

In FY2008, CISL will deploy LSF on bluefire, the new IBM POWER6 cluster, and integrate its data into the consolidated system accounting database.

This project is made possible through NSF Core funding.

## Fiber installation along bike path between two campuses

This project was successfully completed and is fully operational. Networking projects are supported by UCAR Communications Pool indirect funds.

## Cabling Foothills Lab Building 0

This project was successfully completed and is fully operational. Networking projects are supported by UCAR Communications Pool indirect funds.

## Storage Area Network (SAN) deployment for CDP/ESG

In FY2007, DSG plans to make data available on our SAN to TeraGrid users via a web interface for downloading datasets formatted specifically for popular models used today. Changes in our existing infrastructure will make these data available to a broader user community at much higher transfer speeds.

The SAN is supported by NSF Core funding.

## CISL portal

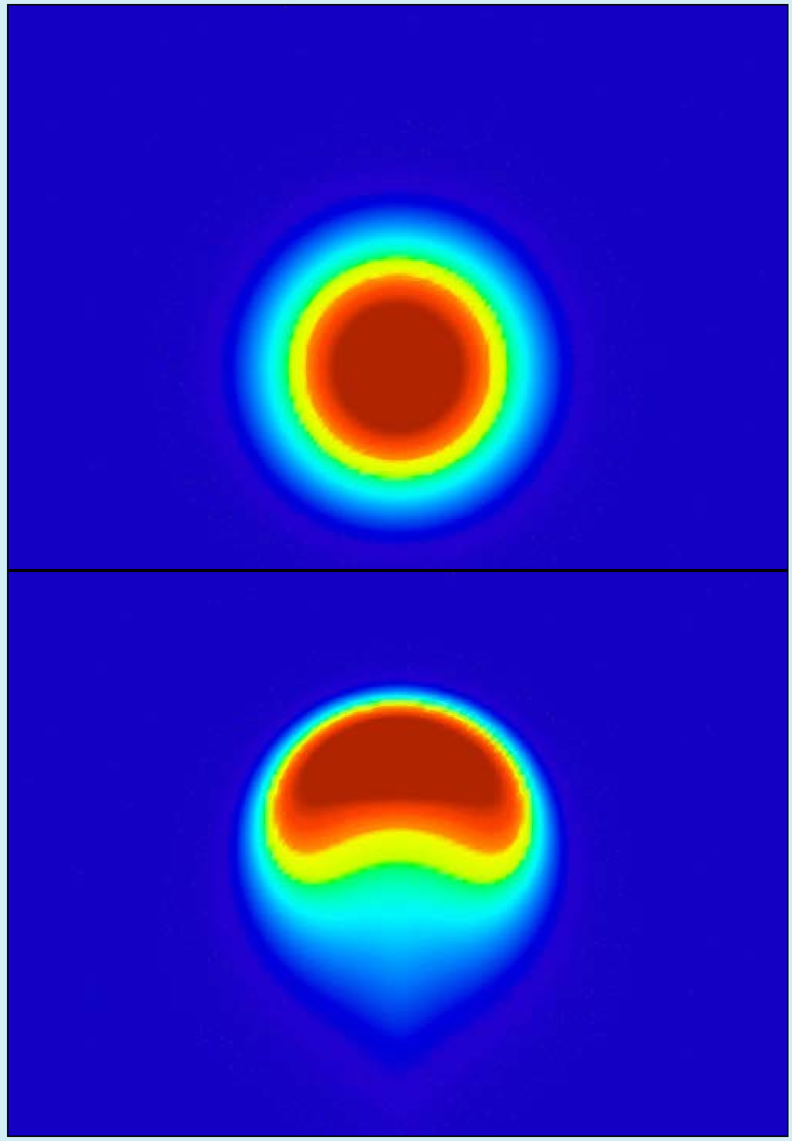
The CISL portal was enhanced in FY2007 to report additional accounting information. This portal has achieved production status and is now fully operational. For FY2008, the CISL portal will be maintained but not upgraded. Future development will occur as needs arise, most likely in the areas of reporting, supercomputer status, and data entry delegation.

The CISL portal is supported by NSF Core funding.



*Postal address: P.O. Box 3000, Boulder, CO 80307-3000 • Shipping address: 1850 Table Mesa Drive, Boulder, CO 80305 • Contact*

# Research in computational science and math for geophysics: TDD and IMAGe

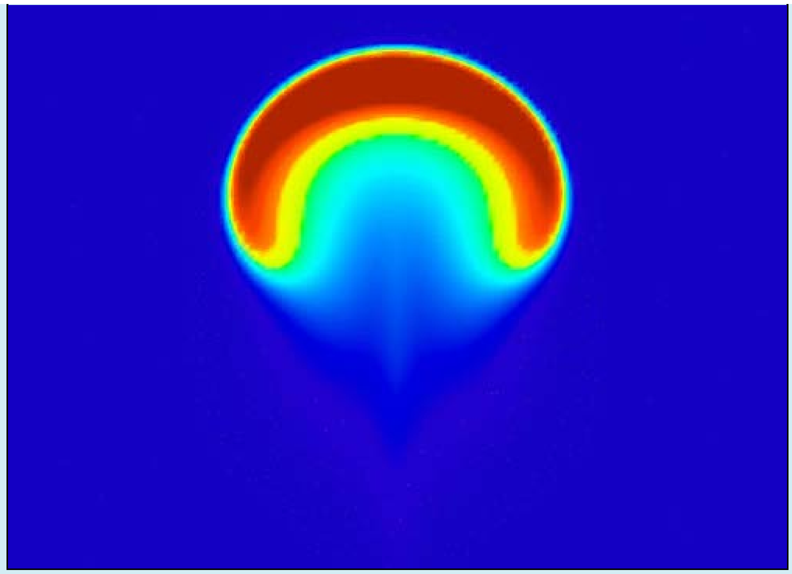


The research activities within CISL's Technology Development Division (TDD) and Institute for Mathematics Applied to Geosciences (IMAGe) support scientific computation, numerical modeling, and the statistical analysis of geophysical data and model experiments. This research is important to maintain an innovative computational and modeling facility at NCAR, and more broadly, to lead the geophysics community in adopting new computational and mathematical approches that enhance scientific research. This mission is aligned with NCAR's strategic priority of "Conducting computer science, computational science, applied mathematics, statistics, and numerical methods R&D."

Given this broad priority, the research in CISL must span several disciplines and address computational science at many levels. These include improvements to network flow and scalability of existing codes to different numerical methods for simulating the flow of geophysical fluids. Integrated with the computational science are areas of applied mathematics that include data analysis, models for multiscale processes, and techniques for assimilating data into numerical models. Because these different elements are coordinated through a single lab, there is an easy transfer of technology and ideas from prototypes and theoretical results in IMAGe, to issues of implementation and workflow in TDD, and finally into incorporation as tools and models for the communities served by CISL. There is also a valuable reverse transfer whereby emerging computational capability and data storage spur particular research that takes advantage of these features.

## Institute for Mathematics Applied to Geosciences (IMAGe)

For FY2007, the IMAGe program on statistics and numerical models provided a focus for statisticians to build collaborations with geophysical modeling groups, and for modelers to be aquainted with statistical methods for more efficient design and analysis of numerical model experiments. Other important accomplishments are advances in data assimilation and high-order numerical methods. During this period several large numerical experiments of flows with and without magnetic fields were conducted to test aspects of turbulence theory. In addition, a new research direction was taken in reconstructing paleoclimate.



This is a detailed simulation of a rising bubble of hot air and is similar to the small-scale motion of the atmosphere expressed by nonhydrostatic physical equations. This computation is significant because it is found using highly accurate numerical methods and can be implemented on large, massively parallel supercomputers. As models for the Earth's climate increase in spatial resolution, it will be necessary to simulate the complex motions of the atmosphere using nonhydrostatic fluid equations to accurately represent processes such as thunderstorms or the effect of mountainous terrain.

IMAGe plans for FY2008 are continuations of these activities. Some important milestones are incorporating higher-order numerics and conservation into a dynamical core for the NCAR global atmosphere model, combining several different climate proxies into a climate reconstruction, and numerical experiments of turbulent flows for spherical geometry. In the coming year, we will focus on the applications of RBFs to unsteady fluid flows based on incorporating both local node refinement and filtering. The IMAGe Theme-of-the-Year program for FY2008 will be on Geophysical Turbulence Phenomena. Its goal is to synthesize theory, observations, and computation to advance the understanding of turbulence.

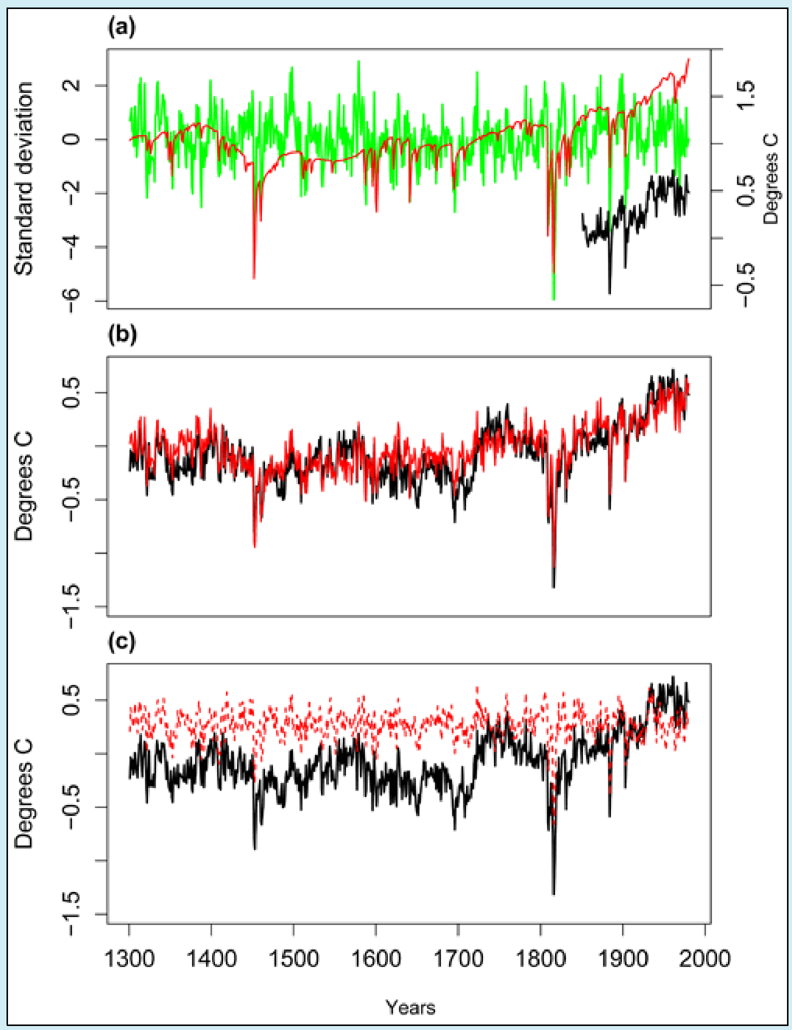
## Technology development

TDD researchers developed scalable versions of POP and CICE as well as a sequential CCSM coupler that currently runs on the IBM Blue Gene/L (BG/L) system at production resolutions. This is a significant simplification in design and opens the door to ultra-high-resolution coupled climate simulations using very large numbers of processors.

FY2008 plans are continuations of existing work. Some important milestones include deploying a new computer to support our experimental systems research and TeraGrid activities, and developing a service oriented architecture for the geosciences. Further, development will proceed on an ultra-high-resolution configuration of CCSM that is suitable for execution on 10,000 to 30,000 processors.

## Earth system modeling infrastructure

One of the major accomplishments of FY2007 was the successful completion of a beta test of a coupled, ESMF-based COAMPS-NCOM application. The atmospheric portion of COAMPS (Coupled Ocean Atmosphere Mesoscale Prediction System) is in operational




This figure reports the results from testing a Bayesian statistical method to reconstruct past Northern Hemisphere temperatures based on tree rings and other proxy information. For this test case, the true temperature series has been obtained from a numerical experiment with the NCAR paleoclimate model. Figure (a) depicts some synthetic annual data (green) that is similar in quality from a network of tree ring chronologies and derived from the model temperatures, the radiative input to the use at the Navy Fleet Numerical Meteorology and Oceanography Center (FNMOC). Coupling it to NCOM (NRL Coastal Ocean Model) improves the predictive capability of the system at high resolution. The coupling was accomplished within the ESMF component architecture using the ESMF sparse matrix multiply for regridding. The coupled system is expected to be transitioned to FNMOC operations beginning in FY2008.

atomosphere at a global scale (red) and the model temperature over the period of instrumental temperature records. Figures (b) and (c) are reconstructions (red) of the past tempertures using a Bayesian hierarchical statistical model, and can be compared to the true model temperatures. The reconstruction in (b) also uses the radiation series in a simple statistical form and provides a more accurate estimate of temperature than when the tree ring information is used alone (Figure c). Reconstructing past climate using single types of climate proxies may not reproduce behavior at all time scales, such as the results in (c). This example is important for demonstrating the value of including additional covariate information, such as radiation input, when reconstucting past climate. The statistical framework used to solve this problem faciliates incorporating important physical information and can aid in capturing the patterns and cycles of climate over longer periods.

In FY2008, the ESMF team will publicly release a version of the framework (v3.1.0) that contains wholly redesigned data structures for the representation of grids and fields. These structures allow for the representation and manipulation of rectilinear and curvilinear grids and to a limited extent, multi-patch grids. This release will also enable users to represent a wide variety of grids in index space, and to perform highly scalable redistribution and sparse matrix multiply operations using them.

## Visualization and enabling technologies

Scaffolding upon knowledge gained in the VSTO project, we began to investigate emerging ontology-based semantic systems as a core foundation for several activities. Our experiments spanned the Earth System Grid, the Community Data Portal, the Earth System Curator, and CADIS, and the results were very promising, particularly as they relate to the potential for improved human-computer interfaces.

We will continue this R&D work into FY2008, and plan to deliver an initial production release of powerful new knowledge-based tools during the year. In FY2008 we also plan to investigate scalability and performance strategies in the context of our community analysis and visualization tools. This work will span the intertwined areas of data models, aggregation schemes, complex grid topologies, and display models.

## Computational science

The Computational Science Section developed a High-Throughput Computing (HTC) service for BG/L. Designed as a high-performance computing platform for large parallel jobs, BG/L previously allocated resources in 64-CPU partitions. HTC allows each of the 2,048 processors in BG/L to run independent programs, making BG/L a candidate platform for more diverse Grid-enabled workflows in use at NCAR. In FY2007, we developed a Grid-enabled interface supporting HTC on BG/L. This new interface accepts single-processor tasks using the Globus Resource Allocation Manager (GRAM), aggregates HTC tasks into BG/L partitions, and requests partition execution using the underlying system scheduler. By separating HTC task aggregation from scheduling, we provide the ability for workflows constructed using standard Grid middleware to run both parallel and serial jobs on BG/L.

## Support

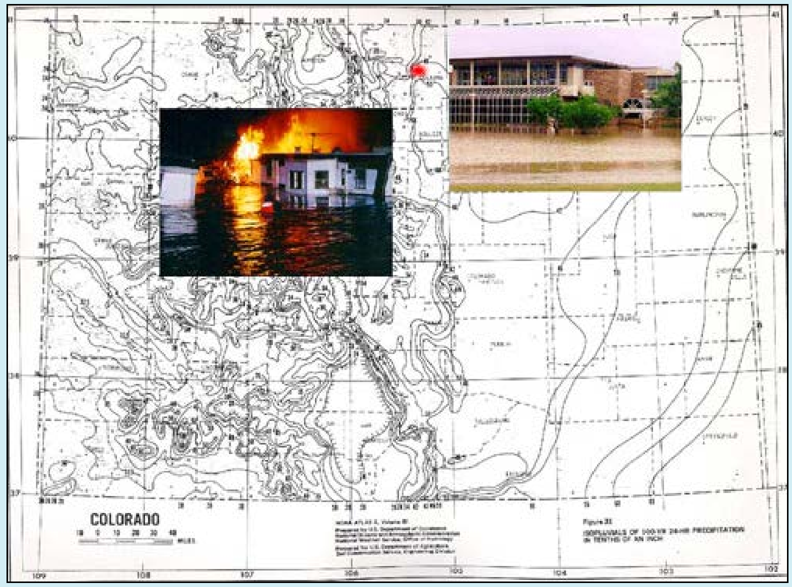
Support by funding agencies other than the NSF is indicated in the individual reports in this section of the CISL annual report.


*Postal address: P.O. Box 3000, Boulder, CO 80307-3000 • Shipping address: 1850 Table Mesa Drive, Boulder, CO 80305 • Contact*

CISL Director's message
CISL annual report Table of contents
**Strategic goals**: science, facilities and technology
CISL research catalog

# IMAGe research: New algorithms, tools, and geophysical models

The power of mathematical science is that similar methods and models can be used to solve problems in very different contexts. The Institute of Mathematics Applied to Geosciences (IMAGe) was formed in October 2004 to develop tools, methods, and models that can address some of NCAR's fundemental science problems. IMAGe is also actively introducing the mathematics community to new problems that are posed by geophysical processes and observations. Two important vehicles that support this interdisciplinary activity are the Theme of the Year workshops and publically available software for numerical and statistical methods. IMAGe contributes to the NCAR strategic priorities of "Conducting research in computer science, applied mathematics, statistics, and numerical methods" and "Engaging a broader and more diverse community."



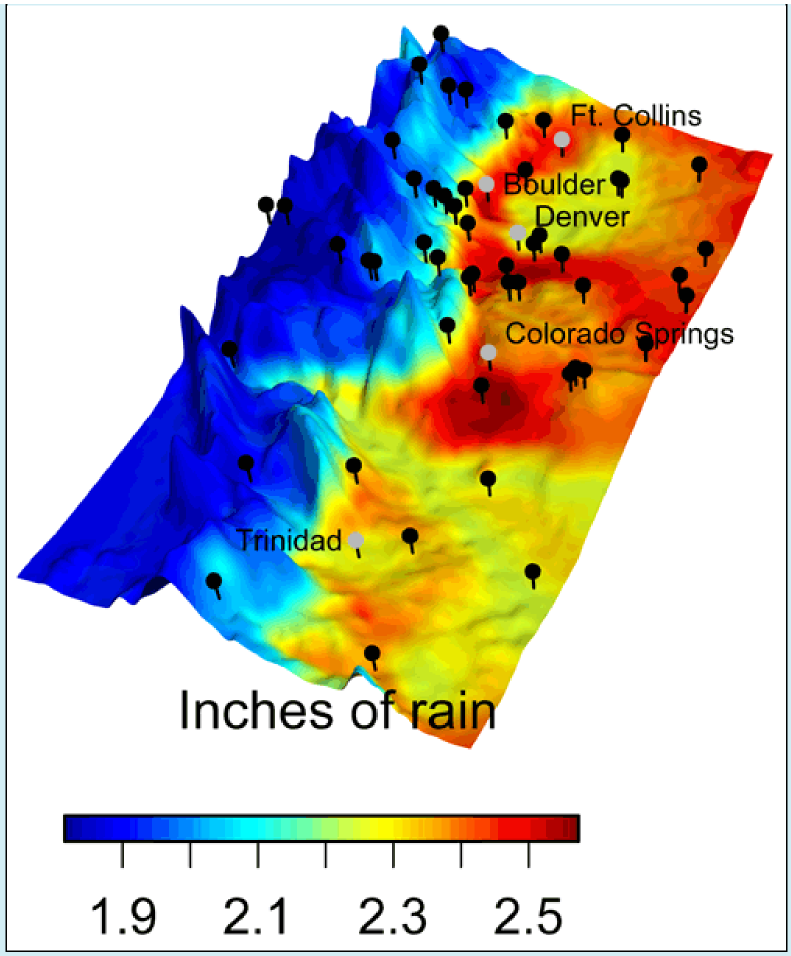

A precipitation atlas overlaid with scenes from the July 1997 Fort Collins, Colorado flood where 10 inches of rain fell on the city in 6 hours. Despite common descriptions of future climate change as "global warming," extreme precipitation events driven by climate change also have large economic and ecological impacts. Statistical methods being developed in IMAGe are allowing modelers to refine the accuracy of their estimates of past climate and enhance their ability to project future weather and climate events. (Photos by John Weaver.)

Some accomplishments during FY2007 include multi-scale models for the complex structures produced by fluid flow, statistical models for analyzing regional climate model output, and developing methods to match parameters in large geophysical models to observations. Each of these projects is complemented by publically available software that makes these advances accessible to the research community. The FY2007 Theme of the Year (TOY) was a successful series of three workshops on statistics and numerical models that brought together students, faculty, modelers, and statisticians. This TOY featured a summer school that established connections between students from a diverse range of backgrounds as they learned about models and methods for understanding the Earth's carbon cycle.

In FY2008, IMAGe will develop:

- Extensions to adaptive alogrithms for simulating magnetohydrodynamical flow
- New numerical methods that are conservative, high order, and scale to large numbers of processors
- Methods for synthesizing different kinds of climate proxy data to estimate past climate and for summarizing multi-model regional climate experiments
- Data assimiliation methods for tracing sources and sinks of atmospheric constituents

The 2008 TOY will bring modelers together with mathematicians and statisticians to study geophysical turbulence phenomena. This effort recognizes NCAR's longstanding




A newer type of precipitation atlas is overlaid on an exaggerated topographical isosurface of the Colorado Front Range showing Fort Collins at the top. The data for this figure is based on extrapolating daily precipitation data from the weather stations located at the black and gray markers. Elevation is shown using perspective and shading, and the different colors represent an extreme amount of precipitation expected to occur in a 24-hour period on average once every 20 years. For example, the red color around Fort Collins correlates to a value of less than 2.5, indicating an extreme rainfall event of approximately 2.5 inches in a 24-hour period about every 20 years. This can also be interpreted as a 5 percent chance per year that Fort Collins will receive 2.5 inches of rain in 24 hours. This kind of information is important for flood planning and designing roads and other permanent structures.

interest in turbulence as a foundation for understanding the dynamics of the atmosphere and ocean. It will be codirected by Keith Julien (Applied Mathematics CU) and is in partnership with the Institute for Pure and Applied Mathematics at UCLA. This thematic program will consist of three workshops that span turbulence theory, observations, and computation. A summer school will revisit these three lines of research from the workshops, bring new talent into this field, and foster multi-disciplinary perspectives.


*Postal address: P.O. Box 3000, Boulder, CO 80307-3000 • Shipping address: 1850 Table Mesa Drive, Boulder, CO 80305 • Contact*

Find People | Contact/Visit
UCAR | NCAR Annual Report | UOP | CISL report | EOL report | ESSL report | RAL report | SERE report



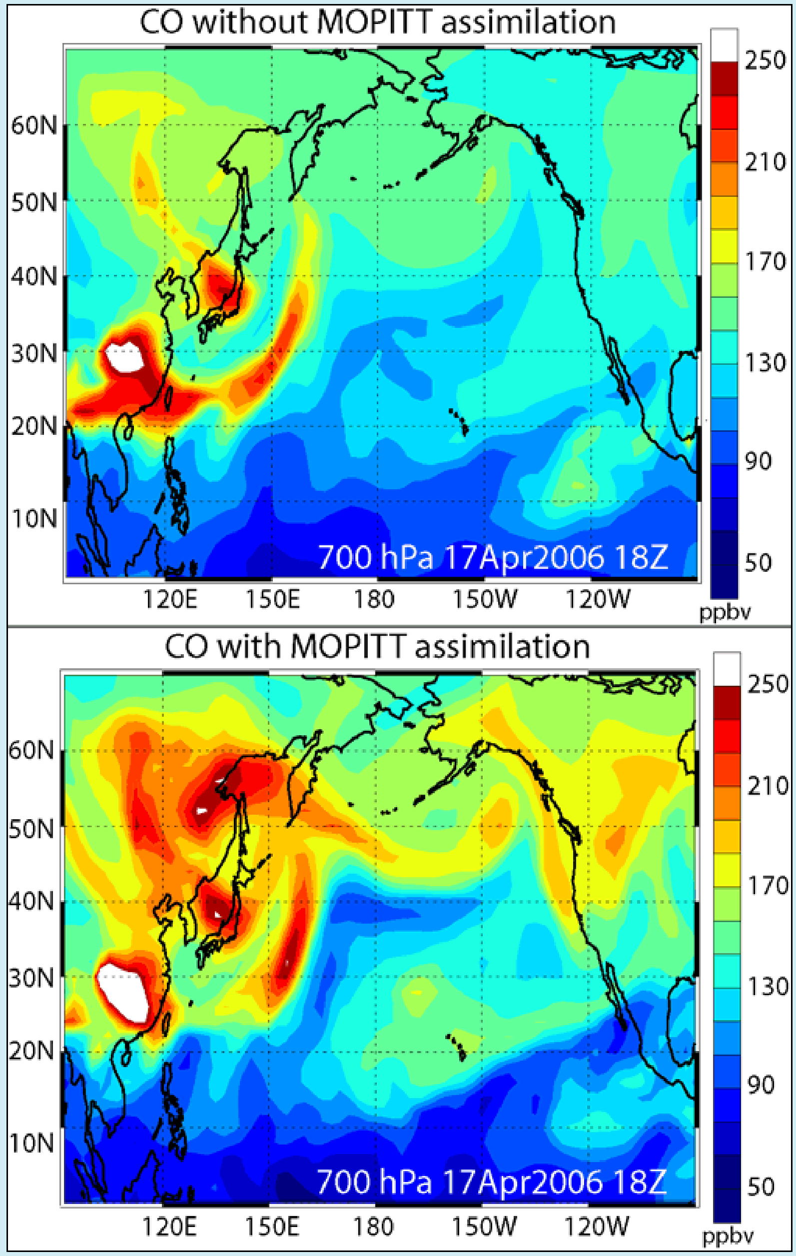
CISL Annual Report 2007

Search

CISL Director's message
CISL annual report Table of contents
**Strategic goals**: science, facilities and technology
CISL research catalog

# Data assimilation research

Data assimilation is the process of merging data from observations with computer models. It can transform diverse and incomplete observations to gridded estimates that can be easily used and interpreted. The assimilation process also produces quantitative information on model error, forecast skill, and observational errors, all of which allows us to improve the models. Data assimilation is providing rapid advances in geophysical studies. The Data Assimilation Research Section (DAReS) of IMAGe performs fundamental research on ensemble data assimilation methodologies for application across a wide range of geophysical problems. DAReS develops and maintains the Data Assimilation Research Testbed (DART), a software facility for doing ensemble data assimilation. DAReS also provides support to a growing community of NCAR, university, and government laboratory collaborators who are interested in applying ensemble data assimilation methods.




These two plots show 700 hPa concentration of CO from a DART/CAM assimilation using all standard observations for numerical weather prediction (top) and from a DART/CAM assimilation that included CO observations from the MOPITT instrument on the EOS Terra spacecraft (bottom). Comparison with aircraft observations (not shown) indicates that assimilating the MOPITT observations improves the analysis. These results, produced by Ave Arellano of ACD, demonstrate DART's abilities to facilitate innovative research involving assimilation of novel observations.

DAReS supports three of NCAR's strategic priorities: "Developing community models," "Developing and providing advanced services and tools," and "Enhancing science education." The DART user community includes members from many NCAR divisions, more than a dozen universities, and several government labs. Within NCAR:

- Researchers in CGD are using DART/CAM (Community Atmosphere Model) to validate and improve climate models
- MMM is using DART/WRF (Weather Research and Forecasting Model) to assimilate radar observations for convective-scale and hurricane prediction research
- ACD will use DART as a central piece of a new satellite observing system testbed
- COSMIC is using DART/WRF to assimilate GPS radio occultation observations
- RAL is using DART/WRF to study boundary layer assimilation and modeling
- HAO is exploring using DART for space weather and solar dynamo prediction

University groups are using both DART/WRF and DART/CAM, and several researchers have incorporated their own models including hydrological models, small-scale tracer transport models, and ocean/atmosphere GCMs. A DART/WRF system was tested during the

NOAA/NSSL Spring Program to make predictions of severe weather over the central U.S. Researchers at the California Institute of Technology are preparing to use a DART/WRF system to assimilate observations of the Martian atmosphere. DAReS provides support for all these activities and uses feedback from users to develop more powerful and generic assimilation tools. DART has also been used to support graduate data assimilation classes at several universities. In July 2007, DART was used to provide six afternoons of computer exercises supporting an IMAGe workshop on assimilation of carbon dioxide observations.

The Jamaica release of DART was made available to the community in April using CISL's new subversion facility. Jamaica contains a number of enhanced assimilation algorithms and new parallel implementations that allow DART to run efficiently on a variety of parallel computing platforms.

Fundamental data assimilation research focuses on advancing ensemble methods to make them more powerful and generic, capable of being effectively applied to many problems as nearly "black-box" algorithms. Assimilation research will continue to focus on improving methods for dealing with sampling error (a major concern for generic filtering algorithms). New non-Gaussian ensemble filtering algorithms have been developed in the past year. These algorithms should facilitate the assimilation of discrete structures like thunderstorms and allow the use of observations with complex error characteristics. These algorithms will be tested in DART/WRF in FY2008.

This is the main page for DAReS and the DART facility.

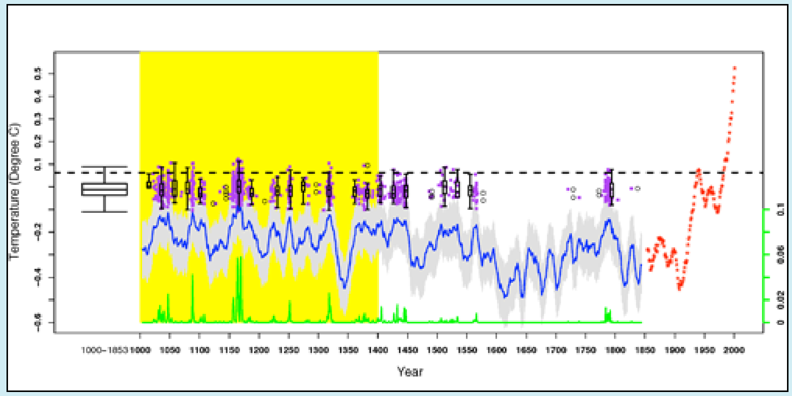
The Data Assimilation Research Section is supported by NSF Core funding.


*Postal address: P.O. Box 3000, Boulder, CO 80307-3000 • Shipping address: 1850 Table Mesa Drive, Boulder, CO 80305 • Contact*

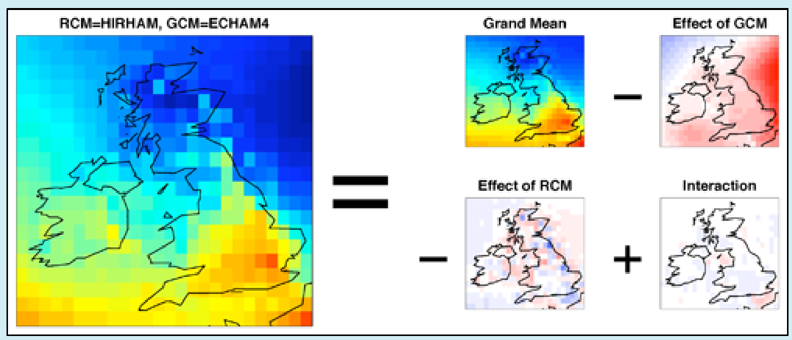
CISL Director's message
CISL annual report Table of contents
**Strategic goals:** science, facilities and technology
CISL research catalog

# Geophysical Statistics Project

For the past decade, the Geophysical Statistics Project (GSP) has been a leader in training and research emphasizing the synergy between the geosciences and the statistical sciences. Aside from basic methodological and theoretical statistical research, GSP has had a strong training component supporting from four to six postdoctoral visiting scientists. The postdocs are immersed in research activities that not only focus their skills as applied statisticians but also expose them to important applications in the geosciences.




This figure shows the uncertainty of decadal average (blue line with gray band) and the uncertainty of decadal maxima (purple dots and box plots), accompanied by instrumented decadal temperature (red). It is widely acknowledged that past temperature reconstructions may contain substantial uncertainty that is difficult to quantify in its full complexity, and this blurs our understanding of the temperature evolution and the significance of the recent warming. This figure results from a statistical method to reconstruct past temperatures together with their confidence ranges by keeping track of different sources of uncertainties. This method offers, for the first time, an explicit answer to questions about decadal average temperatures because we now have the ability to account for the serial correlation of uncertainty.




This figure shows the decomposition of the output of a particular run of a simplified regional climate model (RCM) experiment. The 30-year average summer temperature for a control run is organized into effects that can be attributed to the particular global climate model (GCM) that was used as forcing for the RCM, the particular RCM, as well as the interaction associated with the particular GCM/RCM pair. This analysis of variance (ANOVA) approach incorporates a linear combination of Gaussian processes and represents a novel statistical technique for analyzing such experiments. Further, it helps climate model researchers understand model biases and sources of variation in the model output, and it leads to improved projections of climate change that are based on multi-model ensembles.

In addition to these core activities, GSP also has an active visitor program providing research opportunities for visiting graduate students and junior and senior faculty members from across the nation and abroad. As with the postdoctoral training program, the goal of these programs is to foster collaboration between graduate students, postdocs, the permanent and visiting statistical staff, and the NCAR scientists. These programs, as well as the research and training aspects of GSP that emphasize the interaction between statistics and the geosciences, embody the tenets of integration, innovation, and community building within the NCAR strategic plan. Specifically, this program supports the NCAR strategic priorities of "Conducting computer science, computational science, applied mathematics, statistics, and numerical methods R&D," "Supporting and enhancing formal science education at all levels," and "Engaging a broader and more diverse community in the atmospheric and geosciences."

During FY2007, GSP researchers have been involved in numerous important projects, including:

- Design and analysis of computer experiments, in particular focusing on regional climate models and models of the upper atmosphere and the magnetosphere
- Developing methodology for analyzing extremes of weather and climate
- Stochastic weather generators
- Carbon transport
- Modeling uncertainty in climate reconstruction
- Impacts of climate and climate change on public health

GSP continues to develop methodology for analyzing spatial data, including nonstationary covariance models, models for spatial lattice data, multivariate spatial observations, spatial-temporal models, as well as general methodology for computational statistics and Bayesian hierarchical models.

In FY2008, the scientific focus on computer models will continue, in particular through GSP scientists being involved in such NCAR programs as the North American Regional Climate Model Assessment Program (NARCCAP) as well as in collaborations with other computer modeling groups across NCAR. Beyond computer models, GSP scientists will continue to assess the impacts of climate and climate change on public health, to develop methodology for analyzing extremes, to develop methodology for quantifying the uncertainty in climate reconstructions, and to develop statistical methodology for the analysis of complex, spatial and spatial-temporal data.

This project is made possible through NSF Core funding, as well as grants through NSF's Division of Mathematical Sciences and NSF's Collaboration in Mathematical Geosciences.


*Postal address: P.O. Box 3000, Boulder, CO 80307-3000 • Shipping address: 1850 Table Mesa Drive, Boulder, CO 80305 • Contact*

CISL Director's message

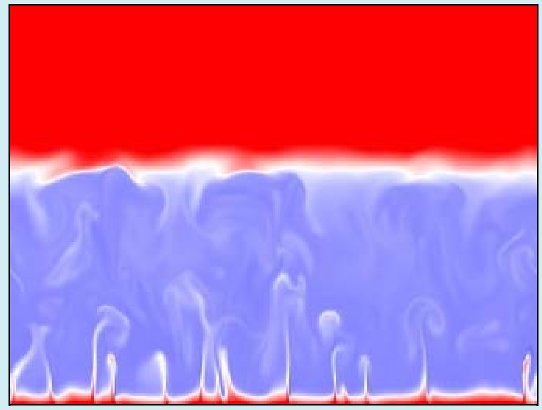
CISL annual report Table of contents

**Strategic goals:** science, facilities and technology

CISL research catalog

# Geophysical Turbulence Program

Research on turbulence has been a significant part of the NCAR scientific program since its beginning in the early 1960s. The original scientific leaders of NCAR recognized that to understand the dynamics of the atmosphere, the oceans, the climate, the sun, and solar-terretrial interactions, it would be essential to understand the relevant turbulent processes. A number of scientific appointmens in the first 10-15 years of NCAR's existence reflected this view and provided an in-house base from which to productively interact and collaborate with the world turbulence community. From these beginnings has emerged a sustained emphasis on geophysical turbulence at NCAR in research, visitors, seminars, and workshops that continues to this day. This emphasis can be found today in the Geophysical Turbulence Program (GTP).



This image shows a snapshot of the temperature field in a direct numerical simulation of penetrative convection. This figure reveals effects of molecular diffusion that may act to alter the widely accepted convective entrainment law. This result is part of a program of investigation to understand the convective atmospheric boundary layer. (Figure courtesy of Peter Sullivan (NCAR/MMM) and H. Jonker (Delft University, Netherlands).

GTP is by construction an interdiscplinary group of about 40 members that spans many divisions and laboratories at NCAR with a few external affiliates. It encompasses research at NCAR on multiscale nonlinear processes with an array of applications in a broad variety of areas. GTP is also the outreach arm of this research.

In FY2007, GTP sponsored 13 seminars and hosted 7 long-term visitors (with an average stay of 25 days) and a one-year visitor. The topics covered in collaboration with NCAR staff represent a broad variety of interests: studies of semi-Lagrangian fluid numerics, collision coalescence of cloud droplets, the entrainment law of the atmospheric boundary layer, spectral element methods for turbulence, turbulence in a rotating sphere with global spectral models, magnetospheric and space physics, and fundamental turbulence scaling laws. A collection of these collaboration summaries appears at GTP contributions by visiting collaborators.

GTP activities advance NCAR's strategic priorities of "Conducting computer science, computational science, applied mathematics, statistics, and numerical methods R&D" and "Engaging a broader and more diverse community in the atmospheric and geosciences." This work is supported by NSF Core funding.



*Postal address: P.O. Box 3000, Boulder, CO 80307-3000 • Shipping address: 1850 Table Mesa Drive, Boulder, CO 80305 • Contact*

CISL Director's message
CISL annual report Table of contents
**Strategic goals:** science, facilities and technology
CISL research catalog

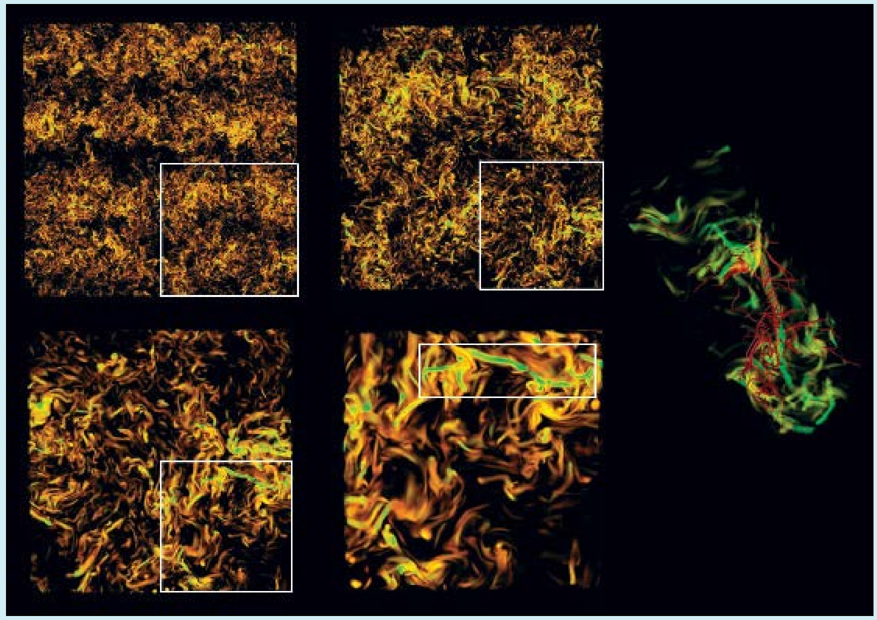
# GTP contributions by visiting collaborators

This is a collection of summaries of the work conducted by some of the visitors to the Geophysical Turbulence Program in FY2007:

- **Brachet, Marc** summary of collaboration with Annick Pouquet (NCAR), Duane Rosenberg (NCAR), and Pablo D. Mininni (NCAR).
- **Cossette, Jean Francois** summary of collaboration with Piotr Smolarkiewicz and Paul Charbonneau (Universit\351 de Montr\351al).
- **Jonker, H.** summary of collaboration with Peter Sullivan (NCAR).
- **Montgomery, David** summary of collaboration with Pablo Mininni (NCAR), Annick Pouquet (NCAR), and Leaf Turner (Cornell Univeristy).
- **Wang, Lian-Ping** summary of collaboration with Wojciech Grabowski (NCAR).

# Numerical turbulence algorithms and code development

The Turbulence Numerics Team (TNT) staff includes Aimé Fournier (Project Scientist), Jonathan Graham (Graduate Student in Applied Mathematics, CU, supported by an NSF-CMG grant), Ed Lee (Graduate Student in Applied Mathematics, Columbia University), Pablo Mininni (Senior Postdoc, supported by an NSF-CMG grant), Annick Pouquet (Senior Scientist and Section Head), Duane Rosenberg (Software Engineer). Details about the general report below appear in the CISL Research Catalog organized by the last names of the research team members.



Three-dimensional rendering of regions of strong vorticity in a $2{,}048^3$ hydrodynamic simulation. From left to right and top to bottom, successive zooms into the structures are shown. Note the small-scale vortex filaments and the development of clusters of vortex tubes at intermediate scales. As a reference in the last zoom (right), velocity field lines are shown in red. These figures show the complex flow structures that develop at very high Reynolds number ($R_{\lambda}$ 1,300), and they provide an excellent test case for the study of turbulence as it appears in nature, the intricate dynamics of which lead to complex behavior and modified transport properties.

## Turbulence science

We have pursued investigations of homogeneous and isotropic turbulence and turbulent structures at high Reynolds numbers, incorporating a broad variety of phenomena. For neutral fluids, we have run high Reynolds number ($R_{\lambda}$ 800) simulations in an effort to study energy transfer between scales. We find that 20% of the energy flux in the small scales is due to interactions with the large-scale flow. A recent high-resolution ($2{,}048^3$) hydrodynamic allowed for a more refined analysis at still higher Reynolds number ($R_{\lambda}$ 1,300) showing that convergence to the asymptotic turbulence regime appears to be slow; that even though the nonlocal interactions diminish with Reynolds number, they are measureable with the highest resolution data we can currently afford.

This year has seen significant progress on applying and understanding regularizations as subgrid scale (SGS) models in the study of the Navier-Stokes equations. We find that certain regularizations may be useful as a model of unresolved scales, as they are able to reproduce the Navier-Stokes energy spectrum, and may offer a significant, though suboptimal (independent of Reynolds number) computational savings. Other regularizations are found to reproduce intermittency properties of these flows.

Using our recently developed spectral method for studying neutral and conducting incompressible fluids inside a rigid, "hard" spherical boundary, we have added the ability to study a richer set of physical effects that can more faithfully treat aspects of atmospheric flows and planetary and solar dynamos.

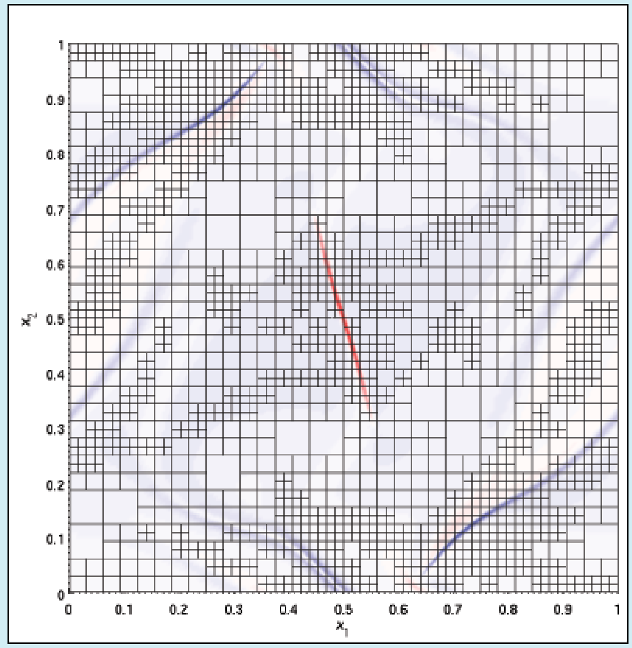
For conducting magnetohydrodynamic (MHD) flows, we have extended our previous results to show that the nonlocal behavior of the energy transfer in MHD is the result of a correlation between the velocity and magnetic fields. These MHD studies raise a number of interesting questions concerning the role of magnetic helicity, possible implications for dynamos, and fundamental aspects of universality in MHD.

In an important new development, we have carried out late-time analysis of a **breakthrough MHD simulation** at the unprecendented resolution of $1536^3$, and find that the energy spectrum is composed of two contributions, each moderately resolved. The appearance of this spectrum with two small-scale inertial ranges has never been observed before, and it corresponds to the interplay between Alfvén waves and turbulent eddies. It may be interpreted as a partial breakdown of universality in MHD.

Finally, we continue to investigate the ability of adaptive mesh refinement (AMR; see also below) to accurately model turbulent phenomena, partly to determine how well AMR can accelerate long time integration simulations, and also to establish a formal direct link between the AMR and the multi-resolution analysis of the flow and its structures.

## Numerical turbulence algorithms and code development

The IMAGe Turbulence Numerics Team (TNT) develops both tools and models that enhance our capability to investigate geophysical turbulence, and it applies these capabilities to fundamental scientific objectives. This program complements the Geophysical Turbulence Program and focuses on the accurate simulation and understanding of fluid turbulence, as found in the atmosphere and for charged flows in the presence of magnetic fields. TNT research emphasizes simplified physical systems that still reproduce the complexity and multi-scale properties associated with turbulent flows but that allow for the highest possible Reynolds number. The code development and applications pertain directly to the NCAR strategic priorities of "Conducting computer science, computational science, applied mathematics, statistics, and numerical methods R&D" and "Developing and providing advanced services and tools."



Contour plot of current density in an adaptive simulation of the Orszag-Tang vortex configuration. Red is high current, blue is low current, and the equivalent resolution is $512^2$. Note the strong, thin current sheet at the center. This simluation demonstrates the ability of an explicit adaptive MHD spectral element solver to accurately capture small-scale structure in a flow that exhibits complex nonlinear behavior including intermittent magnetic reconnection.

TNT members have broad experience in developing a variety of algorithms for studying turbulence. Our highly scalable codes include a 2D and 3D pseudo-spectral hydro- and magnetohydrodynamics (MHD) code that may include a Hall current. These codes are proven to scale up to several thousand processors. These codes have also been modified to include a Lagrangian-averaged ("alpha") model that smooths the velocity locally and has proved useful for studies using very high Reynolds numbers. We also have a new (strictly) spectral method to solve the equations of hydrodynamics and MHD in a sphere, with which studies can be made of fluid turbulence (with rotation) at moderate Reynolds numbers with a variety of boundary conditions.

We have significantly modified the pseudo-spectral codes to make the addition of new physics easier, and to simplify the maintenance of the code as the number of users increases. Support for FFTW 3.x and new options for POSIX and MPI I/O were added. Now the pseudospectral code has a dynamical core, and the different solvers are picked at compile time by the user. A solver for rotating flows has already been written and tested, and simulations up to 5,123 grid points and Rossby numbers down to 0.05 were done. We are currently analyzing these results. Options for a solver for stratified flows are already in place, and our next task is to implement and test such a solver.

TNT continues work its high-order adaptive mesh refinement code, GASpAR. This year's activities have focused on developing an explicit incompressible MHD solver to extend the existing Burgers and Navier-Stokes solver capabilities. This new solver has been applied to a challenging turbulent MHD problem in the literature, and it was found to produce excellent agreement with established results. We also continue work on preconditioning in collaboration with IMAGe/CMG and have obtained preliminary results from an optimized additive Schwarz preconditioner that, in its first stage, will be applied to our iterative Krylov methods used with conforming elements. We have made a strategic decision to postpone adding modeling (e.g., so-called 'alpha' models) this year, and have instead made strides toward a full three-dimensional solver capability that we will pursue as well in FY2008.

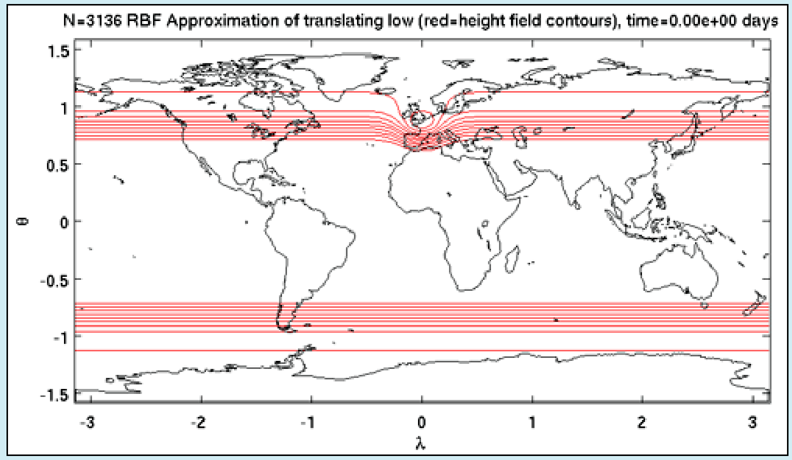
We continue to develop new aspects of exploration and applicability for spectral elements, and to apply our extpertise in the area of spectral elements and numerical methods to areas of investigation that are of traditional interest to NCAR.

Finally, in collaboration with our visitor Marc Brachet, we have begun to develop and test a newly developed parallel version of a symmetric FFT algorithm for use in pseudo-spectral studies of problems that have the same symmetries as the so-called Taylor-Green vortices. We will continue our work on this project in FY2008 because it may enable us to achieve resolutions up to four times that of a standard pseudo-spectral code, and hence, to probe significantly higher Reynolds number flows.

TNT research is supported by NSF Core funding and partially by NSF grant CMG-0327888.

# Numerical methods: Application of radial basis functions to modeling

While computer technology has advanced dramatically in recent years, numerical schemes currently used for climate and solar modeling fall drastically short of scientists' expectations. Spherical harmonics require large grids to resolve small features, and this is computationally impractical. Spectral element methods can resolve small features, but they require higher resolution near artificial boundaries to achieve high accuracy. Both methods involve high algorithmic complexity and are impossible or awkward to apply to irregular geometries. As a result, geoscientists and computational mathematicians are searching for new options. Radial basis functions (RBFs) offer the geosciences community a new and efficient numerical approach for solving time-dependent partial differential equations (PDEs).




RBFs were used to produce this 23-day simulation of a steadily translating low pressure system, mode led by the forced nonlinear shallow water equations. This simulation used simple algoritms on 3,136 nodes with a time step of 10 minutes. This result demonstrates that RBFs can be applied to geophysical models, and that this approach shows promise for efficiently using thousands of processors to produce highly accurate Earth system simulations. (See 8 MB animation.)

Building on the accomplishments of FY2006, the IMAGe Computational Mathematics Group together with the University of Utah, University of Colorado-Boulder, University Of Michigan-Ann Arbor, Arizona State University, and Uppsala University, Sweden continue research in the developing area of RBFs for climate and solar modeling.

Results from the deformational flow test case reported in FY2006 are compared to a discontinuous Galerkin spectral element scheme (DGSE) in the table that follows. Because this test case has just been developed, comparison is limited to this method since it is the only one for which results are available in the literature. The table shows that to achieve a given accuracy for this test case, the RBF method needs a much lower resolution while being able to take much larger time steps than the DGSE method.

| Method | N | L2 error | Time step |
|---|---|---|---|
| RBF | 4096 | 1e-5 | 600 minutes |
| DGSE | 55296 | 1e-5 | 6 minutes |

In 2007, our efforts furthered the topic by concentrating on solving the shallow water wave equations on the sphere using RBFs. This research concentrates on the performance of RBFs for three test cases of the shallow water equations with known solutions. The first test case is a steady-state solution for global nonlinear zonal geostrophic flow. The second is similar to the first except that the wind field is compactly supported (i.e. nonzero in a limited band region), emitting a more complex solution. The last is a forced nonlinear system with a translating low pressure center in the Northern Hemisphere that is superimposed on a westerly jet stream.

RBFs numerically solved the first test case trivially. The solution is second-order spherical harmonics that RBFs can reproduce exactly with just nine nodes on the sphere. We could stably integrate at machine precision for decades. For the second test case, the solution is not an exact spherical harmonic expansion, and the errors compare well against other spectral methods as shown in the table. For the third test case, the comparision analysis to other spectral methods is currently being performed. However, the RBF solution can be seen in the animation above.

The following table summarizes the results for the second test case to compare the performance of RBFs with spherical harmonics (SH), double Fourier series (DF), and spectral elements on a cube (SE). It shows that the RBF method achieves superior accuracy with significantly fewer processors.

| Method | N | L2 error | Time step |
|---|---|---|---|
| RBF | 1849 | 1e-8 | 10 minutes |
| SH | 2048 | 2e-6 | 6 minutes |
| DF | 2048 | 2e-6 | 6 minutes |

| | | | |
|---|---|---|---|
| SE | 6144 | 8e-7 | 1.5 minutes |

In the coming year, we will focus on applying RBFs to unsteady fluid flows. This will require mathematical breakthroughs in the areas of local node refinement and filtering for RBFs.

This work advances NCAR's strategic priority of "Conducting computer science, computational science, applied mathematics, statistics, and numerical methods R&D" and is supported by NSF grant ATM-0620100.


*Postal address: P.O. Box 3000, Boulder, CO 80307-3000 • Shipping address: 1850 Table Mesa Drive, Boulder, CO 80305 • Contact*

# Adaptive-mesh grid techniques for climate modeling on millennial time scales

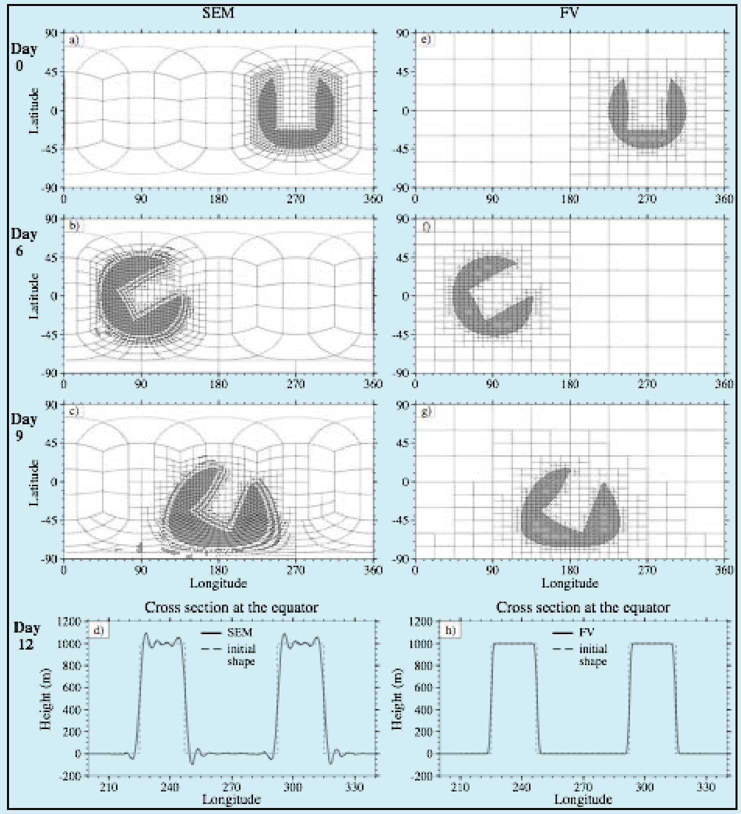
To provide a just comparison between non-conforming adaptive techniques in climate modeling, more testing was performed during FY2007. Two defects of the spectral element approach were pointed out by the new tests:

- The cubed sphere mesh introduces a Rossby-Haurwitz number 4 wave into the simulation at low resolution.
- Oscillations can drive a physically positive constant quantity to a negative value during the course of a simulation (the Gibb's phenomena).

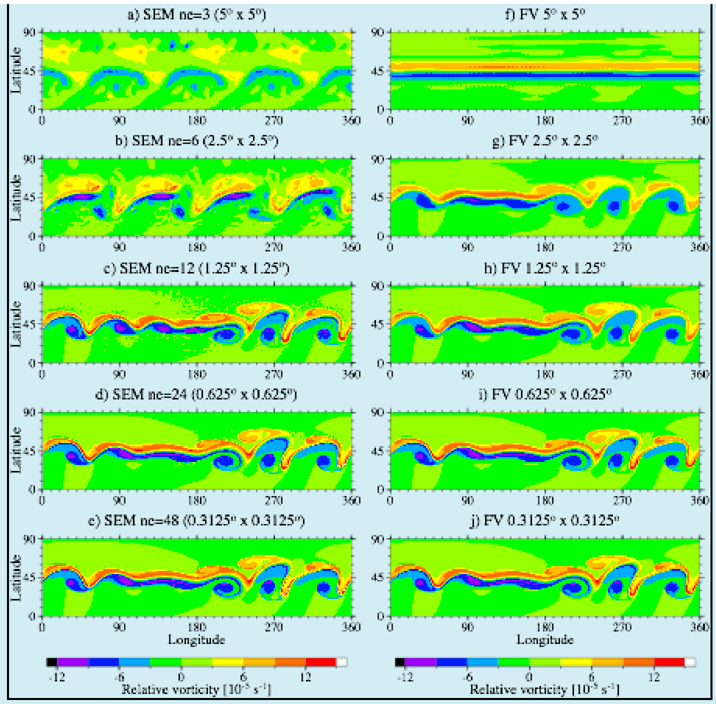
In the second case, the error norms between the two techniques are comparable, but the lower-order method may have a more physically valid distribution of the error. When more grid points are added, the non-physical wave present for the cubed sphere mesh disappears, but no Fourier analysis was performed to demonstrate this. On the positive side, for the flow over a mountain test, the spectral element approach was doing much better than the finite-volumes method in terms of error norms. To demonstrate this, the high-resolution reference solution of the Deutscher Wetterdienst center was employed instead of the one from NCAR.

In FY2008, the combination of a more advanced time-stepping procedure will be studied for its suitability with AMR simulations to accelerate the time to solution.

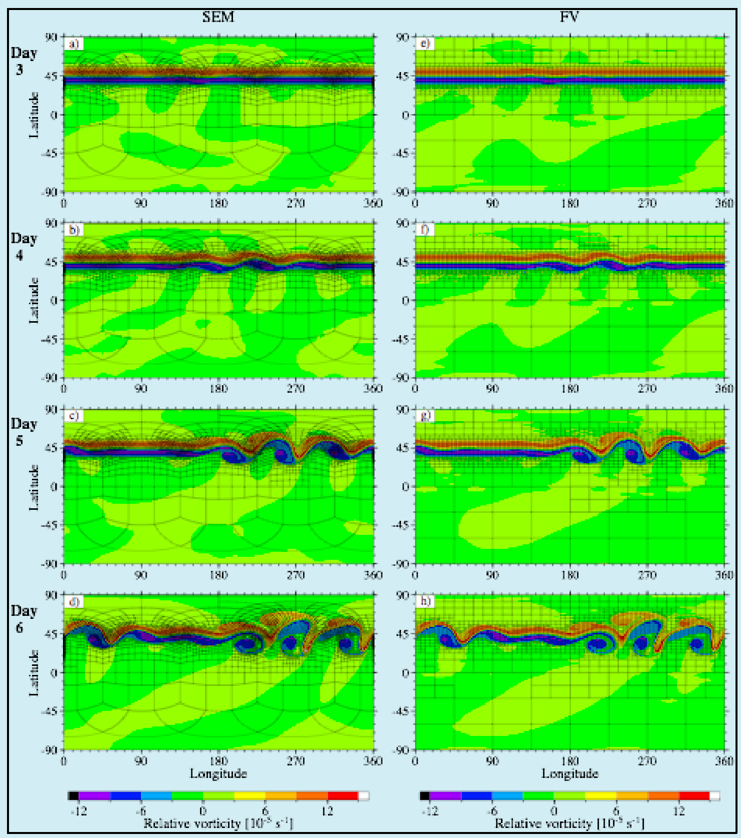
This effort upholds NCAR's strategic priorities of "Conducting research in computer science, applied mathematics, statistics, and numerical methods," "Developing community models," and "Improving prediction of weather, climate, and other atmospheric phenomena." It will yield more efficient and accurate models, help reinforce NCAR's image as a leader in cutting-edge numerical methods, and may set the standard for next-generation climate and weather models. This project exploring adaptive-mesh grid techniques in spectral-element dynamical cores is supported by the NSF with awards 0222282, 0530845, and Core funding.



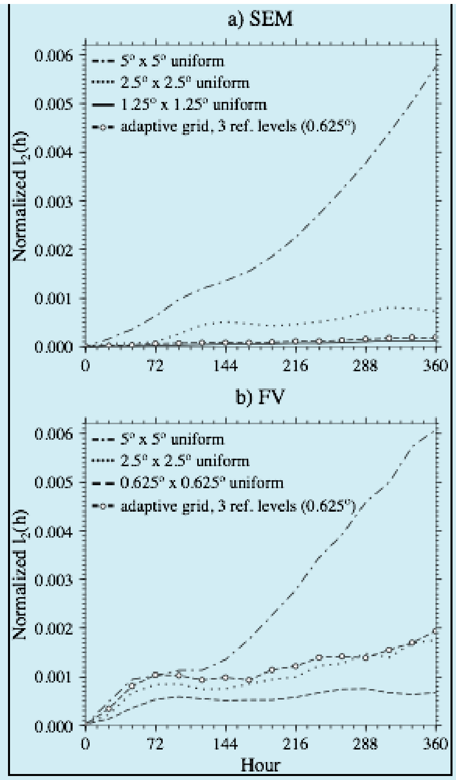

Advection of a slotted cylinder with rotation angle α=30 and three refinement levels (0.625° x 0.625°) in the models SEM (left column) and FV (right column). The height field with h≥0.5 m is shaded in gray. (a,e) Initial height field (h=1000 m). (b,f) height field at day 6 (half a revolution). (c,g) day 9. (d,h) Cross section of h along the equator at day 12 (full revolution). The adapted spectral elements (SEM) and blocks (FV) are overlaid.




Barotropic wave at day 6 in the models SEM (left column) and FV (right column) with uniform (non-adapted) grids at increasing resolutions as indicated above. The relative vorticity field ζ in the Northern Hemisphere is shown.




Evolution of a growing barotropic wave in SEM (left column) and FV (right column) with four refinement levels (finest resolution is 0.3125° x 0.3125°). Snapshots of the relative vorticity field ζ at (a,e) day 3; (b,f) day 4; (c,g) day 5; and (d,h) day 6. The refinement criterion is |ζ|≥3x10E-5 s-1, the adapted spectral elements (SEM) and blocks (FV) are overlaid.



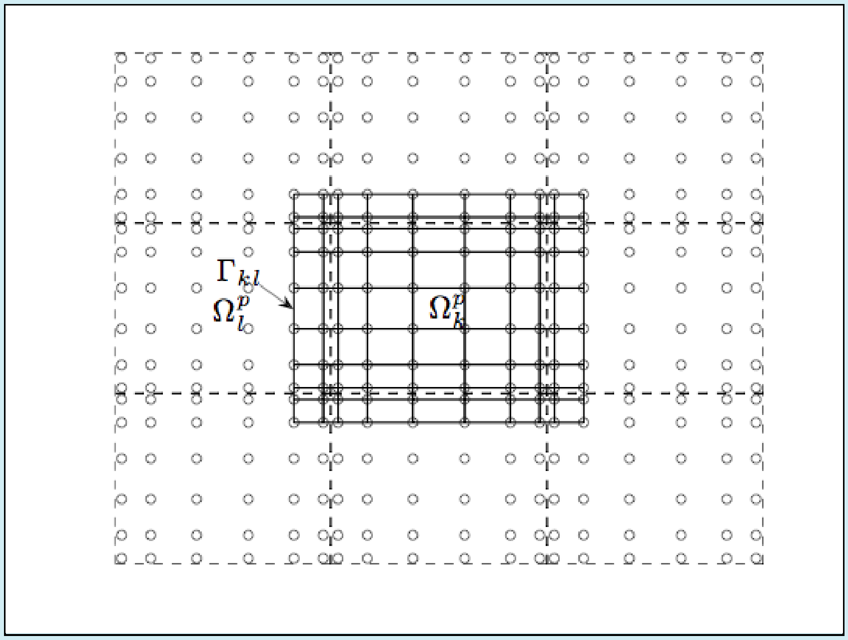

Time traces of the normalized l2 geopotential height error norms for the flow over a mountain (test case 5). The adaptive simulations with three refinement levels (0.625° x 0.625° at the finest level) and several uniform-resolution runs are compared to a T426 spectral transform reference solution.


*Postal address: P.O. Box 3000, Boulder, CO 80307-3000 • Shipping address: 1850 Table Mesa Drive, Boulder, CO 80305 • Contact*

CISL Director's message
CISL annual report Table of contents
**Strategic goals:** science, facilities and technology
CISL research catalog

# Scalable numerical methods for partial differential equations

In FY2007, work focused on the GASpAR geophysical and astrophysical spectral element adaptive code. Major code updates needed to be performed to support the special communication necessary in Schwarz and optimized Schwarz methods. This was completed and tested during FY2007. Also, since the optimized Schwarz preconditioning is a non-symmetric method, a new Krylov subspace method was required. The BiCGStab method was chosen because it produced satisfactory results for the HOMME model and the optimized Schwarz technique. Also accomplished in FY2007 is the inclusion of standard Schwarz preconditioning to test the new features of the code. It is based on the work of Fisher in 1997. A low-order Q1 finite element is constructed on an overlapping grid.




An overlapping domain, on which the partial differential equation is discretized using a low-precision method, is built on top of the high-order element of the GASpAR code. The special boundary conditions applied to this overlapping element will reduce the overall time to solution of the solver.

Our intent for FY2008 is to complete the optimized Schwarz work for incompressible MHD equations with a special coarse solver based on radial basis functions that seem to offer flexibility in an adapted mesh environment. The work for the POP ocean model will be postponed until the technology is sufficiently mature in the GASpAR code.

This project supports NCAR's strategic priorities of "Conducting research in computer science, applied mathematics, statistics, and numerical methods," "Developing community models," and "Improving prediction of weather, climate, and other atmospheric phenomena." It is made possible through NSF Core funding.


*Postal address: P.O. Box 3000, Boulder, CO 80307-3000 • Shipping address: 1850 Table Mesa Drive, Boulder, CO 80305 • Contact*

# CISL research: Computational science

The CISL Computer Science Section is responsible for tracking and evaluating new computing technologies, making early adoption decisions, and performing systems research. Section members are actively pursuing research in the following areas:

- High-performance computing
- Grid computing
- Experimental systems
- Linux clusters
- Experimental networking and evaluation of high-performance interconnects
- System and network performance analysis
- High-performance file systems and archival storage systems
- Parallel Algorithms and Architectures
- Model development

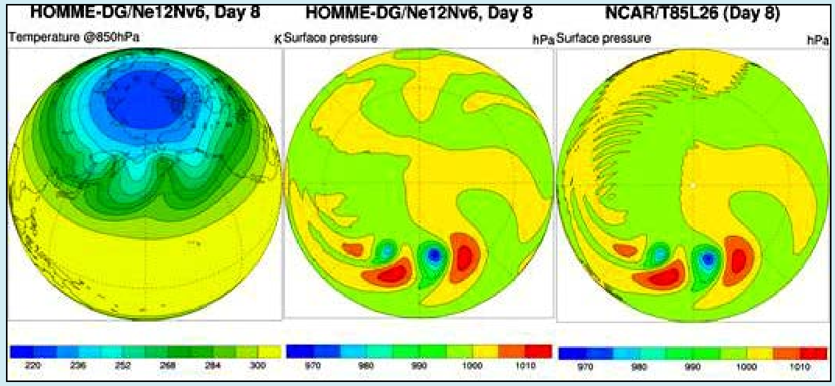
Research results from the past year include our successes in model development through numerical methods and scaling techniques, networking advancements through collaborations, dedicated networks, and innovative diagnostics, and visualization research yielding high-fidelity data compression applications.

In the area of archival storage, we are continuing to develop a reliable and high-performance file system for archival storage using low-density parity check codes (LDPC). The advantage of moving to an LDPC scheme based on an open software infrastructure is that it allows us to leverage emerging storage solutions. Our system also promises significantly increased fault tolerance.

These efforts support NCAR's strategic priorities of "Providing capability and capacity supercomputing to the community," "Developing and providing advanced services and tools," and "Creating an Earth system knowledge environment." These CISL research projects and programs are supported by NSF Core funding, with other support as indicated by the individual reports in this section.

# Numerical methods: High-Order Method Modeling Environment (HOMME)

The future evolution of the Community Climate System Model (CCSM) into an Earth System model will require a highly scalable and accurate flux-form formulation of atmospheric dynamics. Flux form is required to conserve long-lived trace species in the stratosphere. Accurate numerical schemes are essential to ensure high-fidelity simulations capable of capturing the convective dynamics in the atmosphere and their contribution to the global hydrological cycle. Scalable performance is necessary to exploit the massively parallel petascale systems that will dominate high-performance computing (HPC) for the foreseeable future. This activity directly supports NCAR's strategic goal of "Developing community models for weather, climate, atmospheric chemistry, and solar-terrestrial research."




These images show the evolution of temperature (left panel) and surface pressure disturbances (central panel) simulated by the discontinuous Galerkin (DG) dynamical core in HOMME. The object of this test is to assess the evolution of an idealized baroclinic wave in the northern hemisphere. When compared to the NCAR global spectral model (right panel), the DG simulation is smooth and free from "spectral ringing" (spurious oscillations). Having a dynamical core that is accurate, scalable, and conservative is essential for climate science simulation.

The High-Order Method Modeling Environment (HOMME), developed by CISL's Computer Science Section, is a vehicle to investigate using high-order-element-based methods to build conservative and accurate dynamical cores. Currently, HOMME employs the DG and spectral element methods on a cubed-sphere tiled with quadrilateral elements. HOMME can be configured to solve the shallow water or the dry/moist primitive equations, and has been shown to efficiently scale to 32,768 processors of an IBM BlueGene/L (BG/L).

The objective of this project is to extend HOMME to a framework capable of providing the atmospheric science community with a new generation of atmospheric general circulation models (AGCMs) for CCSM based on high-order numerical methods on the cubed-sphere that efficiently scale to hundreds of thousands of processors, achieve scientifically useful integration rates, provide monotonic and mass-conserving transport of multiple species, and easily couple to community physics packages such as Community Atmosphere Model (CAM) physics. Achieving these objectives will allow climate scientists to take full advantage of the extraordinary petascale computing capabilities being deployed by NSF in the next five years, and will lead to dramatic increases in climate science productivity. The development timeline is such that the proposed technology will be freely available to the community for the Intergovernmental Panel on Climate Change (IPCC) fifth assessment science runs, currently scheduled to begin in April 2010. To achieve this requires work in four areas: physics, validation and verification, time integration, and scalability.

In FY2007 we have integrated CAM physics into HOMME and developed conservative baroclinic models in both the DG and spectral element branches of the HOMME framework. The DG approach is a high-order and inherently conservative method, and it employs flux-form primitive equations on the cubed-sphere. Initial validation results using Held-Suarez, baroclinic instability, and aqua-planet tests are promising. In addition, some of the scalability lessons learned during the development of HOMME have been transferred to the components of CCSM (e.g., POP).

This research and development effort supports NCAR's strategic priorities of "Developing and providing advanced services and tools" and "Creating an Earth system knowledge environment." In addition to NSF Core funding support, two Department of Energy programs sponsor this research: the Climate Change Prediction Program (CCPP) and the Scientific Discovery through Advanced Computing (SciDAC) program.

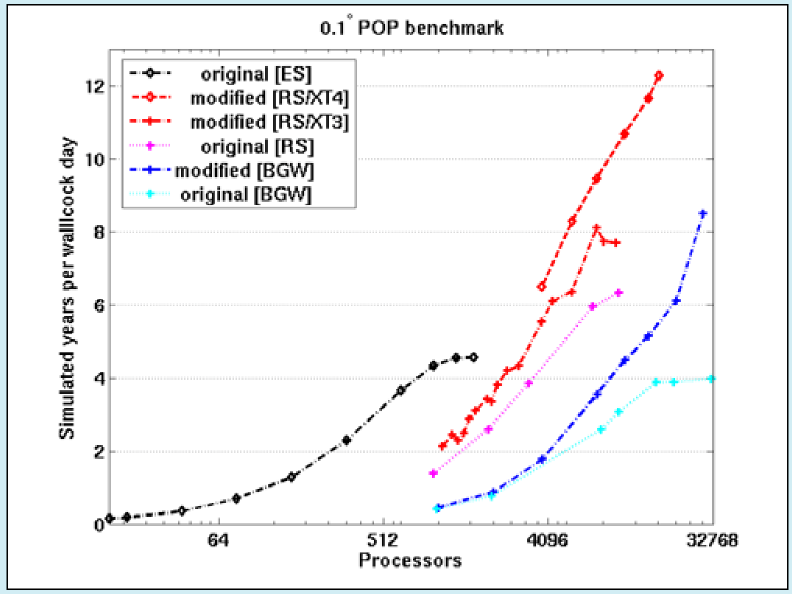
CISL Director's message

CISL annual report Table of contents

**Strategic goals:** science, facilities and technology

CISL research catalog

# Improving scalability of CCSM components




A plot of the simulation rates of 0.1-degree Parallel Ocean Program (POP) benchmark on the Earth Simulator (ES), Cray RedStorm XT3 (RS/XT3) and XT4 (RS/XT4), and Blue Gene Watson (BGW) supercomputers. This plot shows that several code modifications can double the POP benchmark's simulation rate compared to the best performance achieved in its standard form. The RS and BGW systems can sustain a simulation rate greater than five years per wall-clock day; this rate will allow long-timeframe climate simulations to be completed within usefully short times.

The recent re-emergence of highly parallel systems has placed a premium on code scalability. In particular, NSF plans to deploy a petascale sustained system in the 2010 timeframe has accelerated our need to significantly increase the number of processors on which application codes can run efficiently. In its standard configuration, one of NCAR's flagship applications—the Community Climate System Model (CCSM)—only utilizes approximately 200 processors. Clearly, the scalability of the CCSM model must be significantly increased to successfully utilize compute cycles on the upcoming 100,000 to 500,000-processor petascale systems. Currently the systems providing the largest scale parallelism are the IBM Blue Gene and Cray XT4 systems. These prototype petascale systems provide the opportunity to examine and improve the scalability of CCSM component models on large processor counts in preparation for the upcoming NSF petascale system.

We initially examined the ability of the Blue Gene/L system to perform high-resolution ocean modeling using the Parallel Ocean Program (POP). We used the POP 0.1-degree benchmark to gauge the impact of several code modifications designed to increase simulation rate. The code modifications involve: a) redesigning data structures in the POP, and b) adding a partitioning algorithm based on space-filling curves. Both modifications reduce POP's compute resource requirements, which allows for more efficient utilization of systems with large processor counts and limited memory bandwidth.

The figure shows the simulation rates for the POP 0.1-degree benchmark using the original and modified configurations on the Earth Simulator, IBM Blue Gene/L, and Cray RedStorm supercomputers. Note that the combination of the 1D-data-structure-based solver and space-filling curve partitioning increases the simulation rate on 30,000 IBM Blue Gene/L processors from 4.0 to 7.9 simulated years per wall-clock day. Our techniques also improved the simulation rate on 7,600 Cray RedStorm processors from 6.3 to 8.1 simulated years per wall-clock day. Based on our success with POP, we have used space-filling curves to increase the simulation rate of the Community Ice CodE (CICE) at 0.1 degrees by 33%.

In FY2007, the success with POP and CICE has spurred the development of a sequential CCSM coupler, a significant simplification in design versus the current design. The creation of the sequential coupler, improvements in the memory footprint of the Community Land Model (CLM) at large processor counts, and the improvements in the scalability of the Community Atmosphere Model (CAM) by our Department of Energy collaborators, has enabled the creation of a sequential CCSM capable of executing in low-memory environments. A development version of CCSM, based on the sequential coupler, currently runs on Blue Gene at production resolutions.

In FY2008, development will proceed on an ultra-high-resolution configuration that is suitable for execution on 10,000 to 30,000 processors.

This work advances NCAR's strategic priority of "Conducting research in computer science, applied mathematics, statistics, and numerical methods." It is supported by NSF Core funding, as well as the Department of Energy CCPP program grant DE-FC03-97ER62402 and DE-PS02-07ER07-06.



*Postal address: P.O. Box 3000, Boulder, CO 80307-3000 • Shipping address: 1850 Table Mesa Drive, Boulder, CO 80305 • Contact*

CISL Director's message
CISL annual report Table of contents
**Strategic goals**: science, facilities and technology
CISL research catalog

# Networking research projects and technology tracking

NETS is a principal collaborator in number of nationally recognized networking and data communications research and development projects. NETS hosts and presents at national and regional meetings on a variety of networking projects. NETS continued work on an NSF STI award for the Network Path and Applications Diagnosis (NPAD) project, and NETS contributed to the NIH BRIN (National Institutes of Health) (Biomedical Research Infrastructure Network) Lariat project.

Del Harris, a Network Engineer with NETS, works on a wireless networking antenna linking NCAR/UCAR campuses. NETS is constantly tracking, testing, and deploying new technology as appropriate to provide UCAR users with state-of-the-art networking service. As business continuity has become a higher priority for the organization, NETS has broadened their deployment of MAN wireless technology to provide backup services between all campuses as a disaster recovery measure.

NETS staff serve on the board and the executive committee of the National LambdaRail, Inc. (NLR), a consortium of leading U.S. research universities and private-sector technology companies building and operating a network infrastructure for new forms and methods for research in science, engineering, health care, and education as well as for research and development of new Internet technologies, protocols, applications, and services. NETS has continued to manage network connections between the NCAR computing facility and the TeraGrid, an open scientific discovery infrastructure combining leadership-class resources at partner sites to create an integrated, persistent computational resource.

NETS staff serve in a number of leadership roles in the Quilt, including the Quilt, Inc. Board of Directors, Steering Committee, Executive Committee, the Peering Committee, the Commodity Internet Services Committee, and the Regional Optical Network Committee. The Quilt's specific purposes and objectives are to promote the delivery and geographical aggregation of advanced network services to the broadest possible research and educational community; promote end-to-end continuity, consistency, reliability, interoperability, efficiency, and cost-effectiveness in the development and delivery of advanced network services that reflect the diversity of its participants and foster innovation; and represent the participants' common interests to national advanced research and educational networking organizations, backbone network service providers, industry, government, standard-setting organizations, and other organizations involved in or influencing the development and delivery of advanced network services. Through NETS involvement in the Quilt, we are able to effect and track technology trends in networking equipment, fiber optic technologies and implementation methods, regulation, and commodity Internet services and technologies.

NETS will continue their leadership roles in these areas in FY2008 and use the experience and knowledge gained to advance UCAR, the FRGP, and the UPoP networking technology and infrastructure.

NETS' research activities support NCAR's strategic priority of "Developing and providing advanced services and tools." This work has many funding sources: NSF Core funds, FRGP, and UCAR Communications Pool indirect funds.

CISL Director's message
CISL annual report Table of contents
**Strategic goals:** science, facilities and technology
CISL research catalog

# Layer 2 networking for researchers

NETS worked with Front Range GigaPoP (FRGP) and UCAR users to utilize new Layer 2 networking capabilities available on National LambdaRail (NLR) to provide high-speed, dedicated networks between specific locations. In particular, we have worked with NOAA-Boulder on multiple projects. One project provides a persistent high-performance lightpath (1 Gbps) directly between two science centers, one in Moscow and one in Boulder, Colorado, bypassing the much slower rates of the standard Internet.

NLR provides a Layer 2 service called FrameNet. This service provides dedicated and non-dedicated Layer 2 waves. Dynamic wave testing is in progress. This service has proved to be far more popular than expected, usage is growing rapidly, in part due to the ease, flexibility, and low cost of setting up. This provides users, including UCAR and the FRGP, with a low-cost technology for testing dedicated bandwidth for scientific applications.

This high-speed service is already transferring extremely large scientific data files between two major science centers, the Geophysical Center and Space Research Institute, Russian Academy of Science (GC and IKI RAS) in Moscow and the National Geophysics Data Center (NGDC), National Oceanographic and Atmospheric Agency (NOAA) in Boulder, Colorado. Another path is planned to be installed in November 2007 between NOAA-Boulder and NOAA-DC, and another between NOAA-Boulder and NOAA-Oklahoma in Spring 2008.

The ease and flexibility of this technology is proving very valuable to researchers, and NETS expects to see the use of this service grow with time.

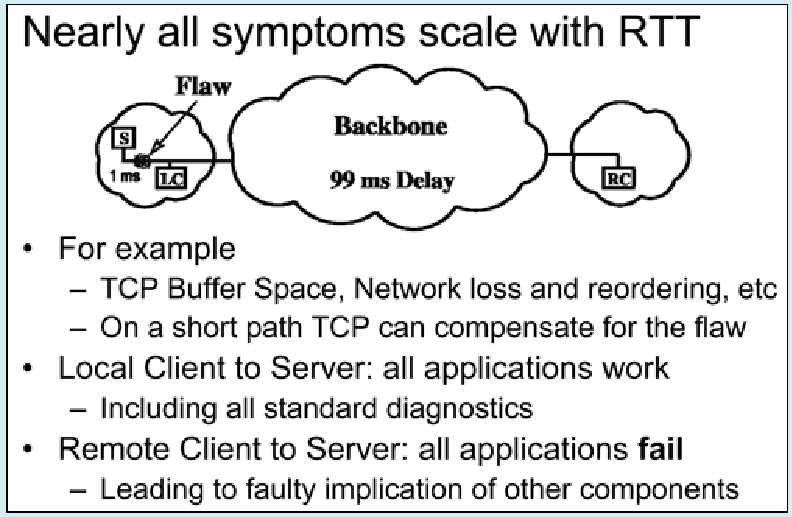
NETS' research activities support NCAR's strategic priority of "Developing and providing advanced services and tools." This work has many funding sources: FRGP, U.S. Department of Commerce, and UCAR Communications Pool indirect funds.

# Network Path and Applications Diagnosis (NPAD)

The primary goal for the Network Path and Applications Diagnostics (NPAD) project was to develop network diagnostic techniques that address the effects of path delay inherent in transmitting data across wide area networks. This effort investigated an unexplored area of the Internet end-to-end performance problem.

During the final year of this project, we have further refined the prototype diagnostic tool (pathdiag) and successfully deployed it at multiple sites across the United States: Pittsburgh Supercomputing Center and Three Rivers Optical Exchange, National Center for Atmospheric Research and the Front Range GigaPoP, Internet 2 in Ann Arbor, Michigan, Duke University, and Lawrence Berkeley National Laboratory. This project will be completed by November 30, 2007.

We have prepared and submitted a technical paper that summarizes the project for publication.




This slide from one of the NPAD presentations notes that nearly all network problems are affected by Round Trip Time (RTT). NPAD attempts to address diagnosing network problems taking into account path delay.

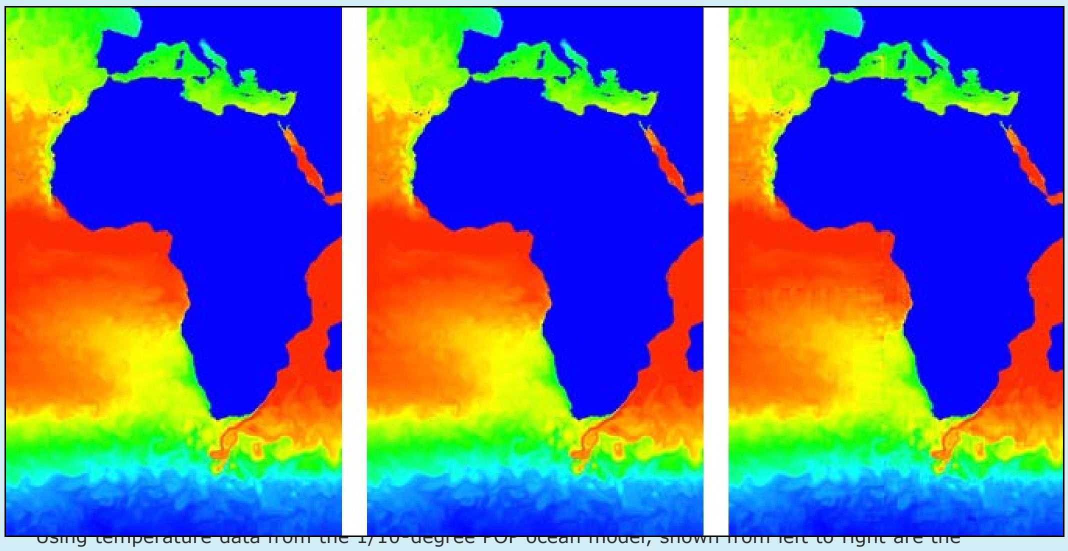
NETS' research activities support NCAR's strategic priority of "Developing and providing advanced services and tools." This work is supported by NSF award 0334061 through subaward 1120444-145302 with the Pittsburgh Supercomputing Center.

# Scientific data compression research

The Scientific Data Compression Research project began in FY2006. Building on the success of CISL's VAPOR work that employs wavelet-based progressive data access to permit the exploration of terascale data sets, CISL began investigating the application of wavelet-based lossy data compression techniques applied to a variety of model simulation outputs. The methods employed are similar to those now widely used in the compression of digital media. The goals of this work are to:

- Determine whether, and to what degree, scientific data sets can tolerate information loss
- Investigate a variety of compression methods and determine which may be most appropriate for geoscience data
- If successful, develop user tools for data compression

Exponential growth in transistor density in computers is producing ongoing increases in computer processing power. These increases enable computational scientists to create numerical simulations of physical phenomena at unprecedented scales, and this generates extraordinary amounts of data. For example, the recent IPCC work yielded over 100 terabytes of climate model data. While microprocessor performance continues to double roughly every 18 months, other computing technologies are improving at much more modest rates. In particular, storage and networking bandwidths have lagged behind. As a result, the challenge of storing, analyzing, managing, and sharing large simulation data sets is becoming increasingly problematic and hampers scientific productivity. Lossy signal compression techniques, such as those ubiquitously used for digital media and now being investigated by CISL, may provide relief for researchers drowning in data.



Using temperature data from the 1/10-degree POP ocean model, shown from left to right are the original data, a 64:1 compression, and a 512:1 compression. Image quality remains high even at high compression rates. This work holds potential to significantly improve our ability to store and visualize the data produced by high performance computers.

While extending integer, digital-media, lossy compression techniques to floating-point scientific data is relatively straightforward, the scale of the data and the desire to preserve essential data properties (such as smooth derivatives) introduces many subtle challenges. In FY2007, CISL continued working with a number of domain scientists to identify promising wavelet decompositions for maintaining essential data properties while applying high compression rates. Progress was also made in developing computationally efficient algorithms for handling very large data sets. CISL collaborated with three CGD groups at NCAR and one external group: the Southern California Earthquake Center (SCEC). Experiments with the CGD groups achieved varying degrees of success: the degree of compression that could be tolerated was found to be highly sensitive to the type of operation to be subsequently performed. In some cases, data could be aggressively compressed while in others only minimal compression was possible. More promising results were achieved with SCEC, where the set of data operators is small, known in advance, and preliminary work suggests that fairly aggressive compression can be tolerated.

All of these efforts are works in progress. In FY2008 we will continue experiments with various groups, in particular the SCEC seismic simulation data. We will also explore parallelization of our algorithms to prepare for petascale computing, and we will continue to investigate more efficient algorithms (both computationally and in storage requirements) for encoding compressed data.

This research supports NCAR's strategic priorities of "Developing and providing advanced services and tools" and "Conducting research in computer science, applied mathematics, statistics, and numerical methods." This work is made possible by NSF Core funding.

# Continuation of research reports from FY2006

## Numerical turbulence algorithms and code development

This section has been incorporated into Turbulence science: Numerical algorithms and code development

## 10G networking technology implemented at NCAR

This project is no longer classified as research. The report appears in this year's cyberinfrastructure section as 10 Gbps end-to-end technology implemented at NCAR.


*Postal address: P.O. Box 3000, Boulder, CO 80307-3000 • Shipping address: 1850 Table Mesa Drive, Boulder, CO 80305 • Contact*

# Toward an Earth system knowledge environment

The development of an Earth System Knowledge Environment (ESKE) is a cornerstone of NCAR's and CISL's strategic plans. Our goal is to continually develop new cyberinfrastructure that may be integrated into powerful, collaborative problem-solving environments. These environments are developed to accelerate the community's ability to engage in research and scientific discovery and construct complex workflows. Our efforts span modeling frameworks, critical scientific data archives, federated data and knowledge systems, digital preservation, collaboration, and analysis and visualization environments.

In many cases our efforts are tied to major interagency, national, and international initiatives, including the World Meteorological Organization (WMO), the Intergovernmental Panel on Climate Change (IPCC), the International Polar Year (IPY), the National Digital Information and Infrastructure Preservation Program (NDIIPP), and the THORPEX Interactive Grand Global Ensemble (TIGGE).

Our strategy is to cultivate opportunities to:

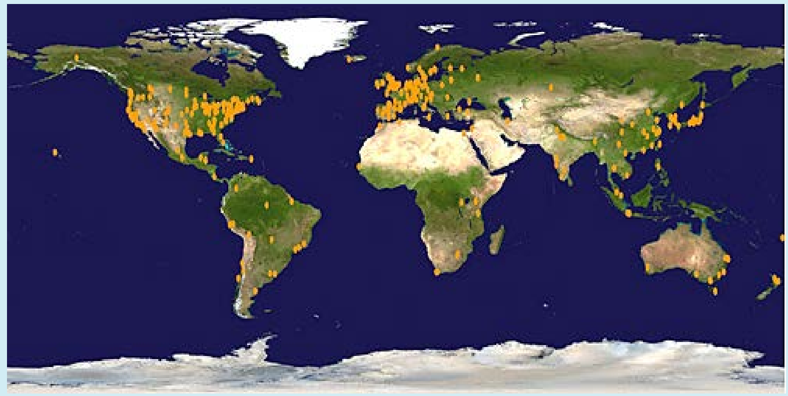
- Advance the state of the art through R&D grants complemented by NSF Core funding
- Transition the most promising and effective results into production capabilities that we support and distribute
- Integrate across capabilities to amplify our investments

This section describes CISL's activities and plans that contribute to the realization of the ESKE.


*Postal address: P.O. Box 3000, Boulder, CO 80307-3000 • Shipping address: 1850 Table Mesa Drive, Boulder, CO 80305 • Contact*

# The Earth System Grid Center for Enabling Technologies (ESG-CET)

The Earth System Grid Center for Enabling Technologies (ESG-CET) is a five-year project funded by the U.S. Department of Energy (DOE) SciDAC-2 program to develop and deploy an international virtual facility for climate and related impacts research. A follow-on to our earlier ESG project, the effort has grown into a large-scale collaboration among NCAR (CISL, CGD, and HAO), Argonne National Laboratory (ANL), Oak Ridge National Laboratory (ORNL), Lawrence Livermore National Laboratory Program for Climate Model Diagnosis and Interpretation (LLNL/PCMDI), NOAA's Pacific Marine Environmental Laboratory (NOAA/PMEL), the University of Southern California Information Sciences Institute (USC/ISI), Lawrence Berkeley National Laboratory (LBNL), and Los Alamos National Laboratory (LANL).



This map shows the geographic locations of the sites that use the Earth System Grid (ESG) to acquire climate simulation data, IPCC coupled model results, the CCSM climate model, and an array of analysis and visualization tools. ESG provides services to over 6,000 registered users around the world. (See larger image.)

ESG currently provides a production service for most of the joint NSF/DOE climate change simulations conducted over the last six years as well as the IPCC Fourth Assessment Report data holdings. Access is provided through a combination of a web portal plus desktop applications that mediate large-scale transfers to the user. ESG currently has over 6,000 registered users worldwide, manages over 180 TB of data in archives distributed around the nation, and has delivered over 300 TB of data to its constituents. From this past year alone, more than 300 scientific journal articles have been published from analyses of data delivered by the ESG. ESG thus plays an important role in advancing NCAR's strategic plan including "Developing and providing advanced services and tools," "Engaging a broader and more diverse community in the atmospheric and geosciences," "Creating an Earth system knowledge environment."

This effort intends to advance the global community's ability to improve climate research. It is also an excellent example of cross-agency collaboration to advance science. Details are available at the ESG website.

During FY2007 we continued to operate our production systems and grow our data offerings as new climate data products have become available. We have also developed and delivered a new multi-file download capability that makes it much easier for our users to acquire large sets of climate simulation results. Our primary focus this year has been to:

- Develop new requirements for our internationally federated system
- Research and create prototypes of new technology components
- Forge relationships and plans with collaborators at international climate research and data centers

We have begun to work with the CCSM development group to identify next-generation strategies and processing capabilities to more strongly match the production model runs with ESG systems. One of the highlights of our work this year has been research and development work in using Semantic Web technologies to support a discovery and selection process that encompasses a broad range of digital assets (e.g. models, visualization tools, datasets, analyses, etc.). This reflects a scaffolding activity whereby we are leveraging some of the knowledge and experience gained in the Virtual Solar Terrestrial Observatory (VSTO) project. While we had intended to integrate ESG as a TeraGrid Science Gateway in FY2007, security challenges delayed completion of this step. We have also begun refactoring and engineering a new, shared framework that will serve as a foundation for the new system.

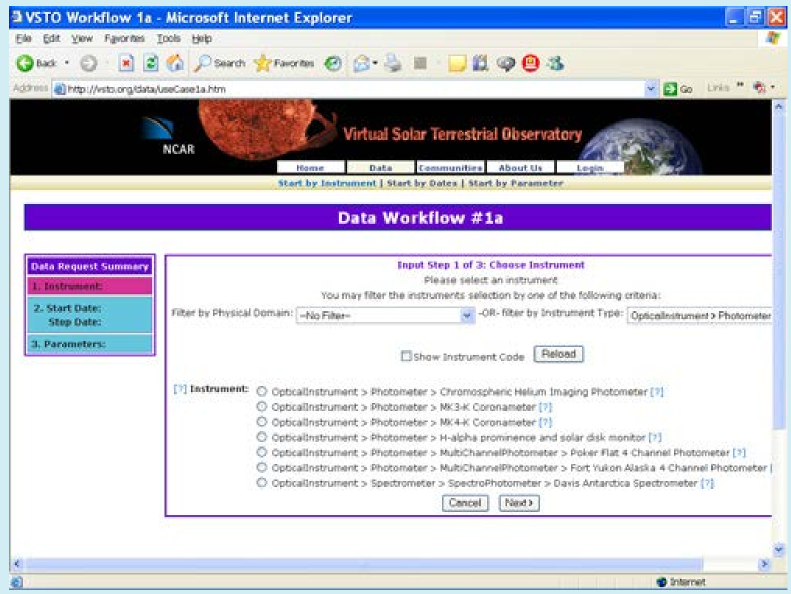
In FY2008 we plan to develop and release a beta version of the new ESG environment, featuring semantically enabled user interfaces and discovery tools, international system federation, and a virtual organization infrastructure that links multiple "gateways" into a powerful community resource. Having now developed strategies for bridging across NCAR and TeraGrid security domains, we will establish ESG as a TeraGrid Science Gateway in FY2008 as well.

Primary support for this project is from DOE's Scientific Discovery Through Advanced Computing program contract DE-FC02-06ER25772 with additional support from NSF via NCAR's Cyberinfrastructure Strategic Initiative and NSF Core funding.


*Postal address: P.O. Box 3000, Boulder, CO 80307-3000 • Shipping address: 1850 Table Mesa Drive, Boulder, CO 80305 • Contact*

# The Virtual Solar Terrestrial Observatory (VSTO)

The Virtual Solar Terrestrial Observatory (VSTO) is an NSF-funded collaboration of the NCAR High Altitude Observatory (HAO), NCAR's Computational and Information Systems Laboratory (CISL), and McGuinness & Associates. The goal of the project is to research and develop a next-generation knowledge environment that will allow seamless integration and data access in the areas of Solar, Solar-Terrestrial, and Space Physics (SSTSP). By providing a higher-level semantic layer on top of the current array of data formats, services, and repositories, the project is aimed at facilitating and empowering data providers, scientists, researchers, and educators across all these domains. The goal of the three-year project, which ends in 2007, is to deliver a fully functional prototype allowing virtual access to selected services comprising observational and model data, different data formats, and different data archives.




The image above is a snapshot of the VSTO portal's data search and query interface, which exposes an ontology-based instrument selection capability. The Virtual Solar-Terrestrial Observatory (VSTO) is a production semantic web data framework providing access to observational datasets from fields spanning upper atmospheric terrestrial physics to solar physics. The observatory allows virtual access to a highly distributed and heterogeneous set of data that appears as if all resources are organized, stored, and retrieved/used in a common way. (See larger image.)

Semantic data integration is an increasingly important area across all of our areas of science and technology, especially as we strive to provide capabilities that bridge across domains and disciplines. VSTO thus occupies an important strategic position in NCAR's and CISL's cyberinfrastructure R&D portfolio. The same technologies, design patterns, and interfaces that are being developed for VSTO have substantial promise for other scientific disciplines including climate, weather and forecast, and later for the biogeosciences, geochemistry, and water cycles, and carbon cycles. VSTO primarily addresses two NCAR strategic goals: "Improve Understanding of the Atmosphere, the Earth System, and the Sun" and "Provide robust, accessible, and innovative information services and tools."

In FY2007 a primary project milestone was achieved: releasing a production VSTO system, which is depicted in the image above. Along the way, we completed development of integrated workflows for instruments, dates, and parameters according to a suite of key use cases developed primarily in the earlier phases of the project. VSTO now effectively integrates the holdings of the Mauna Loa Solar Observatory (MLSO) and the CEDAR databases, and it represents a first example of broad semantic integration in its field.

In addition to the operational portal, we also began the process of exposing semantic web services to VSTO's capabilities. Our first thrust in this area was to design, develop, and release a service interface for a sister project: VITMO, A Virtual Observatory for the Ionosphere-Thermosphere-Mesosphere community. As VSTO and other projects like it release such services, we contribute to building the Semantic Web and future Knowledge Networks.

Further, the project team authored several papers and posters, providing excellent visibility for VSTO at conferences, workshops, and in the published literature. Funding support for VSTO will end in 2007, so this phase of the project is now coming to a successful close. The team is now exploring options for broadening our disciplinary focus and complementing other initiatives planned or already underway.

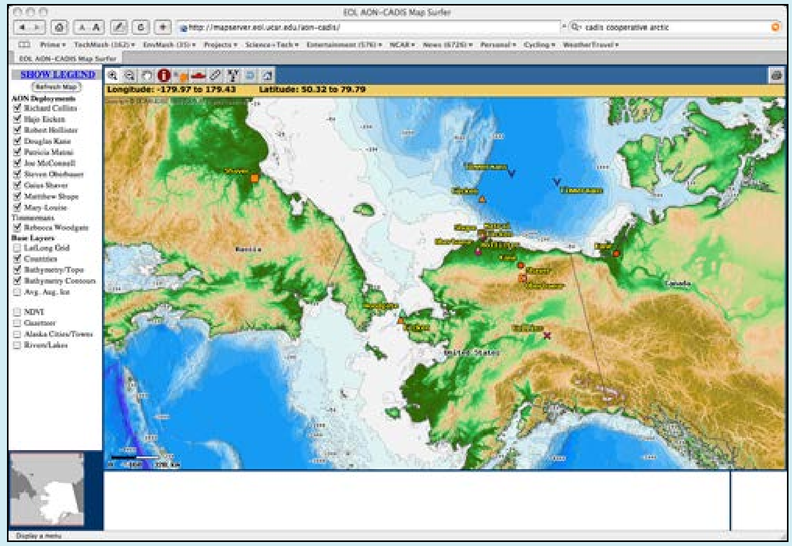
VSTO is primarily supported through a grant from the National Science Foundation, along with NSF Core funding for NCAR.


*Postal address: P.O. Box 3000, Boulder, CO 80307-3000 • Shipping address: 1850 Table Mesa Drive, Boulder, CO 80305 • Contact*

# The Cooperative Arctic Data and Information Service (CADIS)

Arctic science in the U.S. lacks a single coordinated force setting a data management direction. This needs to change to:

- Address the challenges of data management for Arctic-wide observing systems
- Meet scientists' growing expectations for sharing and working with data across diverse disciplines and in the broad Pan-Arctic geographic domain
- Encourage the international exchange of data
- Reduce overlap and wasted effort spent developing data management solutions for small numbers of users




The image above shows a prototype MapServer-based interface to Arctic Observing Network (AON) research efforts. One of the project's challenges will be to integrate data management and access capabilities with powerful geographic information systems and related interfaces. CADIS provides an opportunity to deliver a broad and diverse collection of research datasets to a multidisciplinary community in support of the International Polar Year (IPY).

The Arctic Observing Network (AON) is supported by the National Science Foundation and consists of more than 30 land, atmosphere, and ocean observation programs, some existing and some as new observing capabilities. This International Polar Year (IPY) initiative will succeed in supporting the science envisioned by its planners only if it functions as a system and not as a collection of independent observation programs. AON planners envision a data management system through which:

- Scientists can find all data relevant to a location or process
- All data have browse imagery and complete documentation
- Time series or fields can be plotted online
- All metadata are in a relational database so that multiple data sets and sources can be queried

The Cooperative Arctic Data and Information Service (CADIS) is a joint effort of the University Corporation for Atmospheric Research (UCAR), the National Snow and Ice Data Center (NSIDC), and the National Center for Atmospheric Research (NCAR) in Boulder, Colorado. Working with NCAR's Earth Observing Laboratory and UCAR Unidata partners, CISL's contributions to CADIS include the application, integration, and enhancement of Community Data Portal (CDP) infrastructure to support the needs of the Arctic research community. CADIS addresses several NCAR strategic priorities including "Exploring atmospheric, Earth System, and solar processes, variability, and change," "Developing and providing advanced services and tools," and "Creating an Earth system knowledge environment."

CADIS began in mid-FY2007, and our efforts in this early phase of the project have been focused on designing high-level architecture for the system, developing data and metadata standards that align with international standards, extending the CDP infrastructure to accommodate CADIS datasets, designing metadata authoring and publishing systems, and prototyping new web-based visualization tools for some of the data sources that we will need to address in CADIS.

In FY2008 we will develop and release our first evaluation capabilities with a primary focus on physical and chemical systems. Building on community feedback, we will refine and evolve our requirements and continue to advance our CDP technology base in support of CADIS.

More information on CADIS is available at the project website.

CADIS is supported via a combination of NSF special support and NSF Core funding.

# The Earth System Curator

The Earth System Curator project is creating a software environment for assembling, running, and archiving information about climate models. The intent is to make it easier for scientists to perform modeling experiments and to coordinate with each other on efforts such as Model Intercomparison Projects and Intergovernmental Panel on Climate Change (IPCC) assessments. The Curator project will enable groups to prepare data for submission to the Program for Climate Model Diagnosis and Intercomparison (PCMDI) for IPCC analysis. Curator partners include NCAR (the Earth System Grid and Earth System Modeling Framework projects), the Geophysical Fluid Dynamics Laboratory, MIT, and the Georgia Institute of Technology.

One of the first goals of the Curator project is to help supplement and refine metadata schemata such as the Numerical Model Metadata (NMM) conventions so that they better serve model analysis projects, and so that they are complete and precise enough to serve as the foundation for software tools that can automate workflow tasks. The Curator team will define an extended schema that utilizes CF and NMM conventions.

The Curator itself will be a distributed environment, based on this extended schema, that allows modelers to:

- Archive and query models, experiments, model components, and model output
- Test the technical compatibility of model components
- Assemble and run multi-component models

The proposed Curator architecture includes:

1. A central CDP-Curator Portal that provides access to Earth system model component software, output datasets, and metadata describing these. The CDP-Curator portal will utilize the Community Data Portal (CDP) developed at NCAR.

2. Satellite sites that can assemble and run models, and archive experiments and data. The prototype for the Curator satellite site is the Flexible Modeling System Run-time Environment (FRE) and associated database at GFDL.

3. A lightweight interface that enables model components to be described and archived by groups that don't have a Curator software installation. Provider sites will use a schema based on Curator extensions to NMM.

By creating a common modeling infrastructure that serves the climate domain, the Earth System Curator supports the NCAR strategic priority of "Developing community models for weather, climate, atmospheric chemistry, and solar-terrestrial research." It also fulfills NCAR's strategic priority of "Creating an Earth system knowledge environment" by serving as a key element of this effort to integrate the suite of scientific software at NCAR and improve the support of science workflows.

During FY2007, the Curator team continued to develop metadata standards in concert with a broad set of U.S. and European collaborators, focusing on techniques for combining multiple schemata into specific use profiles. Curator staff applied the schema to three interacting components of the GEOS-5 atmospheric GCM as a test case. These components were then used to define the requirements and prototype a component compatibility check capability. Use cases, schemata, and other materials are available on the Earth System Curator website.

In FY2008 the ESMF team will continue to work on schema development, focusing on the capabilities needed for compatibility check and auto-generation, and will complete a prototype of the end-to-end system.

Earth System Curator is supported by a grant from the National Science Foundation Science Engineering Information Integration and Informatics program.



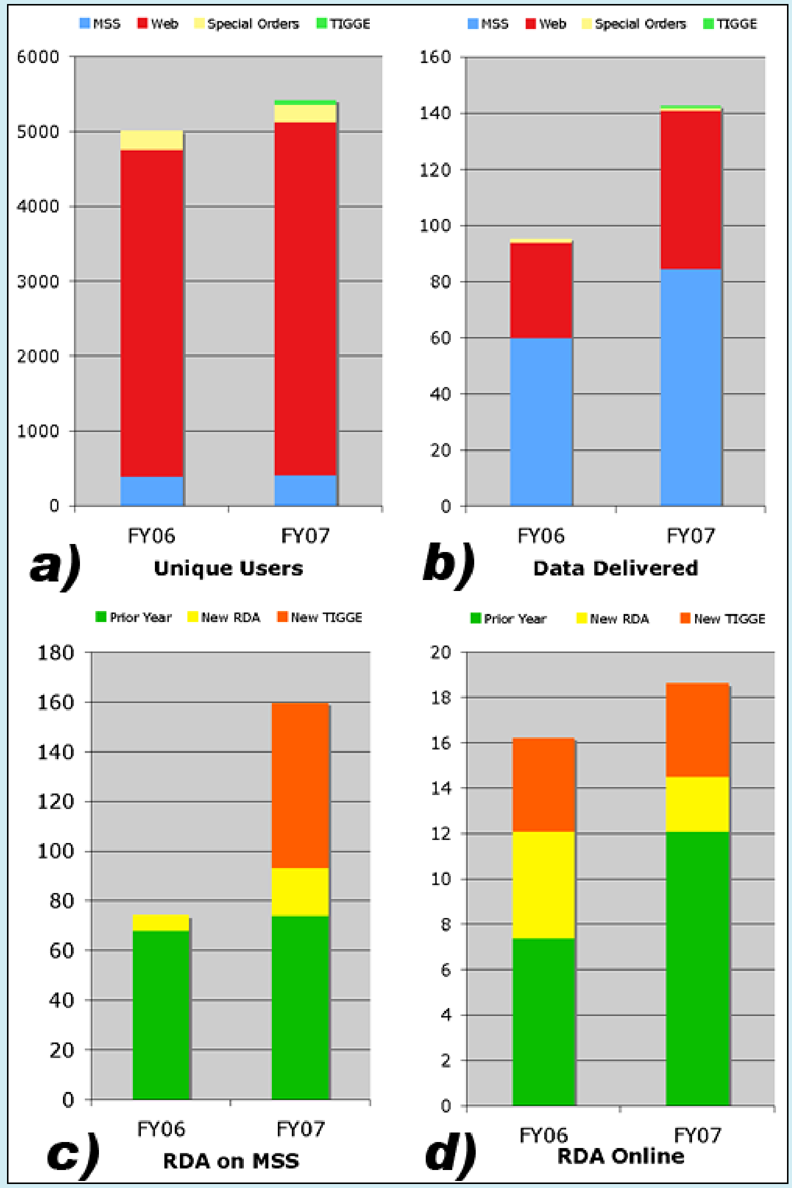
*Postal address: P.O. Box 3000, Boulder, CO 80307-3000 • Shipping address: 1850 Table Mesa Drive, Boulder, CO 80305 • Contact*

# Research Data Archive

The Research Data Archive (RDA) is a key part of the NCAR strategic priority of "Creating an Earth system knowledge environment" because it provides an information resource through a large collection of datasets that support scientific studies in climate, weather, earth systems modeling, and increasingly other related geosciences. The RDA activities can be viewed from two different perspectives: user data services and archive content development.

In FY2007, about 5,400 unique users were provided 140 TB of data through various primary access pathways: the NCAR MSS, public servers on the web, one-time special requests prepared for individuals, and the TIGGE (THORPEX (THe Observing system Research and Predictability Experiment) Interactive Grand Global Ensemble) archive (see charts a and b). The largest user group is associated with the web access pathway (4,700) in contrast with the largest amount of data being distributed via the MSS access pathway (83 TB). This indicates the RDA is known as a world data resource, and when it comes to accessing large significant reference datasets, working directly on CISL computational resources is more effective.

A simple measure of data content development is archive growth. The RDA expanded by nearly a factor of two in FY2007, from 74 to 159 TB (see chart c). TIGGE is part of the RDA, but is shown separately because it alone added 66 TB. Although this factor somewhat overshadows the 19 TB growth in the remaining part of the RDA, this is also large when contrasted to the 6 TB growth in FY2006 (chart c). The most-demanded datasets from the RDA are available online through publicly available web servers. The current online data is 19 TB (chart d). Again, TIGGE is shown separately and does not change between FY2006 and FY2007, because it is a capped rolling 3-week archive with only the most current data. Older data are copied to the MSS and managed so they are directly available to NCAR computational facilities and upon request as a special order to the broader public.




These charts show the service and growth metrics for the Research Data Archive (RDA) during FY2006 and FY2007. a) The number of unique users specified by access pathway: the NCAR MSS, publicly available web servers, one-time special requests prepared for individual users, and TIGGE. b) The amount of data delivered to customers, by access pathway. c) The amount of data in the MSS archive, showing annual growth. d) The amount of data on public servers (a high-demand subset of the RDA archive), showing annual growth. Charts a) and b) indicate the RDA's great significance to the community, and charts c) and d) show the annual progress toward building more valued content into the RDA.

As a whole, the RDA is constantly changing, curation extends and adds to existing datasets, stewardship improves the documentation, creates systematic organization, applies data quality assurance and verification, and develops access for the users. Many routine tasks and background infrastructure developments are necessary to maintain the RDA. Some major activities for FY2008 will be:

- Continued enhancement of the TIGGE archive. Ensemble weather forecast data from five NWP centers will be added to the archive, bringing the total to 10 centers, and a data rate of 300 GB/day in several million 2D gridded fields. Significantly more web and software engineering is required to improve user access through the TIGGE portal hosted by the Community Data Portal. Users need the capability to acquire multi-center temporal-spatial-parameter data subsets on selected uniform horizontal grids.

- Continued frequent updates for NCEP model and observational outputs that are available online. The global final analysis model output and supporting conventional observations account for over 33 TB annually downloaded from the RDA web server. These data are particularly popular for research that requires initial conditions to run regional models for many global locations, e.g. WRF.

- Fully develop and deploy services for the Japanese 25-Year Reanalysis (JRA-25). We have received an extensive agreement with the JMA to partner with them in the distribution of all JRA-25 data products. All data are at NCAR, and significant effort is required to organize, document, and build user access interfaces.

- World-class data resources are built through collaborations, a few projects underway include:

    - Integrated Surface Dataset (ISD): NOAA/NCDC and CISL have compared and assessed each other's surface data holdings and are collaborating to create a "best" merged collection.

    - CISL is hosting, in the RDA, the first international Observing System Simulation Experiment (OSSE) validation dataset. This NCAR outlet will primarily serve the university community; other U.S. and international agencies will serve their own communities.

    - The RDA will receive and maintain a copy of the 20th Century Global Reanalysis being run by NOAA/ESRL at NERSC. Early demonstration computations have shown this reanalysis method capable of defining most major storms and weather events back into the 1800s, which is much earlier than any previous reanalysis.

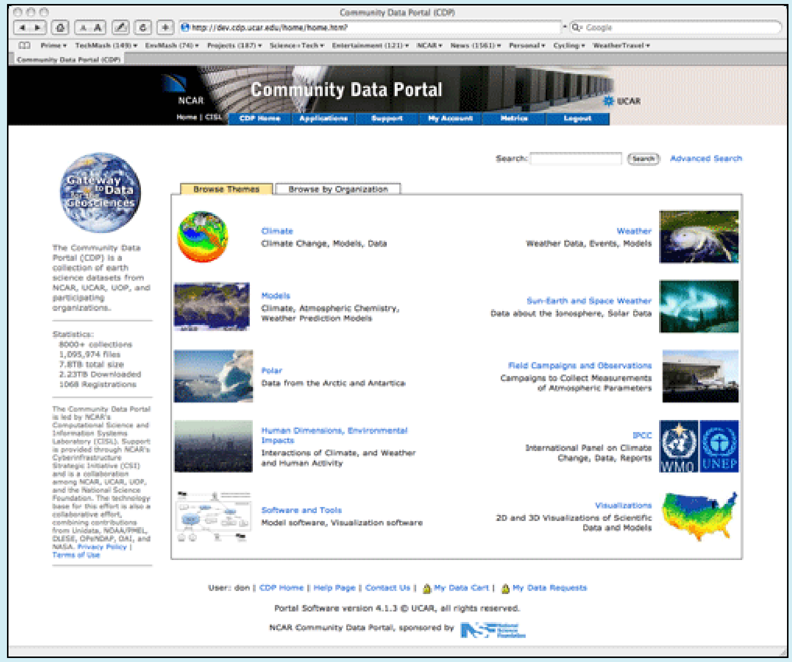
    - Steady progress will continue for the International Comprehensive Ocean-Atmosphere Data Set (ICOADS), a longstanding collaboration (20+ years) between NOAA and NCAR/CISL. A new release was accomplished late in FY2007, and another release is planned for FY2008.

The RDA maintenance and development within CISL is supported entirely by NSF Core funding.


*Postal address: P.O. Box 3000, Boulder, CO 80307-3000 • Shipping address: 1850 Table Mesa Drive, Boulder, CO 80305 • Contact*

# The Cyberinfrastructure Strategic Initiative and the Community Data Portal

The NCAR Cyberinfrastructure Strategic Initiative (CSI) was originally proposed as a collection of strategic activities that spanned data and knowledge management, collaboration environments, and advancing our web presence. Having accomplished our goals and realizing production capabilities in the latter two, our primary focus is now on advancing data and knowledge environments and aggressively developing our opportunity space in this and related areas.




This is a snapshot of the new Community Data Portal (CDP) homepage, which now reflects a more thematic interface to our broad digital asset holdings. We are currently developing a next-generation Semantic Web-based system, and this thematic approach is one step along that path. The CDP has now grown into what is commonly referred to as a "science gateway," where data, models, tools, and knowledge are managed and made available for community access. The CDP serves as a primary foundation for our development of an Earth System Knowledge Environment (ESKE).

The CSI effort currently funds our core foundational thrust, the Community Data Portal (CDP) along with a collection of related strategic priorities and opportunity development. Our overarching goals are to build the cyberinfrastructure, integrate and extend the Information Technology, develop the critical relationships and projects with scientific and educational projects, and foster the development of human resources and culture such that we can effectively develop our ESKE.

The CDP is aimed at developing and delivering innovative cyberinfrastructure that provides a shared technology base and facility for data and knowledge management for a broad set of digital holdings across UCAR, NCAR, and UOP. The basic idea is to develop and deliver the foundations for building science gateways and knowledge environments, including a broad spectrum of functionality spanning data search and discovery, semantic organization, catalogs and metadata browsing, support for virtual organizations, data download and upload, publishing, digital preservation, and analysis and visualization services.

The CSI thus plays an important role in supporting NCAR's strategic priorities of "Engaging a broader and more diverse community in the atmospheric and geosciences," "Developing and providing advanced services and tools," and "Creating an Earth system knowledge environment."

The more significant FY2007 highlights include:

- Data, modeling, and technology project support:
  In FY2007, we continued to support the spectrum of existing projects and began work on a number of new ones. This included IPCC, the THORPEX Interactive Grand Global Ensemble (TIGGE), the NCAR GIS Strategic Initiative, HAO's TGCM project, the MILAGRO field project, ACME-07, the Cooperative Arctic Data and Information Service (CADIS), the CGD Celtic Niwot Ridge effort, the Earth System Modeling Framework (ESMF), the NSF Earth System Curator (ESC) project, the IHOPE/ARCHEOMEDES project, TOPSE, and the Google Earth Opportunity Fund effort.

- Technology base advancement:
  In addition to all of the ongoing and new specific-project work, we also engaged in R&D in semantic interfaces, developed a new thematic interface to our CDP holdings, held meetings with our most active users, upgraded our access control systems to accommodate ESMF requirements, collaborated with Unidata in integrating security systems with Unidata software, and developed new web-based visualization capabilities that have been deployed (initially) for the TGCM project.

- World Meteorological Organization Information System (WMO-WIS) support:
  In FY2007 the CSI also supported collaborative efforts to develop the World Meteorological Organization (WMO) Information System (WIS), with CISL staff serving on several WMO committees and expert teams, including the WIS metadata group (IPET-MI), the WIS data and codes group (ET-CTS), the WIS global federation group (ET-WISC), and the WMO

Intercommission Coordination Group (ICG-WIS). We provided technology, support, federation, and coordination in support of a successful WMO WIS conference and demonstration in Seoul, Korea in November 2006. WMO-WIS is slated to be a major contributor to the Global Earth Observing System of Systems (GEOSS) effort.

- THORPEX Interactive Grand Global Ensemble (TIGGE) support:
  CSI-supported staff engaged in the design, software engineering, and deployment of core TIGGE systems that are based in large part on underlying CDP technology.

- Opportunity development:
  The CSI successfully developed funding opportunities for the Chronopolis effort (funded by the U.S. Library of Congress) and the CADIS project (NSF funded). We continued to work with EOL and other partners to develop support for the Virtual Operations Center (VOC) effort as well.

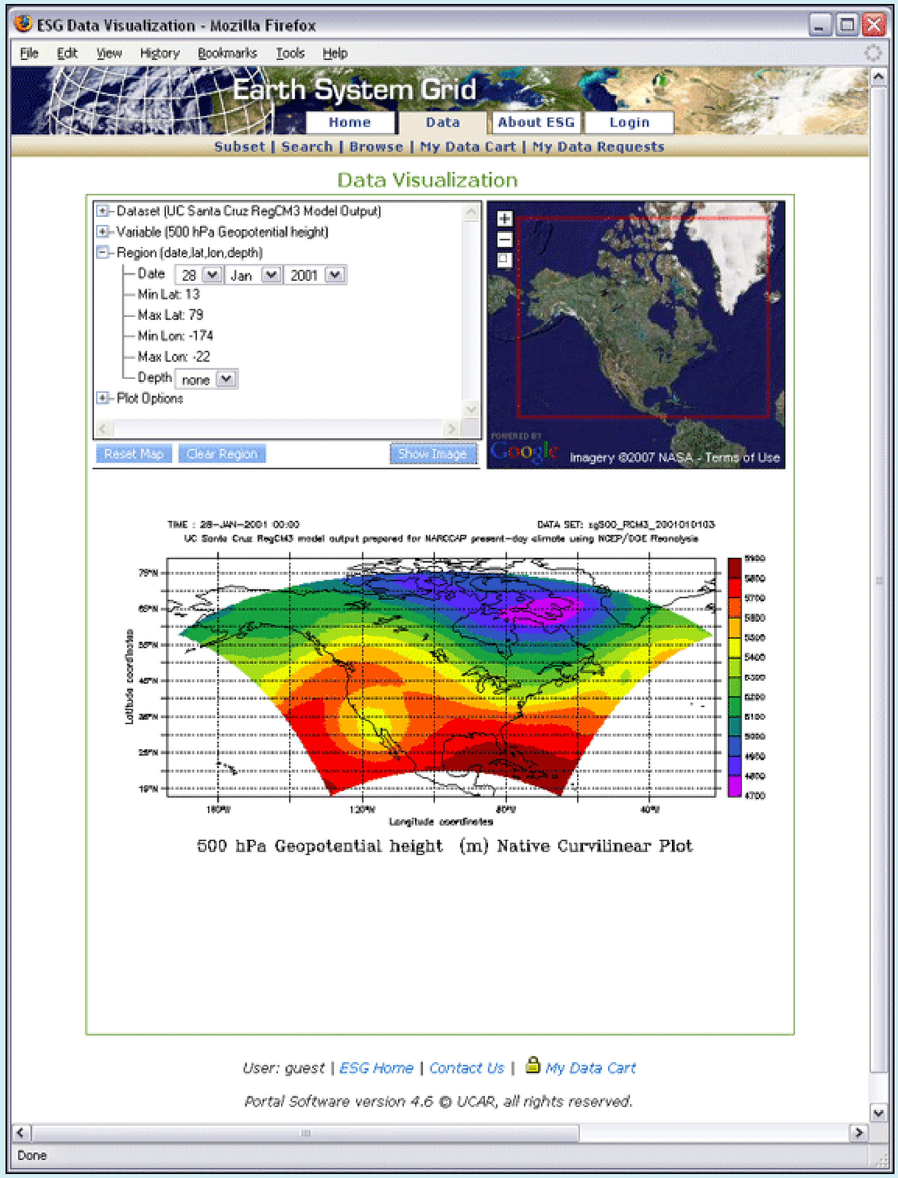
Overall, the CSI has impact ranging from local to global, with a solid track record of building important new collaborations. In FY2008 we will continue to pursue opportunity development in the areas of science gateway and portal development, semantic and knowledge systems, integrated data management, analysis, and visualization environments, and digital preservation initiatives. The initiative now has a large operational responsibility, and we will continue to work with a large number of projects and customers to continue good service, learn from it, and evolve our capabilities accordingly. From a technology standpoint, we will deploy a major upgrade of the overall software base that will include advanced virtual organization capabilities, new semantic interfaces, enhanced metrics reporting tools and infrastructure, and features for persistence and disaster recovery. We will continue our contributions to the WMO-WIS effort, working with international partners to realize our vision of globally federated data and knowledge environments. Overall, an overarching theme in the upcoming year is one of cross-project integration in the ESKE context—with an emphasis on establishing ESKE support foundations.

This project is supported through NCAR Strategic Initiative funding and NSF Core funding.


*Postal address: P.O. Box 3000, Boulder, CO 80307-3000 • Shipping address: 1850 Table Mesa Drive, Boulder, CO 80305 • Contact*

# The North American Regional Climate Assessment Program (NARCCAP)

NARCCAP is an international program that will serve the climate scenario needs of both the United States and Canada. We are systematically investigating the uncertainties in regional scale projections of future climate and producing high-resolution climate change scenarios using multiple regional climate models (RCMs) and multiple global model responses to future emissions scenarios. The technique involves nesting the RCMs within multiple atmosphere-ocean general circulation models (AOGCMs) forced with the A2 and A1B SRES scenarios over a domain covering the conterminous U.S. and most of Canada. The plan also includes a validation aspect through nesting the participating RCMs within reanalyses.




This is a new web-based visualization capability that we are developing for use in NARCCAP and other projects. Integrating elements of the Earth System Grid, NOAA's Live Access Server, and Google Maps, it allows a user to flexibly visualize and download subsets of online scientific data. This tool will allow NARCCAP users to easily access and obtain regional climate modeling data.

CISL's contribution to this project is primarily in the area of providing data management and community access for NARCCAP-produced datasets. This aspect of the work is a collaborative effort with NCAR/SERE, Lawrence Livermore National Laboratory, and the Iowa State University. NARCCAP plans to heavily leverage existing Earth System Grid (ESG) infrastructure as well as established data management practices developed for the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC).

NARCCAP is aligned with several NCAR strategic priorities. Relative to core science as well as societal impacts, it contributes to "Developing community models for weather, climate, atmospheric chemistry, and solar-terrestrial research," "Improving prediction of weather, climate, and other atmospheric phenomena," and "Supporting and conducting integrated regional-scale investigations of climate and weather impacts." Further, CISL's contributions align with NCAR's strategic priorities of "Developing and providing advanced services and tools" and "Creating an Earth system knowledge environment."

A primary accomplishment in FY2007 was completing the NARCCAP Operational Data Management Plan, the implementation face of the general plan that we presented in our original proposal. Building on the Earth System Grid (ESG) as a core technology foundation, the plan had to address new project requirements in the area of effectively integrating NCAR and LLNL storage and computational resources. We acquired, integrated, and deployed a new Nexsan 21-TB RAID unit on our Data Storage Area Network. To execute the planned leveraging of the ESG infrastructure, we developed NARCCAP requirements specifications, extended the ESG registration and authorization system, developed new data publishing systems, published test NARCCAP datasets, and began the process of integrating the distributed infrastructure between NCAR and LLNL/PCMDI. We have already tested large-scale Grid-based data movement tools between our sites, and at this point our baseline data management system is very nearly in place.

In FY2008 we will run the production process of validating datasets, shipping storage arrays, receiving data, quality-controlling it, and publishing online and archival versions of approximately 70 terabytes of data for the general NARCCAP community. As the production process goes into full operation, we will continue to develop and deploy new data delivery services such as subsetting, enhanced queries, and web-based visualization capabilities such as the one depicted in the image above.

More information on the NARCCAP project is provided on the NARCCAP web site.

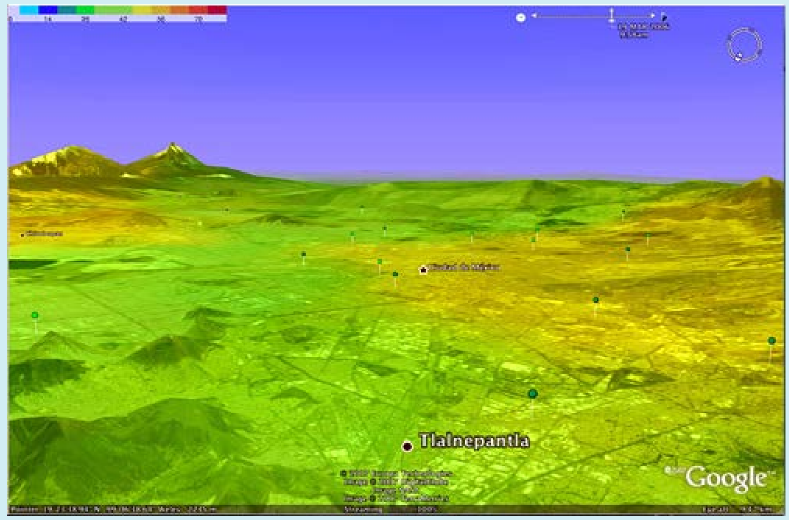
NSF, DOE, NOAA, and OURANOS are providing initial funding for the program.


*Postal address: P.O. Box 3000, Boulder, CO 80307-3000 • Shipping address: 1850 Table Mesa Drive, Boulder, CO 80305 • Contact*

# Bringing new functionality to data visualization using Google Earth

We are developing a set of tools that will exploit the capabilities of commercial "virtual globes" software, in particular the Google Earth product (which is freely available to anyone). Using a variety of information types (gridded three-dimensional model results, surface observations, and aircraft-based observations), we are writing software to provide scientists with additional information about the overall structure of the chemical conditions at the time and location of the observations. Our goal is to explore the feasibility and usefulness of this approach for helping scientists refine their models. The tool will be extended to provide visualizations in a 3D regime, such as comparing the predictions of model outputs to an aircraft track or a dropsonde.

Because these visualizations use readily available commercial tools, they can be easily distributed to scientific colleagues, educational institutions, and the public. We anticipate that schools will be interested in downloading these files with an easy interface and useful information about scientifically stimulating data.




This image shows preliminary comparisons of WRF-CHEM model outputs to station measurements of $O_3$ near Mexico City, Mexico. This image allows a researcher or student to visually compare concentrations of a pollutant to the values produced by a model, and to track this comparison over time. Metadata that describes the station measurement and other station information can be accessed by clicking on the station marker. This visualization technique is significant because it easily allows visual comparisons of scientific datasets to be made in a rich geographic context. (See larger image.)

This project supports NCAR's strategic plan in several respects. It is "Developing and providing advanced services and tools" and "Creating an Earth system knowledge environment" while "Engaging a broader and more diverse community in the atmospheric and geosciences" and "Supporting and enhancing formal science education at all levels."

In FY2007, we began leveraging an existing NCAR visualization tool, the NCAR Command Language (NCL), to create the visualizations. Existing scientific codes that perform complex operations on data are being leveraged to create visualizations that are then placed in the Google Earth context. NCL also can be used to perform data extraction and color mapping so that the tools we are building will also be able to access and visualize a wide range of information available from the NCAR Community Data Portal in a more generalized fashion.

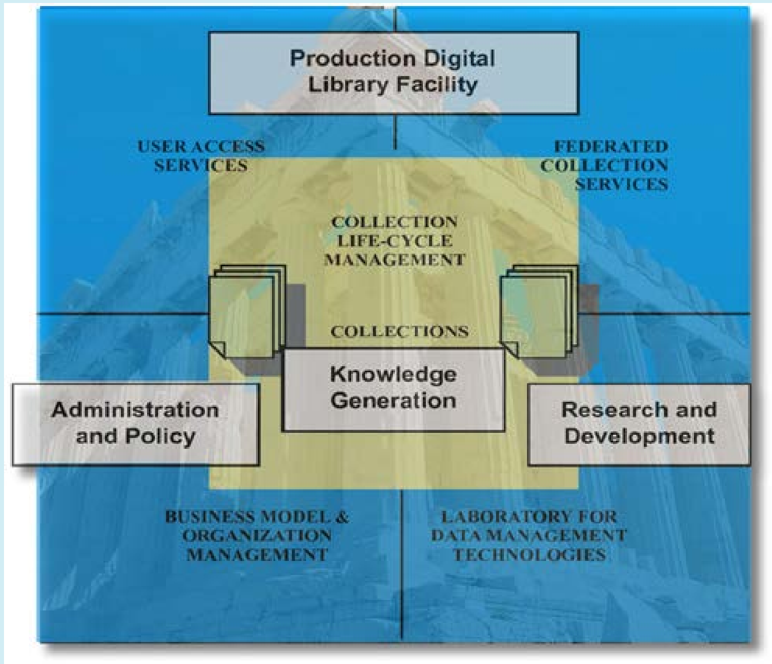
In FY2008, this project will complete the study of use cases by finalizing software that supports automated extraction of data, visualizations, and XML descriptions that will interface to Google Earth software. We anticipate iterations with scientists to refine the products. These products will be distributed via the Community Data Portal to interested parties. We will also provide an assessment of the scientific usefulness for the evaluation of models. If time permits, this functionality will be extended into a more generalized web interface.

This work, performed in collaboration with scientists from NCAR's Atmospheric Chemistry Division, is being funded under the FY2007 NCAR Director's Opportunity fund, which is derived from NSF Core funds.


*Postal address: P.O. Box 3000, Boulder, CO 80307-3000 • Shipping address: 1850 Table Mesa Drive, Boulder, CO 80305 • Contact*

# Chronopolis: Federated digital preservation across space and time

There is a critical and growing need to organize, preserve, and make accessible the increasing number of digital holdings that represent vital intellectual capital, much of which is precious and irreplaceable. Chronopolis is a strategic collaboration among the San Diego Supercomputing Center (SDSC, lead organization), NCAR/CISL, the University of California Library System, and the University of Maryland. It is aimed at developing national-scale digital preservation infrastructure that has the potential to broadly serve any community with digital assets—science, engineering, humanities, and more.




This image represents a conceptual architecture for the Chronopolis Digital Preservation Environment. Through a combination of advanced data management technologies, geographic replication, and policy instruments, Chronopolis is aimed at providing cyberinfrastructure for national-scale digital information preservation.

This new effort encompasses studying viable models and effective systems that facilitate establishing standard reference datasets, preserving collections that evolve over time, and establishing preservation resources "of last resort" for digital assets that might become lost. Digital collections that must persist for 100 or more years are one important focus of this activity. Approaching this problem requires a special synthesis of relationships and capabilities: scientists, librarians, curators, computer scientists, and long-term distributed cyberinfrastructure.

The problem spans the gamut of academic scientific disciplines, historical collections, and digital library content. Though broadly useful, new capabilities developed in Chronopolis are expected to be powerful services that we can potentially offer to the Earth System sciences community through, for example, our Community Data Portal (CDP). This activity addresses NCAR's strategic goal to "Provide robust, accessible, and innovative information services and tools."

In FY2007, we deployed additional core Chronopolis infrastructure on our computational systems and on the TeraGrid, integrating and testing end-to-end capabilities that include archival functions on the NCAR MSS. Under the terms of last year's Memo of Understanding with SDSC, we began the process of replicating some of our unique observational and reanalysis datasets, and these activities have made good use of our new TeraGrid connections.

We also received a positive response from The National Digital Information Infrastructure and Preservation Program (NDIIPP) regarding our expressed interest in developing an NDIIPP-supported Chronopolis pilot project. We are in the final phases of establishing a 1-1.5-year contract with NDIIPP where NCAR will co-develop core preservation infrastructure for the effort. Our pilot project is framed initially as an R&D activity aimed at prototyping a preservation environment for the California Digital Library's (CDL) Web-at-Risk project and the Interuniversity Consortium for Political and Social Research's (ICPSR) data archive.

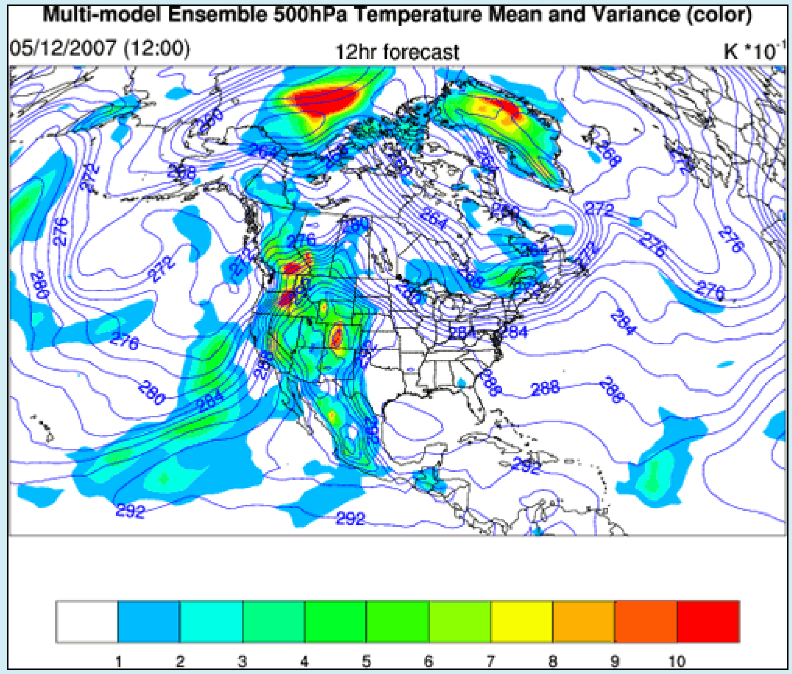
In FY2008 we expect to begin our Chronopolis pilot project, and the first steps will include building and integrating the preservation system. Once we have the prototype system populated and operating, we will simulate a "disaster" and investigate the performance and effectiveness of resurrecting a lost, multi-terabyte data resource. We will also continue our efforts to broaden our support base and associated scope in the upcoming year.

CISL is engaging in Chronopolis as an important strategic thrust, supporting it through a combination of NSF Core funding and NCAR's Cyberinfrastructure Strategic Initiative (CSI).

CISL Director's message
CISL annual report Table of contents
**Strategic goals**: science, facilities and technology
CISL research catalog

# Community tools and frameworks for geoscientific analysis and visualization: NCL, PyNGL, and PyNIO

The NCAR Command Language (NCL) is a data analysis and visualization environment developed primarily at NCAR/CISL with deep collaboration with a number of core scientific groups. NCL enables scientists to easily and effectively read, analyze, and visualize their geoscientific data on platforms ranging from personal systems to high performance computers. PyNGL and PyNIO are software components that provide Python interfaces to NCL's file input/output and visualization capabilities, thereby enabling NCL's software frameworks to be exposed to a wider and more mainstream user base. The NCL and Python tools have been embraced broadly across an international Earth system sciences community spanning research, education, military, government, and commercial organizations. They are used by thousands of people in 74 countries.




This NCL visualization shows a grand ensemble average calculated by averaging the ensemble averages from each of the five modeling centers participating in the TIGGE project. TIGGE (THORPEX Interactive Grand Global Ensemble) is a key component of THORPEX, a World Weather Research Programme to accelerate the improvements in the accuracy of 1-day to 2-week high-impact weather forecasts for the benefit of humanity. Centralized archives of ensemble model forecast data from many international centers are used to enable extensive data sharing and research. TIGGE data is stored in the new GRIB2 data format.

Our efforts here support the NCAR strategic priorites of "Exploring atmospheric, Earth System, and solar processes, variability, and change" along with "Developing and providing advanced tools and services," and "Creating an Earth system knowledge environment."

A top priority for FY2007 was to add support for more scientific data formats. We accomplished this by releasing versions of NCL and PyNIO that:

- Read GRIB2, a second-generation data format standard developed by the World Meteorological Organization for distributing gridded data
- Read/write classic netCDF-4 files, enabling users to access significant data compression capabilities
- Provide better support for HDF-EOS swath and grid data

A second top priority was to collaborate with WRF scientists and software engineers to significantly upgrade the NCL post-processing capabilities for the rapidly growing WRF community. This effort resulted in several analysis and visualization functions being incorporated into NCL, specific to analyzing WRF-ARW data; the August 2007 release of NCL contained these new capabilities.

Finally, our Python efforts were ramped up in FY2007. We released two versions containing several new analysis and visualization functions, new examples, and support for a widely popular array processing package. We also continued to explore options for integrating exploratory and quantitative 3D capabilities via the Python framework.

Future plans for NCL and Python software development and support are largely based on continuous dialogs with the scientific community and on results conducted from a survey in FY2006. Goals for FY2008 include:

- Release NCL, PyNGL, and PyNIO under an open source license
- Research the scalability of NCL to address issues pertaining to large files, data aggregation, and 64-bit machine addressing
- Research the display model on which the visualiation tools are built and address future enhancements required
- Add full support for more data formats
- Integrate interfaces for generating vectors and streamlines on non-uniform grids to the NCL/PyNGL level
- Improve NCL's suite of interpolation routines by adding an interface to SCRIP
- Enhance the Python suite of analysis functions and continue to investigate the integration of 3D tools
- Continue providing high-quality consulting support and training services for the user community

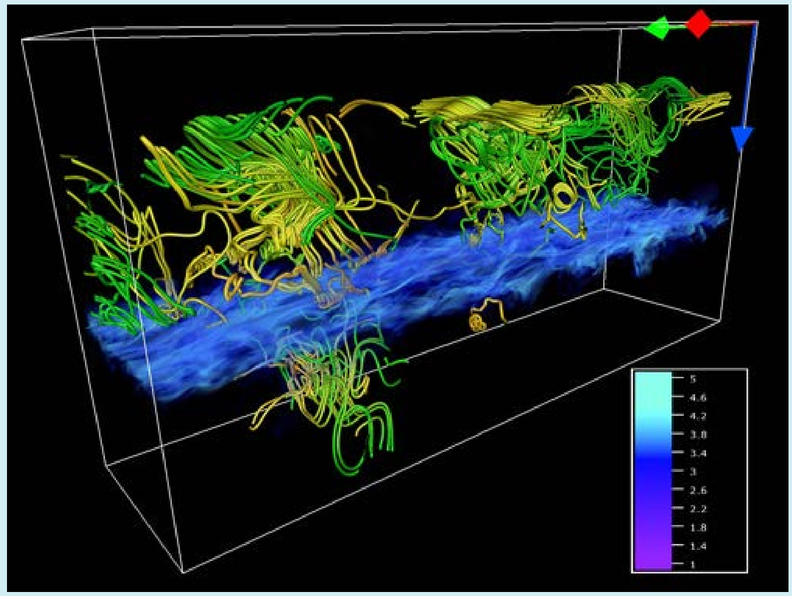
The integration of NCL and its Python counterparts continues to be a core activity of our Earth System Grid Center for Enabling Technologies (ESG-CET) project. ESG will provide support for the integration of our tools as core client applications of ESG, and potentially as server-side capabilities as well.

Our development and deployment of community tools and frameworks for geoscientific analysis and visualization is supported by NSF Core funding.


*Postal address: P.O. Box 3000, Boulder, CO 80307-3000 • Shipping address: 1850 Table Mesa Drive, Boulder, CO 80305 • Contact*

# Visualization and Analysis Platform for Ocean, Atmosphere, and Solar Research (VAPOR)

The VAPOR project is an Open Source software development effort to improve the ability of Earth sciences researchers to analyze and interpret results from some of largest numerical simulation outputs in the geosciences. VAPOR is one component of a larger NSF-ITR-funded research and development project to study time-varying data whose collaborators include NCAR, the University of California at Davis, and the Ohio State University. With NCAR leading software development and our university collaborators taking the lead on research, a mutually beneficial relationship has been established. NCAR provides a steady supply of interesting research challenges to our university partners who help provide solutions to some of our most difficult visualization and data analysis problems. Development of VAPOR is closely guided by a steering committee comprised of turbulence researchers from around the world. This panel of experts sets development priorities, dictates software requirements, and serves as friendly users for testing and evaluating new software features.




This is a visualization of the dynamics of the solar interior. (Image courtesy of Geoff Vasil, University of Colorado.) VAPOR provides a desktop environment for the quantitative and qualitative analysis of high-resolution numerical simulations of turbulence. VAPOR facilitates human understanding of complex geosciences phenomena by allowing researchers to analyze high-resolution data at locations remote from the supercomputing facilities where it is generated.

Decades of continual advancements in microprocessor technologies have led to numerical simulations of earth sciences phenomena computed at unprecedented scales. These simulations generate extraordinary amounts of data. But our ability to manage, analyze, and gain insights from these data has not kept pace with our ability to generate them. For many numerical modelers, the greatest challenge in the discovery process begins after the simulation has completed when the analysis process begins. The VAPOR project focuses on the problem of large-data exploration with an intelligent approach: by exploiting multiresolution data representation coupled with advanced interactive visualization and quantitative analysis capabilities, VAPOR provides a comprehensive desktop environment suitable for exploring terascale-size data sets.

VAPOR supports two of NCAR's strategic priorities: "Developing and providing advanced services and tools" and "Creating an Earth system knowledge environment."

Noteworthy events in FY2007 include:

- Two new major versions of the software were completed and released.
- Over 2,000 copies of VAPOR have been download by the scientific community. VAPOR is widely in use by research groups worldwide.
- VAPOR has been cited in multiple refereed scholarly scientific publications and numerous scientific presentations.
- The VAPOR team continued its education efforts, hosting Ph.D. interns from the University of Colorado and the Colorado School of Mines
- An invited paper on VAPOR was published by *New Journal of Physics*.
- VAPOR was the cornerstone of NCAR's initial TeraGrid visualization efforts.

Version 1 of VAPOR targeted physicists investigating numerically simulated turbulence. Work in FY2008 will broaden VAPOR's capabilities to better meet the needs of a more general Earth and space sciences computational fluid dynamics community. Preliminary research in more aggressive data reduction techniques has been promising; this is the cornerstone to another key area of future development: preparing for petascale computation.

This project is made possible through support from NSF's Information Technology Research for National Priorities (ITR) program, supported by NSF award 0325934 through subaward 009323-01 with the University of California at Davis.

*Postal address: P.O. Box 3000, Boulder, CO 80307-3000 • Shipping address: 1850 Table Mesa Drive, Boulder, CO 80305 • Contact*

# Continuation of Earth System Knowledge Environment reports from FY2006

## SCD Portal (now CISL Portal)

This project is now classified as cyberinfrastructure: CISL Portal.

## Grid-BGC

Grid-BGC is a collaborative project to develop an end-to-end solution that seamlessly couples models, data, and resources to allow geoscientists to simulate terrestrial biogeochemistry over large domains at high spatial resolution. The Grid-BGC project's external funding concluded in October 2006 with the release of a production-grade version of the Grid-BGC science portal to the biogeochemistry community along with user and system documentation. The project received a no-cost extension until 12/31/06, and thus concluded in FY2007.

While development of BGC itself has completed, its workflows remain a primary motivation for continued work in the area of Grid-based service oriented architectures (SOAs). These services form the back end to the Grid-BGC science portal that allow scientists to interactively set up simulations used to model the global carbon cycle. Experiments with the POP, CAM, and WRF models have shown that this SOA can indeed integrate these applications into a grid environment. Grid-BGC is the first working computational grid for carbon cycle simulations, and the SOA designed to support it provides a seamless set of services from which the geoscience community can potentially build other end-to-end solutions. We are generalizing these SOA components into an Extensible Service Provider (ESP) toolkit supporting rapid service deployment for new applications.

The computational components of Grid-BGC workflows are embarrassingly parallel and are traditionally run on Linux clusters, large IBM SMP systems, and other systems that can execute many single-processor tasks efficiently. These types of workflows lead to inefficient usage of massively parallel architectures such as the IBM Blue Gene/L (BG/L) because of allocation constraints forced by its unique system design. Recently, IBM introduced the ability to schedule individual processors on BG/L—a feature named High Throughput Computing (HTC)—creating an opportunity to exploit the system's power efficiency for other classes of computing. In FY2007, we developed a Grid-enabled interface supporting HTC on BG/L and applied it to Grid-BGC workflows. This interface accepts single-processor tasks using Globus GRAM, aggregates HTC tasks into BG/L partitions, and requests partition execution using the underlying system scheduler. By separating HTC task aggregation from scheduling, we provide the ability for workflows constructed using standard Grid middleware to run both parallel and serial jobs on BG/L. This feature allows us to run jobs from Grid-BGC (and similar workflows) on the BG/L.

This effort supports NCAR's strategic priorities of "Developing and providing advanced services and tools" and "Creating an Earth system knowledge environment." NASA has provided funding for the Grid-BGC project through the Advanced Information Systems Technology Office (NASA AIST Grant NAG2-1646) and the Terrestrial Ecology Program.


*Postal address: P.O. Box 3000, Boulder, CO 80307-3000 • Shipping address: 1850 Table Mesa Drive, Boulder, CO 80305 • Contact*

CISL Director's message
CISL annual report Table of contents
**Strategic goals:** science, facilities and technology
CISL research catalog

# Cultivating a scientifically engaged citizenry: Education and outreach

CISL supports numerous programs that foster improved awareness and understanding of geosciences and research methods for a variety of research and educational communities. These activities are supported through internships, seminars and workshops, visually compelling 3D presentations in CISL's Visualization Lab, conference exhibits, partnership with the NCAR Public Visitor Program, a training and outreach program for the NCAR Command Language (NCL) and other visualization tools, and security training for system administrators.


NCAR's exhibit at SC06 combined a variety of outreach efforts: Presentations about the latest scientific results and computing resource enhancements at NCAR, opportunities to network with CISL and NCAR staff, highlights of NCAR's TeraGrid integration work, interactive displays, informative posters, and tables available to attendees for conversations and working on their laptops. This multi-purpose design reaches a broad cross-section of attendees, helping them appreciate NCAR's contributions to the atmospheric and related sciences.

Accomplishments and plans in CISL's education and outreach efforts are discussed in these sections:

- Summer Internships in Parallel Computational Science (SIParCS) program
- IMAGe Theme of the Year education and outreach
- Computing in Atmospheric Sciences workshop (CAS2K7)
- Vislab outreach program
- Training in geoscientific tools
- Conference outreach
- Security training for UCAR system administrators
- Sustained mentoring support for the SOARS internship program

CISL's work across all of these areas broadly supports NCAR's strategic goal to "Cultivate a scientifically literate and engaged citizenry and a diverse and creative workforce." This work is supported by NSF Core funding.

# IMAGe Theme of the Year education and outreach

## Summer 2007 graduate workshop on Data Assimilation for the Carbon Cycle

An acknowledged hallmark of mathematical science is that the same mathematical and statistical methods and models can be used to solve problems in very different contexts. The success of mathematics in the geosciences, however, must be based on geoscientists and applied mathematicians working in multidisciplinary teams and being knowledgable in complementary scientific fields. The long-term investment in multidisciplinary applications must be based on the training of young researchers. The IMAGe summer school "Data Assimilation for the Carbon Cycle" held July 8-13, 2007 is a recent example of NCAR's support of innovative models, developing new algorithms and methods, and training young scientists.


Participation in the TOY workshops is becoming more diverse as IMAGe adds different kinds of activities to its thematic programs. One way to incorporate applied mathematics and statistics to geoscience problems is to offer summer learning opportunities that mix students of different backgrounds in a comfortable environment and encourage interaction and questions. These coordinated activities have the potential to significantly increase the multidisciplinary training of young scientists. This also brings new mathematical approaches to challenging geophysical problems, such as estimating the Earth's sources and sinks of carbon.

Quantifying the flow of carbon into and out of the atmosphere through both natural and human activities is an important problem in biogeoscience and also a key factor in understanding climate change. Measurements of atmospheric carbon dioxide concentrations are limited to a small number of towers or to irregular spatial sampling from the ground or from satellites. The challenge is to make use of these observations to estimate carbon fluxes into the atmosphere. A solution to this problem requires a multidisciplinary perspective that includes an understanding of the carbon cycle, the use of atmospheric circulation models, and skill in statistical modeling and data assimilation. The main purpose of this school was to train the next generation of researchers to tackle problems such as these by working within a multidisciplinary science team that combines geoscientists, ecologists, statisticians, and applied mathematicians. Participants obtained an overview of this problem plus some specific skills in tackling inverse problems and working with geophysical and biogeochemical models.

This summer school was part of the 2007 Theme of the Year (TOY): Statistics and Computer Models; it was also supported by the Mathematical Sciences Research Institute (MSRI). MSRI is the oldest mathematical sciences Institute sponsored by NSF, but the program emphasizing the connections between mathematics and climate is a new focus. Copying the program from the previous school held at MSRI in 2006, the morning sessions consisted of tutorial lectures, and the afternoon sessions used computer exercises to teach data assimilation methods. Each day also featured a special invited lecture on a topic related to the geosciences, ecology, or applied mathematics.

One unique feature of the school was the use of DART software to teach data assimilation. DART, an open source and publicly available software environment, is designed not only for teaching but also for tackling the large assimilation and inverse problems found in the geosciences. Thus the school has not only introduced many students to assimilation, but it has familiarized them with software that can support their graduate research.

Approximately 25 students attended the school, evenly split with backgrounds in mathematics or in the geosciences. The students worked the computer exercises in pairs, and in general the interaction and networking throughout the school was reported to be an important attribute.

Plans for 2008 target two different groups of students. A short school featuring exercises in DART is planned for statistics graduate students in August 2008 to give them experience with geophysical numerical models. The 2008 TOY summer school on turbulence will synthesize experimental, theoretical, and computational approaches to understanding geophysical turbulent flows. This school has the ambitious goal of giving students some computational experience on the NCAR Blue Gene/L, a massively parallel prototype of possible future supercomputers.

TOY summer schools are made possible through NSF Core funding.

*Postal address: P.O. Box 3000, Boulder, CO 80307-3000 • Shipping address: 1850 Table Mesa Drive, Boulder, CO 80305 • Contact*

CISL Director's message
CISL annual report Table of contents
**Strategic goals**: science, facilities and technology
CISL research catalog

# Computing in Atmospheric Sciences workshop (CAS2K7)

CISL staff organized and hosted the eighth biennial session of Computing in Atmospheric Sciences (CAS2K7). Computer experts, scientists, and industry leaders gathered in Annecy, France on September 9-13, 2007, to discuss the status and future of high-performance computing for weather prediction and climate modeling. The meeting drew 80 participants and covered topics that included hurricane and tsunami prediction, weather prediction, climate change, and challenges and advances in computing technologies. Practical applications were presented, including plans for accurate weather forecasting for the 2008 Olympic Games in Beijing, China. The conference provides the opportunity for supercomputing industry leaders to hear about their customers' needs and present their product roadmaps, for scientists to exchange ideas and share experiences about computing resources and applications, and for data experts to discuss innovative methods of enhancing data distribution mechanisms, constructing data preservation archives, and improving the efficiency and effectiveness of data storage and access.


At the opening session of CAS2K7, Program Chair Tom Bettge introduces the meeting's General Chair Al Kellie, who was the first of 37 speakers to address the participants. This biennial workshop is a unique forum for atmospheric scientists, supercomputing center managers, and supercomputing equipment vendors from around the world to discuss accomplishments, plans, and ideas, both formally and informally.

The complete agenda, including copies of presentations, is published on the CAS2K7 web site.

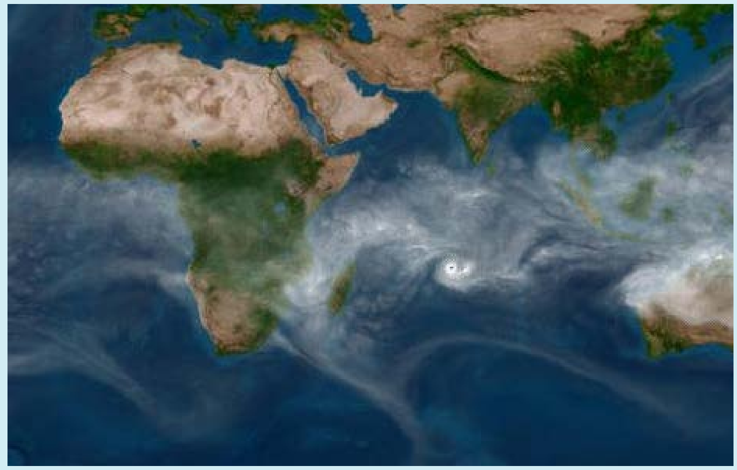
This workshop series supports the NCAR strategic priority of "Engaging a broader and more diverse community in the atmospheric and geosciences."

In addition to the National Science Foundation, CAS2K7 was sponsored by several computer industry entities: IBM, Cray, SGI, Sun Microsystems, NEC, Intel, and AMD.

CISL Director's message
CISL annual report Table of contents
**Strategic goals**: science, facilities and technology
CISL research catalog

# Vislab outreach program

Many CISL outreach efforts are conducted through its Visualization Lab, a visual supercomputing facility that supports collaborative technologies, data analysis and visualization, and theater-style presentations in wide-format, high-resolution, stereo 3D. The room comfortably seats 20 to 30 people and is used for general meetings, videoconferences, and many education and outreach efforts. This facility, with five high-resolution projectors and a 24-by-9-foot (8-by-3.5-meter) display, is used as a 3D presentation platform for education and outreach activities and has seen continual and increased usage since its inception six years ago. The room also provides an AccessGrid capability that helps foster geographically distributed research by providing a virtual meeting place to connect NCAR staff with remote collaborators at universities and other research labs.



This excerpt from an image of total integrated global water vapor was produced from data generated by the CCSM CAM3 model and shows a well-developed tropical cyclone over the Indian Ocean. Animations produced from images like this are used in presentations and other education and outreach efforts to help foster public awareness and understanding of the atmospheric and related sciences. (See full image.)

Visualization Lab outreach efforts dovetail with NCAR strategic priorities that include "Engaging a broader and more diverse community in the atmospheric and geosciences," "Fostering public awareness and understanding of atmospheric and related sciences," and "Providing Robust, Accessible, and Innovative Information Services and Tools." Visually engaging scientific presentations are provided weekly to a wide variety of audiences including K-12 groups, university students, corporate visitors, government representatives, and scientific researchers. Demonstrations of climate change, atmospheric turbulence, ocean simulations, and severe weather are presented in a high-resolution 3D format along with scientific explanations that are tailored to the education level of each audience. The Visualization Lab is frequently used as a backdrop by film crews, who perform on-site interviews with NCAR scientific staff. Media organizations often request digital media and scientific visualizations that are produced in the Visualization Lab for use in film and broadcast productions that potentially reach millions of viewers to help raise public awareness about important and pressing environmental issues.

In FY2007, the Visualization Lab staff continued its successful partnership with the Public Visitor Program and supported approximately 180 presentations, AccessGrid sessions, and general meetings involving over 2,100 participants (a 25% increase from last year). These events included presentations to K-12 audiences, scientific and corporate visitors, and government officials including VIP visitors from the National Science Foundation, the Office of Management and Budget, NOAA, the British Foreign Consulate, and the Chinese Government, to name a few. The CISL Visualization Lab also continued its important role as an outreach liaison with film and television organizations by providing a venue for television interviews with NCAR staff and by developing digital media that was used in productions by the Weather Channel, Seoul Broadcasting System, NBC WeatherPlus, and the Discovery Channel, among others.

In FY2008, the CISL Visualization Lab will continue to collaborate with NCAR scientists to produce new and compelling scientific visualization material that will be used to foster awareness and understanding of the atmospheric and related sciences. It is worth noting that this activity also helps drive our development of new analysis and visualization capabilities. The lab will also continue its productive partnership with the NCAR Public Visitor Program to reach K-12 audiences providing them with engaging, 3D material to help spark their interest in environmental and Earth sciences. We will also continue to liaison with film crews and the media providing them with a venue for scientific interviews as well as digital material from relevant visualization projects that can be used for broadcast and educational purposes. We will continue to provide AccessGrid capabilities with an ongoing emphasis on integrating new technologies and techniques that facilitate enhanced group collaboration. We also intend to investigate new software tools that have the potential to enhance and choreograph presentations and effects for Vislab presentations.

This project is supported by NSF Core funding.


*Postal address: P.O. Box 3000, Boulder, CO 80307-3000 • Shipping address: 1850 Table Mesa Drive, Boulder, CO 80305 • Contact*

CISL Director's message

CISL annual report Table of contents

**Strategic goals**: science, facilities and technology

CISL research catalog

# Training in geoscientific tools

In FY2007, CISL hosted four training workshops for the NCAR Command Language (NCL): three were held locally at UCAR's Corporate Technical Training Center, and one took place at the APEC Asian-Pacific Climate Center in Busan, Korea. To support, enhance, and extend the capabilities of the university community both nationally and internationally, CISL submitted an internal proposal to offer one free yearly NCL workshop at qualifying UCAR member universities, starting in FY2008. We also plan to offer two to three local workshops, and we have been invited to present one at the Eurasia Institute of Earth Sciences in Istanbul, Turkey.

Dennis Shea, an associate scientist in the Climate and Global Dynamics Division of NCAR's ESSL, co-presented an NCL workshop in December 2006 at the APEC Asian-Pacific Climate Center in Busan, Korea. The Director of this relatively new center invited NCAR trainers to help their researchers and some students from a nearby university become proficient using this tool. These workshops help scientists learn to quickly analyze and visualize their data using a single tool, and by the end of the course most students have created a fully functional program for processing their own datasets.

Research will be conducted to determine the feasibility of offering similar training courses for PyNGL and PyNIO. This would most likely involve a collaborative effort with experts from the University of Colorado who already offer a Python scientific training course.

It is important to note that our community contribution in this area is not simply training to use the NCL tool: it is fundamental training in the important practice of Earth System data analysis. This work advances NCAR's strategic goal to "Cultivate a scientifically literate and engaged citizenry and a diverse and creative workforce."

This series of training workshops is supported by NSF Core funds.


*Postal address: P.O. Box 3000, Boulder, CO 80307-3000 • Shipping address: 1850 Table Mesa Drive, Boulder, CO 80305 • Contact*

CISL Director's message
CISL annual report Table of contents
**Strategic goals:** science, facilities and technology
CISL research catalog

# Conference outreach

Since 1989, CISL has deployed a series of exhibit booths for a variety of scientific and technical conferences. In these booths, CISL staff demonstrates supercomputing capabilities, scientific visualization, and other NCAR research in science and technology. At the height of its conference outreach program, CISL staff provided demonstrations and presentations at several conferences each year, including Supercomputing, the American Meteorological Society, the American Geophyscial Union, and others.

CISL Division Directors Rich Loft (left) and Tom Bettge (center) answer questions in the TeraGrid booth at SC06. CISL conducts outreach activities through two booths at the yearly Supercomputing conference, one booth at the yearly TeraGrid conference, and at other venues. By representing NCAR's science and technology efforts at gatherings of researchers every year, CISL shares its expertise and gains valuable new insights from the research community.

In recent years, CISL has focused energy and resources on providing NCAR outreach at the annual Supercomputing and TeraGrid conferences and on local Vislab presentations and outreach activities. In FY2007 and in coming years, CISL will also provide TeraGrid external relations support at the Supercomputing and TeraGrid conferences.

CISL's conference outreach program supports NCAR's strategic priority of "Engaging a broader and more diverse community in the atmospheric and geosciences" and "Fostering public awareness and understanding of atmospheric and related sciences." Specifically, this work advances understanding of the underlying computational and software technologies that are used in geoscience research today. Further, these outreach efforts are "Supporting and enhancing formal science education at all levels" by educating conference attendees from around the world about supercomputing resources and cyberinfrastructure services that enable the geoscience community conduct research.

CISL hosts and provides planning and logistics support for conferences and workshops including:

- SC06
- TeraGrid07
- Workshop on High Performance Computing for Geosciences Research
- Workshop on Geoscience Application Requirements for Petascale Architectures
- CAS2K7
- ScicomP/SP-XXL
- and others

These efforts are undertaken using NSF Core funds.


*Postal address: P.O. Box 3000, Boulder, CO 80307-3000 • Shipping address: 1850 Table Mesa Drive, Boulder, CO 80305 • Contact*

CISL Director's message
CISL annual report Table of contents
**Strategic goals:** science, facilities and technology
CISL research catalog

# Security training for UCAR system administrators

In 2006, the UCAR Computer Security Advisory Committee (CSAC) approved policy 20060104-01 requiring all system administrators and other UCAR staff responsible for computer security to participate in eight hours of relevant training each year. To keep the training costs manageable for divisions and programs, CSAC decided to develop much of that training in-house, although administrators were encouraged to seek training in other venues as appropriate.

This work supports NCAR's strategic priority of "Developing and providing advanced services and tools." Developing and maintaining appropriate cyberinfrastructure security enables all of UCAR's organizational units in "Maintaining an innovative and creative workplace."

In FY2007, five two-hour security training sessions were developed by a former UCAR CSAC member to train UCAR system administrators in rigorously maintaining UCAR cyberinfrastructure at the appropriate security levels. In January 2007, CSAC decided to offer five two-hour training sessions, and eligible UCAR staff could meet their training requirements by attending the prerequisite Security Essentials course plus three of the following four sessions: Securing Unix/Linux, Securing Services, Securing Windows, and Securing MacOsX.

The course developer/trainer formed a security advisory group of several UCAR system administrators to guide the content of the training modules. He also conducted a survey of potential participants that illuminated the need for the MacOsX module.

Two training sessions were delivered in FY2007. The remaining three will be delivered in early FY2008. Training sessions will be updated and repeated as needed under the guidance of CSAC and the security advisory group.

This ongoing training series is supported by UCAR Communications Pool indirect funds.

# Development of spectral-element and other higher-order methods for atmospheric dynamics

Aimé Fournier*

NCAR Institute for Mathematics Applied to Geosciences

*Turbulence Numerics Team – 2007 NAR*

**Sponsored by the NSF cooperative agreement through UCAR**

September 21, 2007

## 1 Historical & scientific context and strategic alignment

A need has long been well established and many investigations undertaken at NCAR and elsewhere, to create high-resolution numerical simulation methods for atmospheric dynamics, that are accurate similarly to spectral methods and computationally efficient similarly to finite-element type methods [2, §1], [3]. In particular, multiresolution analysis & simulation using spectral elements (MASUSE) is well aligned with NCAR strategic priorities [2, §2]. Two research codes that demonstrate the strengths of the spectral-element method (SEM) with static-conforming or dynamic-nonconforming adaptive mesh refinement (AMR) are SEAM [14, and refs. therein] and GASpAR [9, 10], respectively.

## 2 2007 accomplishments

### 2.1 GASpAR application to decaying 2D turbulence at high Reynolds number

GASpAR has now been extended to decaying incompressible Navier-Stokes flows at high Reynolds number $R$ [4]. One goal here is to exploit the localized high accuracy to develop analysis methods for vortex filaments and similar flow structures e.g., using a velocity curvature measure $\vec{u} \times (\vec{u} \cdot \vec{\nabla})\vec{u}$ [5]. Figure 1 shows contours of vorticity $\zeta := {}^{\perp}\vec{\nabla} \cdot \vec{u}$ from biperiodic flow at $R = 2 \times 10^4$ initialized with 3 Gaussian vortices [7, 11]. The diffusive balance

$$\frac{\mathrm{d}}{\mathrm{d}t}\langle \vec{u}|\vec{u}\rangle + 2\nu\langle\zeta|\zeta\rangle = 0 \tag{1}$$

is verified to at worst $8 \times 10^{-3} > \mathcal{O}[\Delta t^3]$ for $0 \le t \le 10t_{\mathrm{eddy}}$. As a qualitative comparison, Fig. 2 shows slice snapshots of $\zeta$ for GASpAR and two pseudo-spectral model (PSM) simulations at approximately the same space and time coordinates. (Note, not every $x^a$ coordinate in PSM is also in GASpAR.) Each gray-curve pair corresponds to the standard deviation of $\zeta$-curve pixels digitally scanned from references KevFar97 and ScKeFa97 and modeled as $\zeta$-distributions.

Another goal is to discover how well AMR can accelerate long-range simulation of an initially very random flow with power-law spectrum that evolves through strong nonlinear interactions into a maximum-entropy state with sensitive but well-known statistical properties [8]. As shown in Figs. 3 and 4 DARe enables coarsening of the computational mesh, with computation savings tending linearly with number $L$ of elements.

### 2.2 Compatibility based exact semi-discrete local conservation properties for continuous SEM

SEM uses a global weak formulation; therefore for several equation types (Burgers, shallow water, Navier-Stokes etc.) exact semi-discrete mass and energy conservation can be obtained, including when one writes

*fournier@ucar.edu, http://www.image.ucar.edu/~fournier/

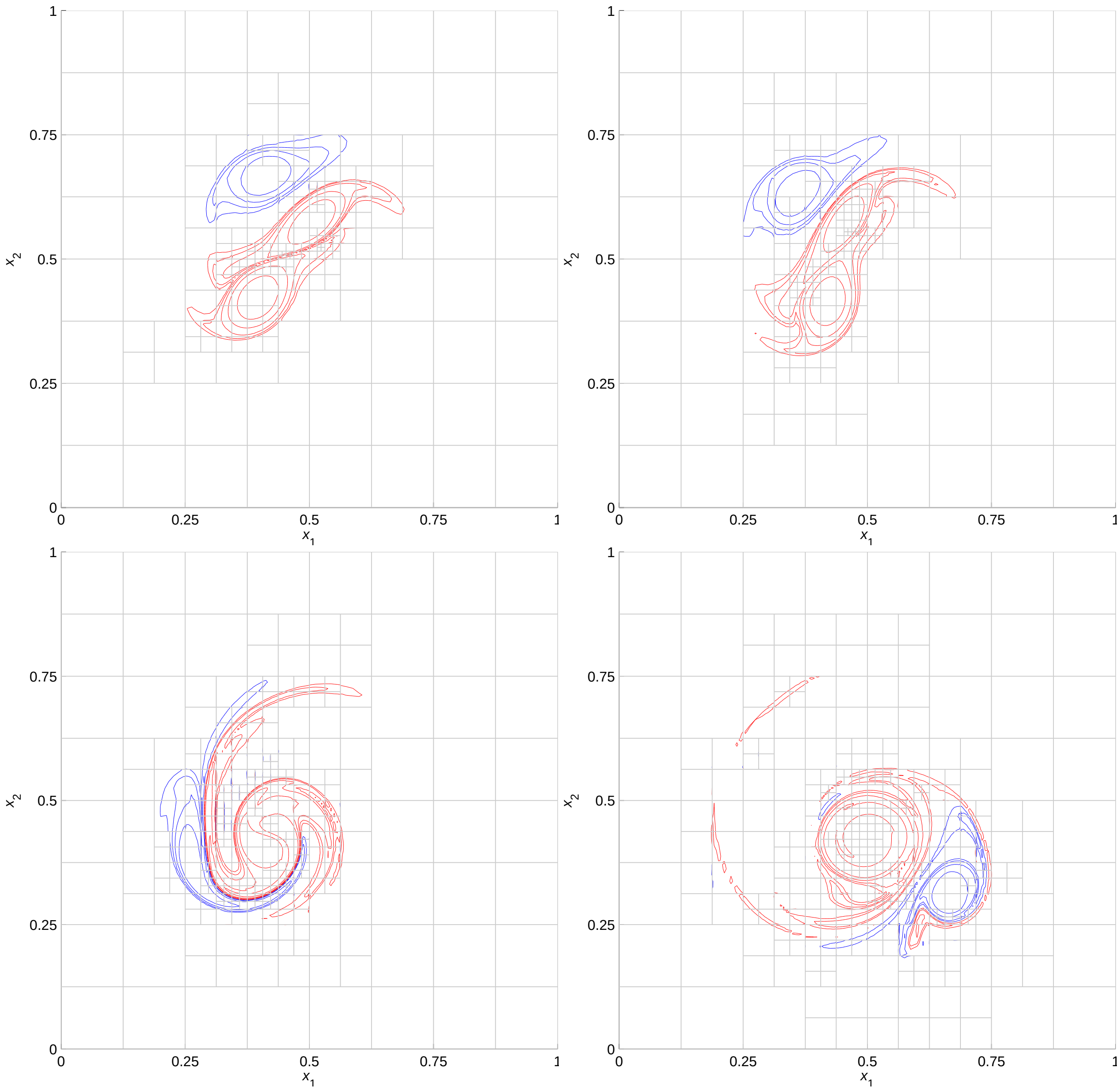



Figure 1: Vorticity $\zeta\,[t,\vec{x}]$ (contours $\log_2(\pm\zeta/\pi) = 0,\ldots 4$): (a) $L = 226$ elements, time $t = 1.82t_{\text{eddy}}$; (b) $L = 256$, $t = 2.25t_{\text{eddy}}$; (c) $L = 331$, $t = 3.96t_{\text{eddy}}$; (d) $L = 409$, $t = 8.25t_{\text{eddy}}$.

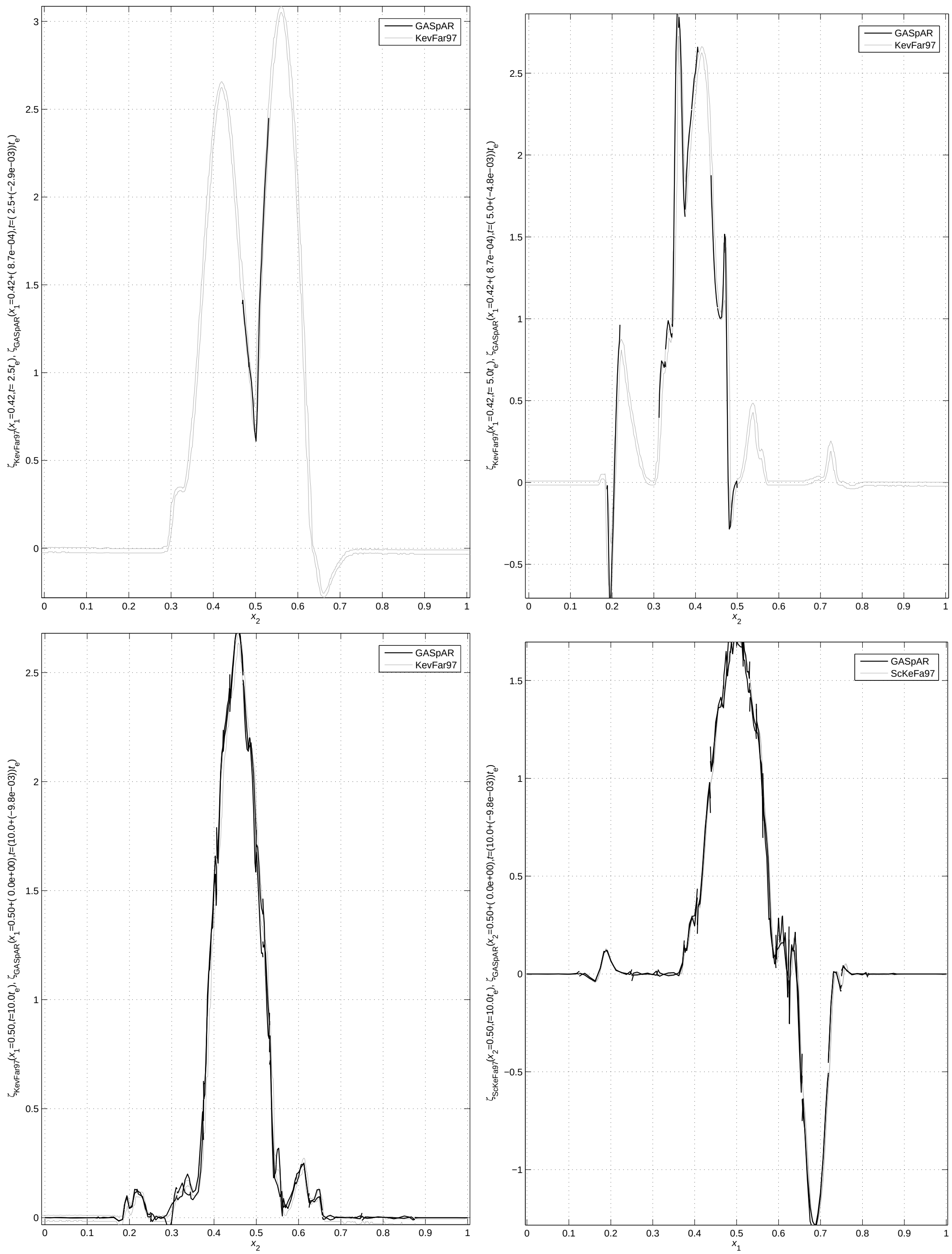



Figure 2: Comparison of GASpAR (black curves, $N_\mathrm{r} \leq 4$ levels of binary-subdivision refinement, $N = 8$ polynomials per element per dimension, viscosity $\nu = 5 \times 10^{-5}/4\pi^2$) and pseudo-spectral (gray curves) 3-vortex simulations, slice snapshots of vorticity $\zeta$: (a) $|t - 2.5t_\mathrm{eddy}| < 3 \times 10^{-3}$, $|x^1 - 0.42| < 9 \times 10^{-4}$ [7]; (b) $|t - 5t_\mathrm{eddy}| < 5 \times 10^{-3}$, $|x^1 - 0.42| < 9 \times 10^{-4}$ [7]; (c) $|t - 10t_\mathrm{eddy}| < 10^{-2}$, $x^1 = \frac{1}{2}$ [7]; (d) $|t - 10t_\mathrm{eddy}| < 10^{-2}$, $x^2 = \frac{1}{2}$ [11].

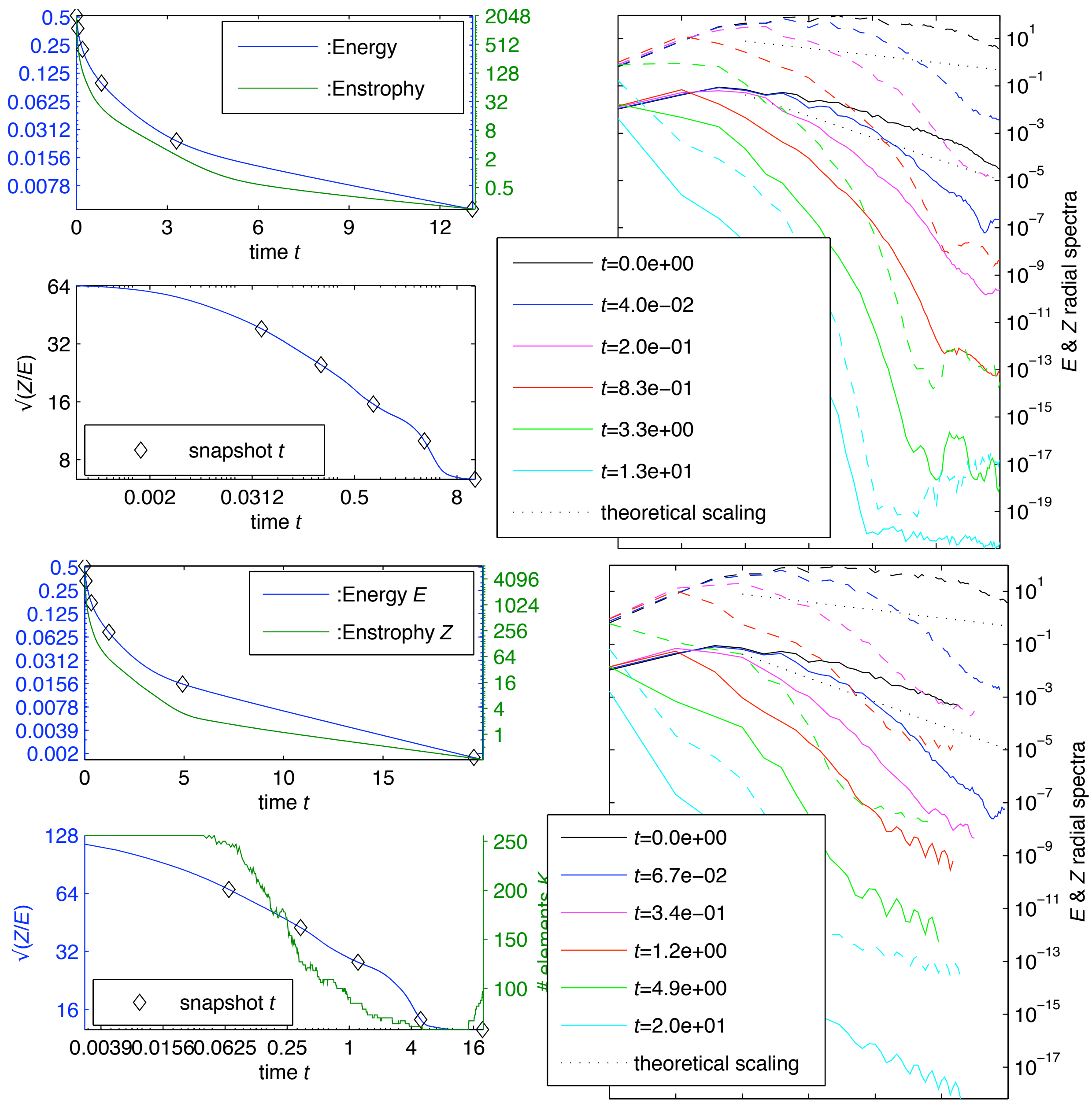



Figure 3: Comparison of GASpAR simulations with $N = 8$, $R = 561$ and (a-c) $N_\mathrm{r} = 0$, $L = 16^2$, (d-f) $N_\mathrm{r} = 3$. Times in (c,f) correspond to markers in (a,b) and (d,e), respectively. Note that the energy and enstrophy norms (a-b,d-e) and spectra (c,f) are similar even though far fewer elements are used when $N_\mathrm{r} = 3$ (e).

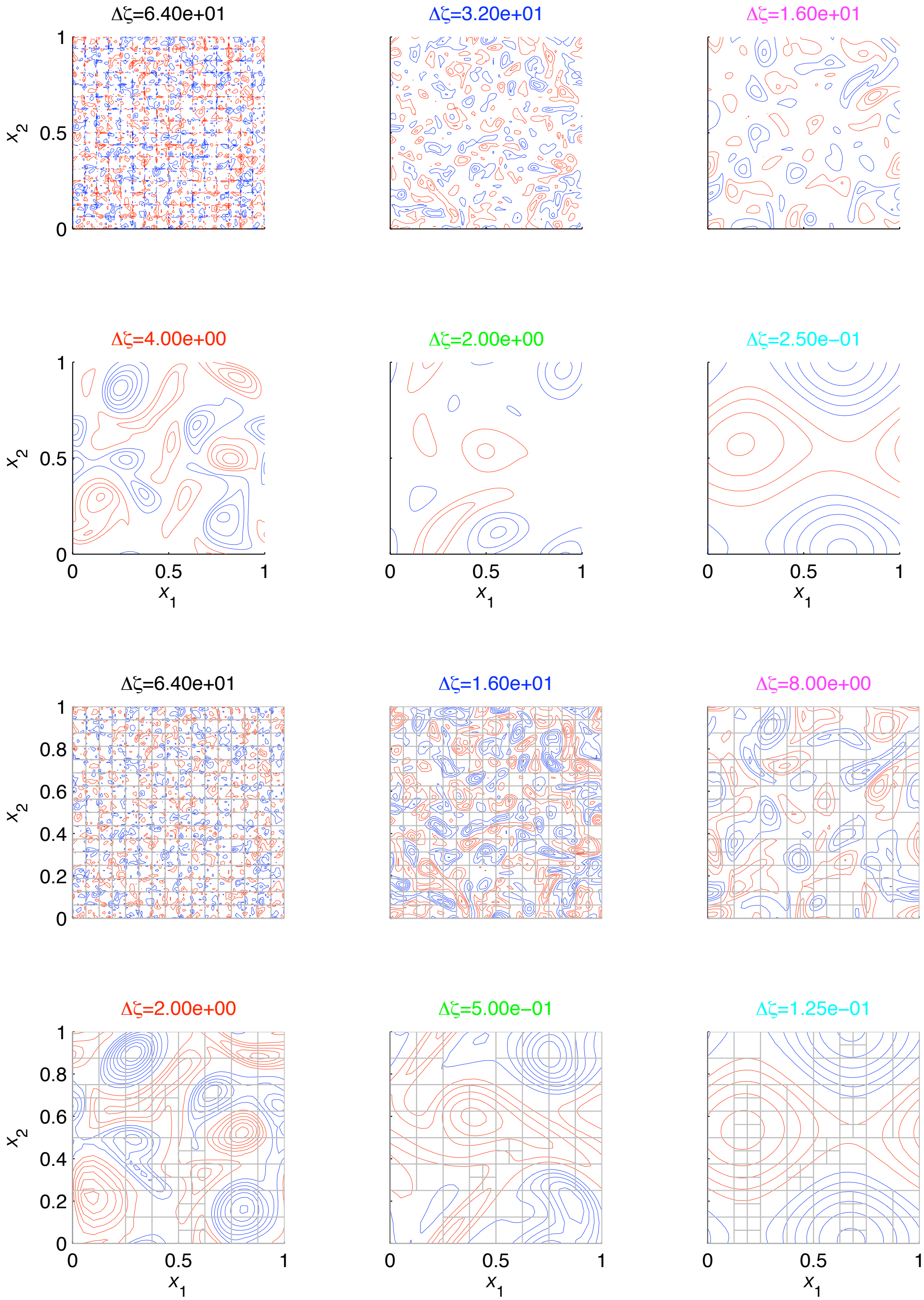



Figure 4: Comparison of GASpAR simulations with $N = 8$, $R = 561$ and (a-f) $N_{\mathrm{r}} = 0$, $L = 16^2$, (g-l) $N_{\mathrm{r}} = 3$. Times in (a-f) and (g-l) correspond to Fig. 3(a) and (d) markers, respectively, and contour intervals $\Delta\zeta$ are indicated. In (g-l) the gray lines show the element boundaries.

the equations in primitive instead of conservation form [12, 13]. For cubic quantities such as shallow-water energy, conservation is semi-discrete, meaning exact assuming exact time integration. For linear and quadratic invariants such as mass and kinetic energy, the discrete approximation to the conserved quantity is conserved exactly. Furthermore, the conservation is local, meaning that one can show that the change in the conserved quantity in an element is given by the sum of the fluxes around the perimeter of the element. This conservation is a consequence of the fact that, even on non-orthogonal unstructured meshes, the discrete divergence operator is the adjoint of the discrete gradient operator. Global conservation is then a consequence of the fact that the flux terms between two adjacent elements exactly cancel. The advection scheme remains oscillatory, but the oscillations are localized and thus much reduced when compared to global spectral methods.

### 2.3 Static, conforming AMR in coupled global-regional climate modeling with SEAM

This author implemented terrain-following coordinates, outlined a particular approach to dynamics-physics coupling, and otherwise contributed to a long-term investigation currently summarized by Wang et al. [14]. With these and others' contributions, Dr Wang coupled SEAM with the CAM2 (Community Atmosphere Model version 2) physical parameterizations and CLM2 (Community Land Model version 2) in such a way that it can be used as an alternative dynamical core in CAM2.

## 3 2008 Plans

This author is on leave of absence for 12 months ending 2008 June, to be a supported Visiting Scientist at the U. Reading Meteorology Department, where at least two collaborative projects are underway:

- Analysis of multiscale dynamics in the UK Met Office data-assimilation system and proposal for multiresolution approaches to improving it;
- Analysis of conforming AMR methods that improve unstructured finite-volume simulation of shallow-water and similar flows in spherical and more general geometries [15], and comparison of these with other local resolution-enhancing strategies.

Other projects currently underway include completing writing up the results described in §2 (at least two articles) and the MASUSE methods [2]. This author independently developed and will write up an application exploiting SEM-based explicit Fourier-series coefficients [1] to decompose the Poisson problem, as independently found by Iskandarani [6].

### References


[1] A. Fournier, 2006: "Exact calculation of Fourier series in nonconforming spectral-element methods", *J. Comp. Phys.* **215**, 1–5 (`http://dx.doi.org/10.1016/j.jcp.2005.11.023`).

[2] A. Fournier, 2006: "Multiresolution analysis & simulation using spectral elements (MASUSE)", *NCAR/CISL Annual Report*, http://www.cisl.ucar.edu/nar/2006/catalog/Fournier1.pdf.

[3] A. Fournier, 2007: "Examples of multiscale and multiresolution simulation", UK Natural Environment Research Council *Scoping Meeting on Earth System Model Software Development for Exploiting Future Computing Architectures*, London.

[4] A. Fournier, D. Rosenberg & A. Pouquet, 2007: "Dynamically adaptive high-order simulation of decaying 2D Navier-Stokes flow", *SIAM Conference on Mathematical & computational issues in the geosciences*, Santa Fe, https://www.siam.org/meetings/gs07/GS07abstracts.pdf.

[5] A. Fournier, D. Rosenberg & A. Pouquet, 2007: "Spatially localized global Fourier analysis of 2D 3-vortex dynamics at $\mathrm{Re} = 2 \times 10^4$ simulated by dynamically adaptive spectral elements", *Vortex dynamics from quantum to geophysical scales*, EUROMECH Colloquium 491, Exeter, http://www.secamlocal.ex.ac.uk/people/staff/adgilber/euro/talks.htm.

[6] M. Iskandarani, 2007: "Comparison of iterative method for the solution of elliptic equations in ocean models", *Sixth International Workshop on Unstructured Mesh Numerical Modelling of Coastal, Shelf & Ocean Flows*, London, http://amcg.ese.ic.ac.uk/images/f/fe/WorkshopAbstracts.pdf.

[7] N.K.-R. Kevlahan & M. Farge, 1997: "Vorticity filaments in two-dimensional turbulence: creation, stability and effect", *J. Fluid Mech.* **346**, 49–76.

[8] Matthaeus, Stribling, Martinez, Oughton & Montgomery, 1991.

[9] D. Rosenberg, 2006: "GASpAR Development", *NCAR/CISL Annual Report,* http://www.cisl.ucar.edu/nar/2006/catalog/Rosenberg1.pdf.

[10] D. Rosenberg, A. Fournier, P. Fischer & A. Pouquet, 2006: "Geophysical-astrophysical spectral-element adaptive refinement (GASpAR): Object-oriented $h$-adaptive fluid dynamics simulation", *J. Comp. Phys.* **215**, 59–80, http://dx.doi.org/10.1016/j.jcp.2005.10.031.

[11] K. Schneider, N.K.-R. Kevlahan & M. Farge, 1997: "Comparison of an adaptive wavelet method and nonlinearly filtered pseudospectral methods for two-dimensional turbulence", *Theor. Comp. Fluid Dynamics* **9**, 191–206.

[12] M.A. Taylor & A. Fournier, 2007: "Local mass and energy conservation in spectral-element discretizations of the sphere (& torus)", *Sixth International Workshop on Unstructured Mesh Numerical Modelling of Coastal, Shelf & Ocean Flows*, London, http://amcg.ese.ic.ac.uk/images/f/fe/WorkshopAbstracts.pdf.

[13] M.A. Taylor & A. Fournier, 2007: "Local mass and energy conservation in spectral-element discretizations of the sphere (& torus)", *International Workshop on Solution of Partial Differential Equations on the Sphere*, Exeter, http://www.metoffice.gov.uk/conference/pdes2007/pdes_2007_programme.pdf.

[14] H. Wang, J.J. Tribbia, F. Baer, A. Fournier & M.A. Taylor, 2007: "A spectral element version of CAM2", *Mon. Wea. Rev.* **in press.**

**[15] H. Weller & H.G. Weller, 2007: "A high-order arbitrarily unstructured finite-volume model of the global atmosphere: tests solving the shallow-water equations", *Int. J. Numer. Meth. Fluids*, to appear.**

# Regularization modeling of turbulent flows

Jonathan Pietarila Graham

September 13, 2007

*Turbulence Numerics Team – 2007 NAR*

*in collaboration with P. Mininni and A. Pouquet (NCAR) and Darryl Holm (Imperial College)*

**Sponsored by NSF (NCAR's Programs and CMG grant 0327888)**

## 1 Historical and scientific context

As the implementation of numerical modeling of geophysical and astrophysical flows exceeds technological limits and since truncation of the omitted scales removes important physics, e.g., of multi-scale interactions, a closure (e.g., subgrid(subfilter)-scale (SGS) modeling) is required. Two main approaches have been developed over the years to model the effects of the unresolvable small scales on the scales resolved in numerical simulations. The first approach is Large Eddy Simulations (LES). LES is widely used, however, in this approach, the Reynolds number ($Re$), a measure of nonlinearity, is not known. Instead, one attempts modeling the behavior of the flow in the limit of very large $Re$. As Kolmogorov's assumption of the self-similarity of turbulence is known to be wrong, the magnitude of $Re$ can be important. Consequently, the other main approach models the effects of turbulence at higher Reynolds numbers than are possible with a direct numerical simulation (DNS) on a given grid, by filtering of the small scales.

A rather novel approach to modeling of turbulent flows employs *regularization modeling* as a SGS model. A SGS regularization model is a modification of the nonlinear term(s) of the fluid flow equations in such a way that the new equations can be proven to have unique, smooth (regular) solutions. This ensures the computability of solutions. In the limit of the model's parameter vanishing, the physical equations are recovered. Furthermore, as only the spectral distribution of energy (not the dissipative processes as in many LES) is modified, a well-defined $Re$ is retained.

Three regularizations can be viewed as SGS models with successively more complex subgrid-stress terms: the Clark$-\alpha$ model, the Leray$-\alpha$ model, and the Lagrangian-averaged Navier-Stokes (LANS$-\alpha$) model. Clark$-\alpha$ is associated with the first term of a Taylor expansion of the subfilter-scale stress. Leray$-\alpha$ and LANS$-\alpha$ represent advection by a smoothed velocity in an Eulerian and a Lagrangian sense, respectively. These regularizations are studied both for their sub-filter scale properties (which, by contrasting with the properties of Navier-Stokes, may lead to a better understanding of turbulence) and for their potential as SGS models. What computational savings are achievable? How do the scalings (energy spectra, intermittency properties, etc.) of the models at subfilter scales differ from Navier-Stokes? As the subfilter-scale energy spectra determine the resolution requirements, these two questions are interrelated.

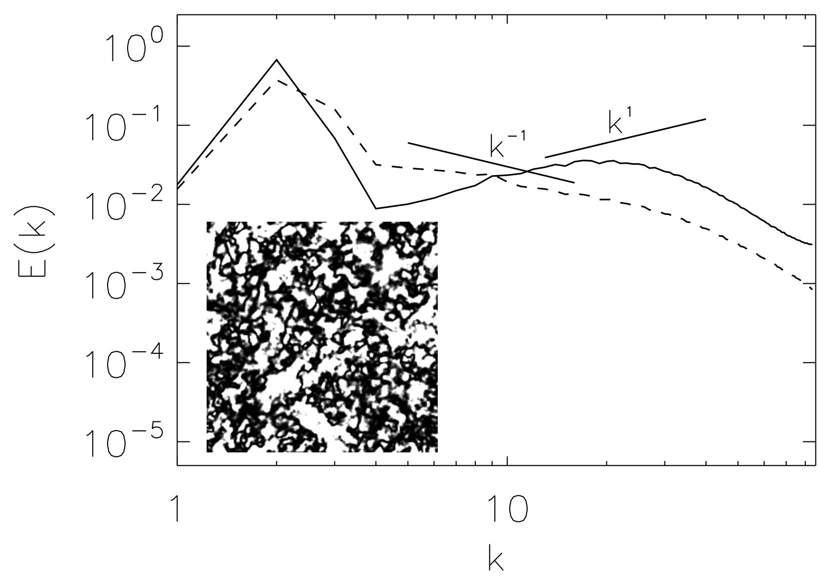



Figure 1: Subfilter-scale spectral energy density, $E(k)$, versus wavenumber, $k$, for LANS$-\alpha$: solid line for the entire flow and dashed line for the flow excluding "rigid bodies" (inset shows 2D slice where many "rigid bodies" are depicted by black pixels). This provides evidence that the flow spatially between the "rigid bodies" (for which $E(k) \sim k^1$) possesses the theoretically predicted $k^{-1}$ energy spectrum. From this result we are able to determine how to apply other theoretical predictions (such as the computational savings achievable) for the LANS$-\alpha$ model.

## 2 How this work supports NCAR strategic priorities

Modeling of unresolved small scales is of importance for geophysical, astrophysical and (aeronautical) engineering applications and can have consequences for meteorological and climate prediction simulations, for instance. While realistic Reynolds numbers will remain out of reach for the foreseeable future, SGS modeling can be an extremely useful tool in the computation of simulations for such applications.

## 3 2007 accomplishments

For LANS$-\alpha$, the predicted subfilter-scale spectrum is $E(k) \sim k^{-1}$ and is important, e.g., to predict the computational savings achievable employing LANS$-\alpha$ as a SGS model. We find this scaling to be subdominant to an energy spectrum $E(k) \sim k^1$ which corresponds to "enslaved rigid body" or "polymerized" portions of the fluid (see Fig. 1) (1). By "rigid bodies," we mean the internal degrees of freedom are frozen and these portions give no contribution to the energy cascade. The sub-filter scaling observed in the third-order structure function corresponded to the predicted $E(k) \sim k^{-1}$ scaling of the energy spectrum. However, regions are observed in the flow where no stretching is acting in the sub-filter scales (see Fig. 1 inset). These regions, which give no contribution to the energy cascade, and hence do not affect the third order structure functions, are responsible for the $E(k) \sim k^{1}$ scaling in the LANS$-\alpha$ energy spectrum. When they are excluded from the energy spectrum calculation, $E(k) \sim k^{-1}$ is recovered (see Fig. 1). From the known energy cascade, prediction of the linear resolution requirement, $N_\alpha$, follows: $N_\alpha^3 < \mathcal{C}\alpha^{-1}Re^{3/2}$ where $\alpha$ is the filter width. We confirm this prediction, the great utility of which is that the single constant, $\mathcal{C}$, can cheaply be determined at low and moderate $Re$ and predicts the resolution requirement for the highest Reynolds numbers attainable. As energy artificially accumulates in the subfilter scales ($E(k) \sim k^1$), for LANS$-\alpha$ viewed as an LES to reproduce the Navier-Stokes energy spectrum it is necessary that $\alpha$ be not much larger than the dissipation scale, $\eta_K$ ($\alpha \gtrapprox 4\eta_K$). As a consequence, the computational savings of LANS$-\alpha$ (a factor of 27 for our case) is fixed and not a function of $Re$.

We derive the Kármán-Howarth equation for both the Clark$-\alpha$ and Leray$-\alpha$ models (rigorous scaling laws in the inertial range can be deduced from these) (2). We confirm one of two possible scalings resulting from this equation for Clark$-\alpha$ as well as its associated $\sim k^{-1}$ energy spectrum. For small values of $\alpha$, Clark$-\alpha$ reproduces the superfilter-scale energy spectrum and intermittency properties of the DNS. As $\alpha$ is increased, Clark$-\alpha$ exhibits increased subfilter-scale intermittency. We find for the Leray$-\alpha$ model, that increasing $\alpha$ decreases the nonlinearity and, hence, the effective Reynolds number is substantially decreased. Therefore even for the smallest value of $\alpha$ studied Leray$-\alpha$ was inadequate as a SGS model. The LANS$-\alpha$ energy spectrum $\sim k^1$, consistent with its "rigid bodies," precludes a reproduction of the energy spectrum of the DNS. We find, however, that this same feature reduces its intermittency compared to Clark$-\alpha$ (which shares a similar Kármán-Howarth equation). Clark$-\alpha$ is found to be the best approximation for reproducing the total dissipation rate (including subfilter scales) and the superfilter-scale energy spectrum, whereas high-order intermittency properties for larger values of $\alpha$ are best reproduced by LANS$-\alpha$ (see Fig 2). Our study indicates that Clark$-\alpha$ may be applicable (especially with regards to the energy spectrum) for larger values of $\alpha$ than LANS$-\alpha$. In fact, if its optimal value is not a function of $Re$, the computational resolution savings would increase as $Re^{3/4}$ for Clark$-\alpha$. This is a topic for future study.

## 4 2008 plans

Future work should address whether in the case of magneto-hydrodynamics the artificial accumulation of energy at subfilter scales is reduced because of the presence of greater spectral nonlocality.

**(a)** **(b)**

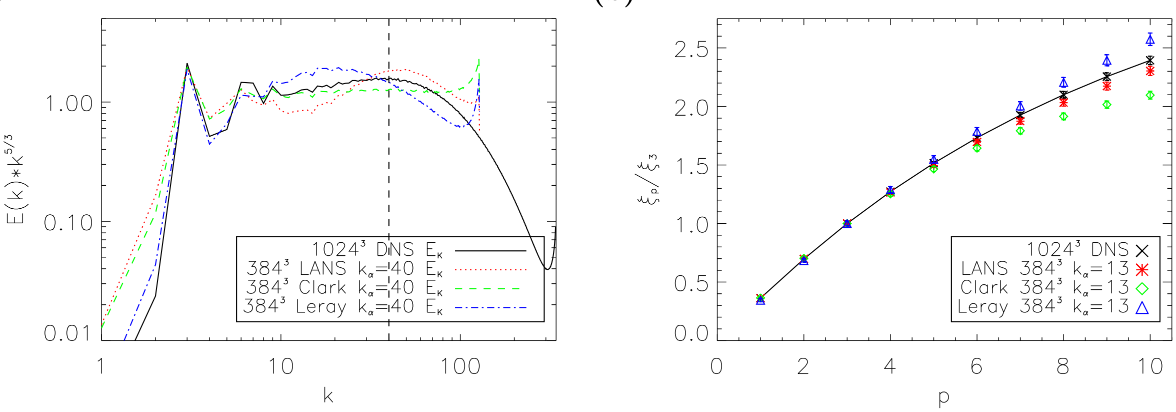



Figure 2: (a) Compensated energy spectrum for a DNS of Navier-Stokes and for regularizations employed as SGS models. Clark$-\alpha$ demonstrates the best prediction for the superfilter-scale energy spectrum (left of vertical dashed line). (b) Normalized structure function scaling exponent $\xi_p/\xi_3$ versus order $p$. Clark$-\alpha$ is more intermittent than Navier-Stokes at subfilter scales while LANS$-\alpha$ demonstrates the best prediction of subfilter-scale high-order intermittency properties. Clark$-\alpha$ is found to be the best approximation for reproducing the total dissipation rate (including subfilter scales) and the superfilter-scale energy spectrum, whereas high-order intermittency properties for larger values of $\alpha$ are best reproduced by LANS$-\alpha$.

The effect of LANS$-\alpha$ on the detailed scale-by-scale energy transfer should also be investigated as our results indicate that a model for local small-scale interactions would improve the $\alpha-$model.

**References**

[1] Jonathan Pietarila Graham, Darryl Holm , Pablo Mininni and Annick Pouquet, "Highly turbulent solutions of LANS-$\alpha$ and their LES potential," submitted to *Phys. Rev. E*; arXiv:0704.1928 (2007).

[2] Jonathan Pietarila Graham, Darryl Holm , Pablo Mininni and Annick Pouquet, "Comparison of three regularization models of the Navier-Stokes equations when viewed as large-eddy simulations," submitted to *Phys. Fluids*; arXiv:0709.0208 (2007).

# ENERGY TRANSFER IN HYDRODYNAMICS AND MAGNETOHYDRODYNAMICS

Pablo Mininni

September 26, 2007

*Turbulence Numerics Team – 2007 NAR*

*Alexandros Alexakis (Nice) and Annick Pouquet (NCAR)*

**Sponsored by NSF through NCAR and through CMG grant 0327888**

Turbulence prevails in the universe, and its multi-scale properties affect the global dynamics of geophysical and astrophysical flows at large scale, e.g. through a non-zero energy dissipation even at very high Reynolds number $R_e$. Furthermore, small-scale strong intermittent events, such as the emergence of tornadoes and hurricanes in atmospheric flows, may be very disruptive to the global dynamics and to the structure of turbulent flows.

Typically energy is supplied to the flows in the large scales, e.g., by a large scale instability. The flow at these scales is inhomogeneous and anisotropic. In the standard picture of turbulence, the interactions of eddies of similar size play the basic role of transferring the energy to smaller scales. The energy then "cascades" to smaller scales. It is then believed that at sufficiently small scales the statistics of the flow are independent of the exact forcing mechanism, and as a result, its properties are universal.

The role of the large scale flow in this scenario is limited to just advecting the small size eddies without significantly distorting them. However, deviations to this picture are known to exist in turbulent flows. The nature of the interactions between different scales in hydrodynamic and magnetohydrodynamic (MHD) turbulence is important for the understanding of the behavior of atmospheric and oceanic flows, and of magnetized astrophysical and geophysical flows in a turbulent state.

**Neutral fluids**

It has been shown, however, even for simple hydrodynamic flows [1] that the large scale flow still plays an important role in the transfer of energy and in the formation of structures in the small scales. In numerical simulations of hydrodynamic flows with Reynolds numbers as high as $R_\lambda \sim 800$, it was observed that 20% of the energy flux in the small scales is due to interactions with the large scale flow. This represents a deviation from self-similarity, and the presence of non-local interactions can be associated with clustering of vortex tubes in regions of intense large

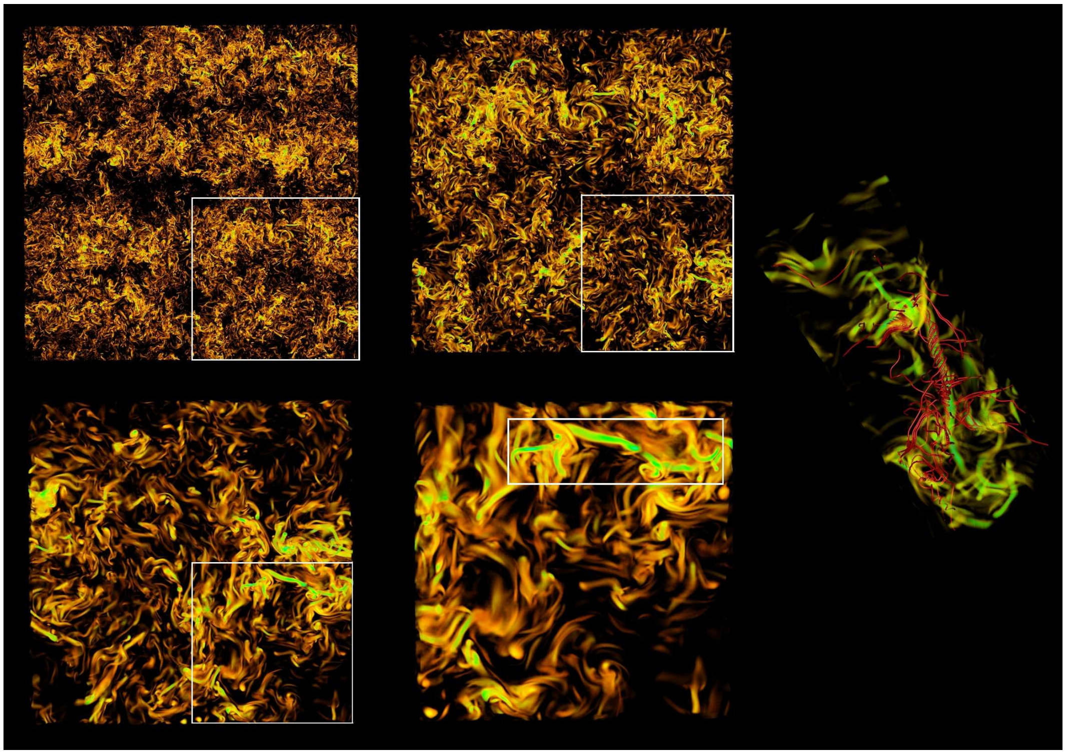


Figure 1: 3D rendering of regions of strong vorticity in a $2048^3$ hydrodynamic simulation. From left to right and top to bottom, succesive zooms into the structures are shown. Note the small scale vortex filaments, and the development of clusters of vortex tubes at intemediate scales. Velocity field lines are shown in red as a reference in the last zoom (right).

scale shear [1], the presence of long-time correlations in the small scales (compared with the eddy turnover time), slower than expected recovery of isotropy, and intermittency (which in turn implies corrections to the energy spectrum).

Recently [2], we performed a hydrodynamic simulation on a grid of $2048^3$ regularly spaced points, with a Taylor Reynolds number of $R_\lambda \sim 1300$ (Fig. ). At this Reynolds number the anisotropic large scale flow pattern, the inertial range, the bottleneck, and the dissipative range are clearly visible, thus providing a good test case for the study of turbulence as it appears in nature. A comparison with runs at lower Reynolds numbers was performed, and showed the emergence of scaling laws for the relative amplitude of local and non-local interactions in spectral space.

The data allowed for a refined analysis of the behavior and structure of turbulent flows as the Reynolds number is increased. We have in particular showed that: (i) the bottleneck (the pile up of energy close to the dissipation scale) is linked to the depletion of nonlinearities as we approach this scale; and (ii) convergence to the asymptotic turbulence regime appears to be very slow: even though the nonlocal interactions do diminish with Reynolds number, they are still measurable at

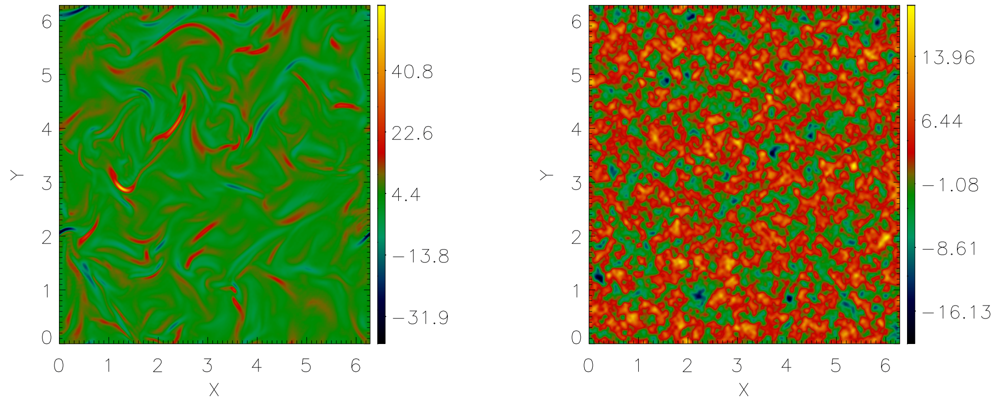



Figure 2: Cross section showing the $z$-component of the current density on the $x$-$y$ plane in an MHD simulation before (left) and after randomizing phases (right). Thin filaments in the cross section, associated to current sheets in the 3D flow, have disappeared in the right panel. While the flow on the left has non-local transfer of energy, the energy transfer in the flow on the right is local.

the largest resolutions we can afford currently. Given the amount of data available after performing these runs, we plan detailed studies of scaling laws using these datasets. We also plan extensions of this study to the case of rotating and stratified flows.

**Conducting fluids**

In MHD flows, the role of the large scale flow and large scale magnetic structures is expected to be even more important since the effect of a large scale magnetic field cannot be removed by a Galilean transformation. As a result, small scales can interact directly with the large scales and we cannot *a priori* follow the same arguments Kolmogorov used in hydrodynamic turbulence. Assumptions of locality of interactions are in question. Accordingly, some phenomenological models try to take into account the effect of non-local interactions, or to consider the anisotropy due to the large scale magnetic field.

Previous results [3] have shown that the locality of energy transfer is indeed in question in MHD flows. In particular, it was demonstrated from simulations that the transfer of energy in MHD has two components: a local one that shares similar properties with hydrodynamic turbulence, and a non-local component for which energy from the large scales is injected directly into the small scales without the intervention of the intermediate scales.

Recently, we extended our previous results to show that the non-local behavior of the energy transfer in MHD is the result of a correlation between the velocity and magnetic fields [4]. This non-locality disappears if we randomize the phases of the two fields (Fig. ). The cascade of magnetic helicity was also investigated, with special focus on the fate of the small scale helicity and its coupling with the large scale flow. The results obtained have implications for dynamo action, in particular for the commonly used distinction between large- and small-scale dynamos.

The study suggests that there are much stronger interactions between widely separated scales in turbulent MHD flows than in hydrodynamic flows. These long range interactions also raise the question of the existence of universality in MHD, both in the dynamo regime as well as in the turbulent steady state.The evidence suggests that it is at least possible that all turbulent MHD flows do not behave in the same way and one run does not span all possible statistical MHD turbulent configurations. However, we believe that there are a finite number of parameters that control the behavior of the flow in the inertial range when kept fixed. Our next steps will try to unravel these behaviors, using high resolution numerical simulations of MHD flows.

**References**

[1] P.D. Mininni, A. Alexakis, and A. Pouquet, "Large scale flow effects, energy transfer, and selfsimilarity on turbulence," Phys. Rev. E **74**, 016303 (2006).

[2] P.D. Mininni, A. Alexakis, and A. Pouquet, "Non-local interactions in hydrodynamic turbulence at high Reynolds numbers: the slow emergence of scaling laws," submitted to Phys. Rev. E (e-print arXiv:0709.1939).

[3] A. Alexakis, P.D. Mininni, and A. Pouquet, "Shell to shell energy transfer in MHD. I. Steady state turbulence," Phys. Rev. E **72**, 046301 (2005).

[4] A. Alexakis, P.D. Mininni, and A. Pouquet, "Turbulent cascades, transfer, and scale interactions in magnetohydrodynamics," New J. Phys. **9**, 298 (2007).

# NEUTRAL AND CONDUCTING FLOWS INSIDE A ROTATING SPHERE

Pablo Mininni

September 26, 2007

*Turbulence Numerics Team – 2007 NAR*

*David Montgomery (Dartmouth), Annick Pouquet (NCAR) and Leaf Turner (Cornell)*

**Sponsored by NSF through NCAR and through CMG grant 0327888**

The subject of fluids in rotating and non-rotating spheres has many branches and applications. The rotating spherical container provides an excellent case study because waves can be determined analytically and verified in the simulations. It is also a convenient configuration for the study of geophysical flows. Experiments done in the past using non-conducting fluids in rotating spheres improved our understanding of atmospheric processes such as Rossby waves and Ekman pumping. Besides atmospheric applications, the generation of magnetic fields in planets through a dynamo mechanism is naturally studied in spherical geometry. Dynamo processes are those in which the motions of an electrically conducting fluid amplify and maintain a finite magnetic field, starting from an arbitrarily small one. They have long been of interest for geophysics and astrophysics, even more so recently because of laboratory attempts to generate magnetic fields in liquid metals.

In the last years, we have developed a computational method to study a neutral or electrically incompressible conducting fluid inside a rigid spherical boundary that isolates the fluid, mechanically and magnetically, from everything outside it [1]. The numerical technique is entirely spectral, using an expansion basis that is specifically adapted to spherical geometry: the Chandrasekhar-Kendall vector eigenfunctions of the curl. Since the hydrodynamic and magnetohydrodynamic (MHD) equations involve several solenoidal fields of which several curls are taken, no numerical spatial differentiations (with their attendant loss of accuracy) are required in this method. The method preserves a high order approximation for any order of the derivatives, and preserves the ideal invariants accurately over long times; it is also gridless (a grid is only used for visualization of the fields) and the resulting absence of any coordinate singularities (e.g., $r = 0$ in spherical polar coordinates) is a considerable advantage. The code has been parallelized using MPI and showed to scale in several clusters.

We recently extended this method to consider the effect of rotation [2]. Unsurprisingly, the dynamical phenomena resulting are markedly different from, and richer than, they were in the case without rotation. When neutral fluids are considered, well known effects such as Ekman pumping,

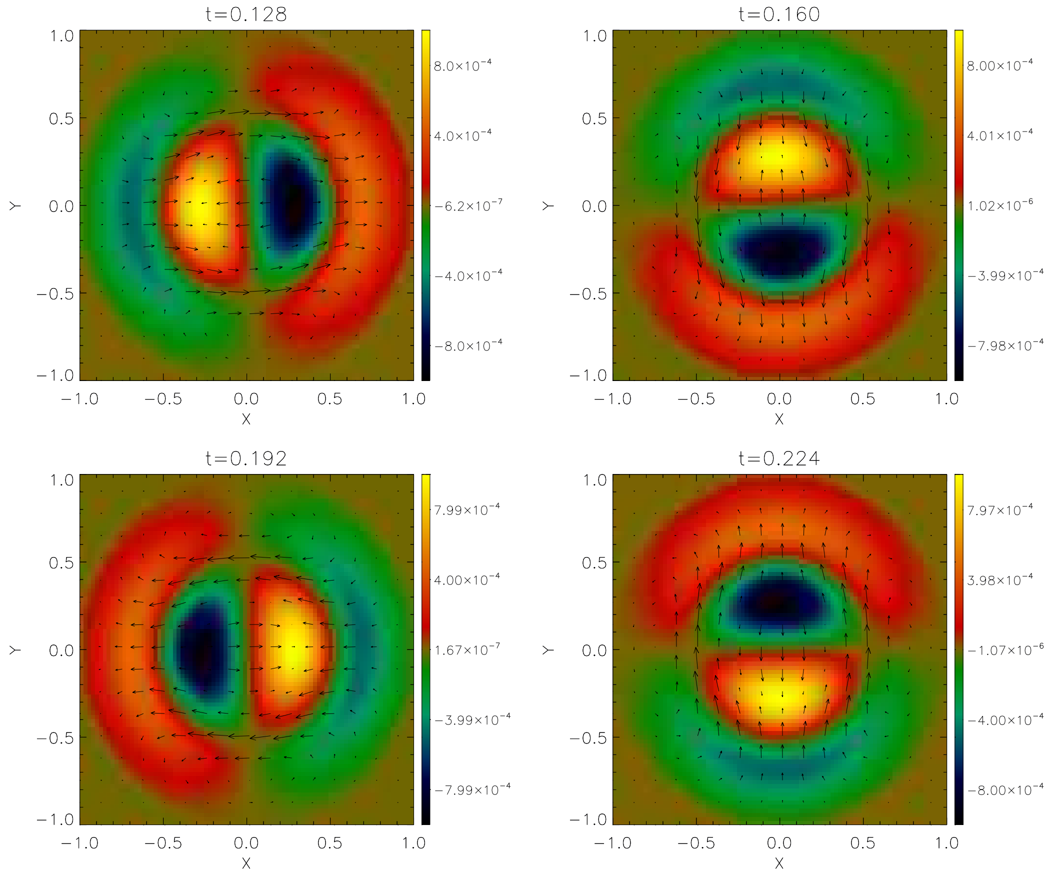



Figure 1: Equatorial cross section of the sphere, showing the velocity field for an inertial wave when the sphere rotates. The reference frame is fixed to the sphere, and the rotation is in the $z$ direction. The axial velocity is indicated by the colors, while the radial and azimuthal velocities are indicated by the arrows. The four panels show four different times, corresponding to a complete oscillation.

inertial waves, and spin-down in free decaying systems are observed. Predictions for the decay of the energy in freely decaying flows and its scaling with the Rossby number, as well as the evolution of inertial waves, were used to validate the code (see Figure ).

When studying conducting fluids, we also considered the effect of rotation in the mechanism of "selective decay". This is a self-organization process that has been thoroughly studied in periodic boundary conditions but not so far in spherical containers, or considering the effect of rotation. While in the absence of rotation the system evolves to a state dominated by magnetic energy with a well organized dipolar pattern, as rotation increases the selective decay process is arrested. Although the reasons for this change are not totally understood, it may be that the rotation results in sufficient two-dimensionalization of the flow, and then the inherently three dimensional nature of the selective decay is compromised.

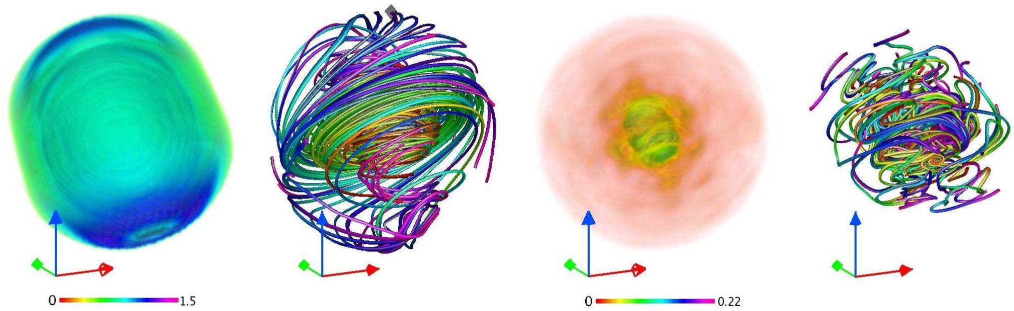



Figure 2: Kinetic energy density with velocity field lines (left), and magnetic energy with magnetic field lines (right) in a dynamo simulation with rotation. Note the development of a circulation in the velocity, and how magnetic structures are aligned with the axis of rotation.

Finally, dynamo runs have been done for different values of the Reynolds, Ekman, and Rossby numbers, to explore the effect of viscosity and of rotation in the generation of magnetic fields in turbulent rotating flows. This process is of interest for geophysical and astrophysical flows. We have found that a bewilderingly wide variety of dynamo behavior is possible. The behavior is sensitive to mechanical and magnetic Reynolds numbers, to rotation rate, and more indirectly to the Ekman number. It is also sensitive to the geometry and strength of the forcing functions and their relation to the axis of rotation. For rotation rates large enough, and viscosities small enough, the dipolar moment of the magnetic field tends to align with the axis of rotation, and has spontaneous reversals on a timescale much larger than the rotation or the eddy turnover timescales. Future investigations will explore in more detail the different regimes found in the space of parameters.

**References**

[1] P.D. Mininni and D.C. Montgomery, “Magnetohydrodynamic activity inside a sphere,” Phys. of Fluids **18**, 116602 (2007).

[2] P.D. Mininni, D.C. Montgomery, and L. Turner. “Hydrodynamic and magnetohydrodynamic computations inside a rotating sphere,” New J. Phys. **9**, 303 (2007).

# Breakthrough Simulations of MHD

Annick Pouquet and Pablo Mininni
September 30, 2007

**Introduction** Magnetic fields permeate the universe, and with the increased resolving capabilities of instruments, a flurry of details on highly complex flows emerge. The origin of such magnetic fields, the dynamo problem, is still not fully understood, in particular when the magnetic Prandtl number $P_M$ (the ratio of kinematic viscosity to magnetic diffusivity) differs substantially from unity [1], as it does in the interstellar medium ($P_M >> 1$) or in convective regions of stars and liquid cores of planets ($P_M << 1$). Assuming that a dynamo mechanism works, often leading to approximate equipartition of the magnetic and kinetic energies as observed for example in the solar wind, one can then ask questions about the nature of the nonlinear dynamics of such a flow. The complete problem (a dynamo taken all the way to the nonlinear stage at a high Reynolds number as encountered in nature, and for $P_M$ differing substantially from unity) is still out of reach, but it might be among the key outcomes in MHD of petascale computing facilities as well as of the experimental devices currently being developed.

**Set-up** One can specifically address the nature of the energy spectra that arise in such conditions. The three-dimensional equations for magnetohydrodynamics (MHD) are solved in a box of length $L_0 = 2\pi$ using periodic boundary conditions and a pseudo-spectral method, dealiased by the standard 2/3 rule with **a grid of $\mathbf{N = 1536^3}$ points**. At all times the dissipation wavenumber is resolved. No forcing term is present (the flow is simply decaying) and no uniform magnetic field is imposed. The initial conditions for the velocity and magnetic fields are constructed from a superposition of three Beltrami (helical) ABC flows to which smaller-scale random fluctuations are added with initial kinetic and magnetic energy $E_V = E_M = 0.5$, magnetic helicity$< \mathbf{A} \cdot \mathbf{b} > \sim 0.45$ (with $\mathbf{b} = \nabla \times \mathbf{A}$ where $\mathbf{A}$ is the vector potential, and the brackets denote volume average); finally the correlation between the velocity and the magnetic field is weak ($\cos(\mathbf{v}, \mathbf{b}) \sim 10^{-4}$). The computation is stopped when the growth of the total dissipation saturates (at $t \sim 3.7$); at that time, the Reynolds number based on the mechanical integral scale is $\sim 9200$, and that based on the magnetic Taylor scale is $\sim 1700$.

**Main results** Last year the focus was on the early-time dynamics, both temporal and spatial, of current and vorticity sheets, the run reaching the time of saturation of the growth of the maximum current. Current and vorticity sheets were found to roll-up, fold and pile up and the growth of the maximum current and vorticity was algebraic, after an initial exponential phase.

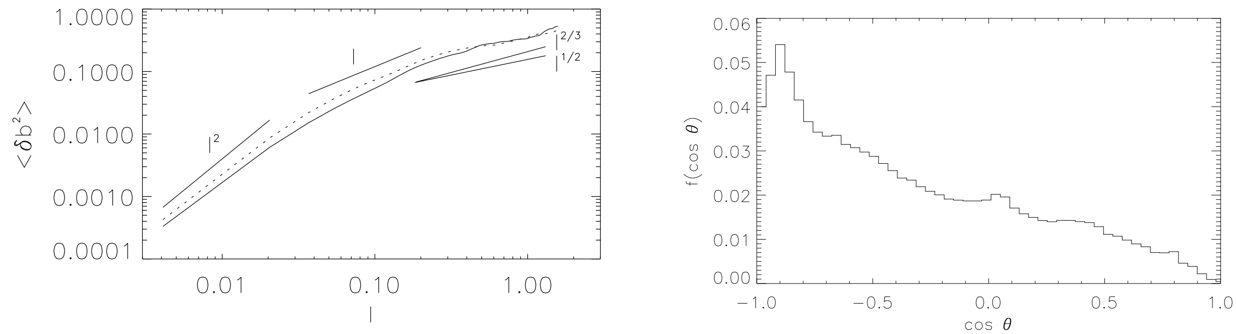



Figure 1: *Left*: Second-order structure function of the magnetic field for the perpendicular (solid) and parallel (dotted line) components. Note that large scale isotropy is broken at small scale. *Right*: Histogram of the velocity-magnetic field angle in a strong current sheet. Both plots are for the decaying MHD run with $1536^3$ grid points.

This year the run was pursued until the maximum of dissipation was reached, and an examination of scaling laws was performed. **The resulting total energy spectrum $\mathbf{E_T(k)}$ is a combination of two components, each moderately resolved. Such an energy spectrum with two different small-scale inertial ranges in MHD (excluding Hall currents) is a novel feature never observed before. It corresponds to the interplay between Alfvén waves and turbulent eddies and it may be interpreted as a partial breakdown of universality in MHD [5,4,3,2]**. This point clearly needs further study: a parametric evaluation of the problem is in order, perhaps using new methods allowing for reaching higher Reynolds numbers numerically. The main findings are now listed below.

- The total energy spectrum at large scale is isotropic and follows the Iroshnikov-Kraichnan (IK) theory $E_T(k) \sim k^{-3/2}$ stemming from the weakening of nonlinear interactions due to Alfvén waves [5]. At small scales, weak turbulence (WT) emerges with $E_T(k_\perp, k_\parallel) \sim k_\perp^{-2}$, the perpendicular and parallel directions referring to the local quasi-uniform magnetic field. This spectrum agrees with the statistical theory developed in 2000 using resonant wave interactions. Figure 1 (left) gives the second-order structure function of the magnetic field $S_{2,b}(\ell)$ displaying three ranges: IK compatible at large scale, WT compatible at intermediate scale and at the smallest scales, the flow is regular with $S_{2,b}(\ell) \sim \ell^2$. Note that WT gives rise to equations allowing for a computation of anisotropic transport coefficients, likely to be useful in modeling turbulent flows in MHD as they occur in the solar environment and the magnetosphere [5].

- Local directional alignment of the velocity and magnetic field occurs rapidly in MHD for a variety of parameters [3]. This is observed both in direct numerical simulations in two and three space dimensions (see Fig. 1, right), as well as in solar wind data. This phenomenon is due to an alignment between the magnetic field and either pressure gradients or shear-associated kinetic energy gradients; as such gradients develop naturally in a turbulent flow, such alignment is observed numerous times. Note that a similar alignment, of velocity and vorticity, occurs in the Navier-Stokes fluid case. This leads to a local weakening in turbulent flows of the nonlinear terms in the small scale vorticity and current structures where alignment occurs.

- The anomalous exponents of structure functions are found to be different from those for fluids, consistent with Iroshnikov-Kraichnan dynamics, with more intermittency in MHD [5], as was found in the 2D case.
- The energy dissipation as a function of Reynolds number is found to be constant, like in the three-dimensional hydrodynamical case and like MHD in two dimensions [5,4,2].

**The NSF-CMG grant 0327888 is acknowledged for supporting this work. Computer time was provided by the NCAR BTS program.**

-5. P.D. Mininni and A. Pouquet, "Energy spectra stemming from interactions of Alfvén waves and turbulent eddies," to appear, *Phys. Rev. Lett.* (2007); see also arXiv:0707.3620.

-4. A. Pouquet, A. Alexakis, P.D. Mininni and D. Montgomery, "Dynamics of the Small Scales in Magnetohydrodynamic Turbulence," IUTAM Symposium on Computational Physics and New Perspectives in Turbulence, Y. Kaneda Editor, Springer -Verlag, to appear, 297-304 (2008).

-3. W. H. Matthaeus, A. Pouquet, P. D. Mininni, P. Dmitruk, and B. Breech, "Rapid directional alignment of velocity and magnetic field in magnetohydrodynamic turbulence," to appear, *Phys. Rev. Lett.*, see also arXiv.org/abs/0708.0801.

-2. A. Alexakis, P. Mininni, and A. Pouquet, "Turbulent cascades and structures in MHD," to appear, *New J. Phys.*, Special Issue on MHD (August 2007).

-1. Y. Ponty, P. Mininni, J-F. Pinton, H. Politano and A. Pouquet, " Dynamo action at low magnetic Prandtl numbers: mean flow *vs.* fully turbulent process," *New J. Phys.*, Special Issue on MHD (August 2007).

0. Abstracts/presentations at AGU and APS

# GASpAR Development

Duane Rosenberg

September 30, 2007

*Turbulence Numerics Team – 2007 NAR*

*in collaboration with Aime´ Fournier and Annick Pouquet (TNT) and Marc Brachet (CNRS) )*

**Sponsored by the NSF cooperative agreement through UCAR**

## 1 Historical and scientific context

Accurate and efficient simulation of strongly turbulent flows is a prevalent challenge in many atmospheric, oceanic, and astrophysical applications. New simulation codes are needed to investigate such flows in the parameter regimes that interest the geophysics communities. Turbulent flows are linked to many issues in the geosciences, for example, in meteorology, oceanography, climatology, ecology, solar-terrestrial interactions, and solar fusion, as well as dynamo effects, specifically, magnetic-field generation in cosmic bodies by turbulent motions. Nonlinearities prevail when the Reynolds number $\mathsf{Re}$ (the ratio of the nonlinear to diffusive terms in the Navier–Stokes equations) is large. The number of 3-dimensional degrees of freedom (d.o.f.) increases as $\mathsf{Re}^{9/4}$ as $\mathsf{Re} \to \infty$ in the Kolmogorov 1941 framework (7, §7.4) . For aeronautic flows often $\mathsf{Re} > 10^6$, but for geophysical flows often $\mathsf{Re} \gg 10^8$ (3; 11)

Computations of turbulent flows must contain enough scales to encompass the energy-containing and dissipative scale ranges *distinctly*. Uniform-grid convergence studies on 3D compressible-flow simulations show that in order to achieve the desired scale content, uniform grids must contain at least $2048^3$ cells (15). Today such computations can barely be accomplished. A pseudo-spectral Navier-Stokes code on a grid of $4096^3$ uniformly spaced points has been run on the Earth Simulator (8), but the Taylor Reynolds number ($\propto \sqrt{\mathsf{Re}}$) is still no more than $\approx 700$, very far from what is required for most geophysical flows. The *main goal of our efforts* is to ask, if the significant structures of the flow are indeed sparse, so that their dynamics can be followed accurately even if they are embedded in random noise, then does dynamic adaptivity offer a means for achieving otherwise unattainable large $\mathsf{Re}$ values.

Thus, we have undertaken a long-term development program to provide a dynamic geophysical and astrophysical spectral-element adaptive refinement (GASpAR) code for simulating and studying turbulent phenomena.

Several properties of spectral-element methods (SEMs, 1; 13) make them desirable for direct numerical simulation of geophysical turbulence. Perhaps most significant is the fact that SEMs performed at high polynomial degree are inherently minimally diffusive and dispersive. The extent of the spatial and temporal scales that characterize turbulence depends critically on $\mathsf{Re}$, so to draw conclusions we must be certain of this number in our computations. Thus, we cannot allow the numerical methods themselves to introduce diffusion. Also, because SEMs use finite elements, they can be used efficiently in high-resolution turbulence studies in domains with complicated boundaries. These qualities, together with their good scalability properties (e.g., 6), suggest spectral element methods to be a good basis for high-order adaptive modeling of turbulent flows.

## 2 How this work supports NCAR strategic priorities

This development work relates directly to at least two of NCAR's strategic priorities: (1) Conducting research in computer science, applied mathematics, statistics, and numerical methods; and (2) Developing and providing advanced services and tools. The connection to both priorities is quite clear, as we are indeed trying to establish the ability of these new high-order adaptive methods to model turbulence, and this has necessitated a good deal of innovation in applied mathematics and numerical methods. Furthermore, the code was released in December 2005, in direct support of priority (2), and, periodic updates are forthcoming. See `http://www.cisl.ucar.edu/nar/2006/4i.6.nt.jsp` and `http://www.cisl.ucar.edu/nar/2006/4i.5.ts.jsp` for additional details.

## 3 FY2007 accomplishments

FY2007 has seen that the plans outlined in the FY2006 Annual Report were largely met. We completed the development and testing of an explicit incompressible MHD solver. This solver uses the Elsasser (2) formulation of the MHD equations, and used a Runge-Kutta (RK) algorithm for time stepping. Each RK stage requires that the divergence constraints for velocity and magnetic field be maintained, necessitating linear solves for the pressure for each Elsasser equation. Our results (14) indicate the method compares extremely well with the pseudo–spectral method with regard to numerical accuracy, on a rather difficult problem in the literature. We also were able to demonstrate the effect of low order polynomials on sup-norm values, showing that local low order may prove detrimental in predicting important quantities in MHD flows such as magnetic reconnection rates, despite nominally high resolution of the simulation.

In addition, we made progress in applying this solver to another important problem related to coronal heating: the magnetic island instability. In this study we compare the results of the adaptive spectral element code with both a pseudo–spectral method, and with a low–order adaptive finite difference (FD) code. We see from the preliminary results that local low order behaves somewhat differently from the above sup-norm problem in that the most striking difficiency is its inability to maintain energy conservation to a sufficient level for long-time intergrations of the unstable flow. There are also significant discrepancies in the sup-norm diagnostics as well. The spectral element method, on the other hand, is shown to compare extremely well with the pseudo–spectral calculations.

In the FY2006 report we stated that *we may in FY2007 add to our PDE solver "toolbox" code* *to accommodate the compressible MHD equations, depending on the physics of the objects we want to model.* We have begun development of this solver, but have not yet begun to test it, as there are a number of numerical issues that must still be resolved.

We made a strategic decision not to implement the 'alpha'-model for high Reynolds number calculations in two space dimensions (2D), and instead began code modifications required to carry out simulations in three dimensions (3D). At this point, the subset of the code that computes two dimensional solutions has been tested, and found to agree with the previous full 2D code.

Together with our long term visitor as the lead, we implemented a robust, low memory, third order accurate Runge-Kutta algorithm to replace an algorithm often cited in the literature, but which we show to be only second order for nominal orders greater than 2. This algorithm has been applied to the generalized advection–diffusion solver in the GASpAR code, and shown to behave as expected for explicit time solutions.

Finally, working with the IMAGe Computational Mathematics Group we have made significant strides toward developing an optimized additive Schwarz preconditioner for our iterative Krylov methods in the Navier–Stokes and MHD solvers. Thus far, we have the first stage of the algorithm with nonzero overlap working for nonconforming element descritizations, and are beginning the second stage of optimizing the preconditioner so that the iteration count is bounded.

## 4 2007 plans

In FY2008, we will complete the development of the 3D code with regular conforming discretizations. To complete the preliminary effort, we must still develop a generic element class that conserves memory better than the 2D code allowed. To effect this, we may also restrict the user to using isotropic polynomial degree. It is possible that we will also undertake the development required to handle nonconforming 3D element connnectivity, and also to accommodate 3D adaptivity. We will continue our development of the optimized preconditioners described briefly above. If we can achieve optimization for conforming elements, we will develop the capability to handle nonconforming elements; this will, in turn, allow us to apply the preconditioner to adaptively refined grids.

## 5 References

### References


[1] Deville, M. O., P. F. Fischer and E. H. Mund, *High-Order Methods for Incompressible Fluid Flow.* Cambridge, Cambridge University Press (2002)

[2] Elsasser, W.M., *Phys. Rev.* **79**, 183 (1950)

[3] Elmegreen, B. G., & Scalo, J., *Ann. Rev. Astron. Astrophys.* **42**, 211–273 (2004)

[4] Feng, H., Mavriplis, C., Vad der Wijngaart, R., Biswas, R., *J. Sci. Comp.*, **27**, nos. 1–3 (2006)

[5] Fournier, A., *J. Comp. Phys.*, **215**, 1–5 (2006)

[6] Fournier, A., Taylor, M.A., and Tribbia, J.J., *Mon. Wea. Rev.*, **132**, pp. 726–748 (2004)

[7] Frisch, U. *Turbulence: The legacy of A.N. Kolmogorov*, Cambridge University Press (1995)

[8] Isihara T., Kaneda, Y., Yokokawa, M., Itakura, K., and Uno, A., *J. Phys. Soc. Japan* **72**, pp. 983–986 (2003)

[9] Karniadakis, G.E. and S.J. Sherwin, *Spectral/hp Element Methods for CFD*. New York, Oxford Iniversity Press, $2^{nd}$ ed. (2005).

[10] Mavriplis, C., *Comput. Methods Appl. Mech, Engrg.* **116**, pp. 77–86 (1994).

[11] C. Meneveau and Katz, J., *Annu. Rev. Fluid Mech.* **32**, pp. 1–32 (2000)

[12] Orszag, S. A. & Tang, J., *J. Fluid Mech.* **90**, 129 (1979)

[13] Patera, A., *J. Comp. Phys.* **54**, pp. 468–488 (1984).

[14] D. Rosenberg, A. Pouquet, and P. D. Mininni, *New J. Phys.* **9**:304 (2007).

[15] Sytine, I., Porter, D., Woodward, P., Hodson, S., and Winkler, K-H, *J. Comp. Phys.* **158**, pp. 225–238 (2000)

ESMF

Home | Support | Components | Partners | Presentations | Projects | Publications

Search ESMF
Advanced

About ESMF | Download | Users | Developers | Management | Work Plans | Metrics | Impacts

## What is ESMF?

The **Earth System Modeling Framework** (ESMF) is software for building and coupling weather, climate, and related models. Read more...

Earth System Curator

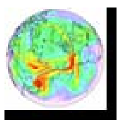
The **Earth System Curator** is developing an ESMF-friendly software environment for assembling, running, and archiving information about climate models. Read more...

## Highlights

The 6th Annual ESMF Community Meeting was held in Boulder, CO from May 30th through June 1st. View pictures and presentations...

$I^3$

The ESMFI$^3$ Initiative aims to automate the assembly of ESMF applications, *May, 2007*. Visit the wiki...



NASA explores climate-chemistry interactions with the GEOS-5 model, built from the ground up using ESMF, *April, 2007*. Read more...

## News

The VOCALS project is using ESMF to facilitate atmosphere-ocean coupling, *May, 2007*.

The National Unified Operational Prediction Capability consortium announces its intent to build its next generation system using ESMF, *January, 2007*.

ESMF Version 2.2.2r, the last entry in the ESMF 2 series, was released. This release includes major rework on the build and performance optimization of the redistribution method, *December, 2006*.

*News archive*

## Quick Links

- FAQ
- Download ESMF
- Release schedule
- Browse source code

## Upcoming Events

### *Telecons*

None scheduled.

To receive telecon emails, review materials, and release notifications, join the JST mailing list.

### *Meetings*

- October 16th: Joint Executive Board/Advisory Board, Camp Springs, MD
- October 17th: Joint Executive Board/Interagency Working Group, Camp Springs, MD

*Meetings archive*



ESMF is sponsored by the Department of Defense, NASA, the National Science Foundation, and NOAA.

ESMF is a registered Open Source project with SOURCEFORGE.net

***Past Listings***

July 2006
January 2007

# ESMF Components

Status as of July 2007.

The names of executable applications are in **bold**.

The names of components that are not meaningful as standalone applications are in normal text.

## Assorted Coupled Systems

| Name | Institution | Code Use | Infrastructure Adoption | Superstructure Adoption |
|---|---|---|---|---|
| **ADCIRC-WASH123** | DoD ERDC | Working prototype | Time Manager, Config, LogErr, SparseMatMul | Runs as an ESMF coupled system with stubs (results not valid) |
| **CICE-HYCOM** | DoD NRL | In routine use | LogErr | Runs as an ESMF coupled system without ESMF regrid |
| **COAMPS-NCOM** | DoD NRL | Working Prototype | Config, LogErr | Runs as an ESMF coupled system with ESMF regrid |
| **MITgcm Coupled Atmosphere-Ocean** | MIT | In routine use (option) | Time Manager, Config, LogErr | Runs as an ESMF component |

## Climate

| Name | Institution | Code Use | Infrastructure Adoption | Superstructure Adoption |
|---|---|---|---|---|
| **Community Climate System Model (CCSM)** | NSF NCAR | Working prototype | Time Manager, Redist | Runs as an ESMF coupled system without ESMF regrid |

## Atmosphere

| Name | Institution | Code Use | Infrastructure Adoption | Superstructure Adoption |
|---|---|---|---|---|
| **Community Atmospheric Model (CAM)** | NSF NCAR | Working prototype | Time Manager | Runs as an ESMF component |

| | | | | |
|---|---|---|---|---|
| **GEOS-5 AGCM** | NASA GMAO | In routine use (required) | Time Manager, Config, LogErr, Redist | Runs as an ESMF coupled system without ESMF regrid |
| **GFDL FMS** composite atmosphere (includes land and ice) | NOAA GFDL | Working prototype | | Runs as an ESMF component |
| **Global Forecast System (GFS)** | NOAA NCEP | In routine use (required) + operational | Time Manager, Config, LogErr | Runs as an ESMF component |
| **MITgcm Atmosphere** | MIT | In routine use (option) | Time Manager, Config, LogErr | Runs as an ESMF component |
| **COAMPS** | DoD NRL | Working prototype | Time Manager, Config, LogErr, Redist, SparseMatMul | Runs as an ESMF coupled system without ESMF regrid |
| **UCLA AGCM** | UCLA | In routine use (option) | Time Manager, Comms (Gather, Scatter etc), regrid (pre-v3.0.0) | Runs as an ESMF coupled system with ESMF regrid |
| **Weather Research and Forecast (WRF) Model** | NSF NCAR and NOAA NCEP | Working prototype (option) | Time Manager | Runs as an ESMF component |

## Atmospheric Dynamics

| Name | Institution | Code Use | Infrastructure Adoption | Superstructure Adoption |
|---|---|---|---|---|
| GEOS-5 finite volume dynamics | NASA GMAO | In routine use (required) | Time Manager, Config, LogErr | Runs as an ESMF component |
| Non-hydrostatic Mesoscale Model (NMM) | NOAA NCEP | Working prototype (required) | | Runs as an ESMF component |
| NMM dynamics package | NOAA NCEP | Working prototype (required) | | Runs as an ESMF component |

## Atmospheric Dynamics Elements

| Name | Institution | Code Use | Infrastructure Adoption | Superstructure Adoption |
|---|---|---|---|---|
| GEOS-5 gravity wave drag | NASA GMAO | In routine use (required) | Time Manager, Config, LogErr | Runs as an ESMF component |

| | | | | |
|---|---|---|---|---|
| GEOS-5 topology | NASA GMAO | In routine use (required) | Time Manager, Config, LogErr | Runs as an ESMF component |

## Atmospheric Chemistry

| Name | Institution | Code Use | Infrastructure Adoption | Superstructure Adoption |
|---|---|---|---|---|
| GEOS-5 atmospheric chemistry package | NASA GMAO | In routine use (required) | Time Manager, Config, LogErr | Runs as an ESMF component |

## Atmospheric Chemistry Elements

| Name | Institution | Code Use | Infrastructure Adoption | Superstructure Adoption |
|---|---|---|---|---|
| GEOS-5 parametrized chemistry | NASA GMAO | In routine use (required) | Time Manager, Config, LogErr | Runs as an ESMF component |
| GEOS-5 stratospheric chemistry | NASA GMAO | In routine use (required) | Time Manager, Config, LogErr | Runs as an ESMF component |
| GEOS-5 GOCHART chemistry | NASA GMAO | In routine use (required) | Time Manager, Config, LogErr | Runs as an ESMF component |
| GEOS-5 aerosols chemistry | NASA GMAO | In routine use (required) | Time Manager, Config, LogErr | Runs as an ESMF component |

## Atmospheric Physics

| Name | Institution | Code Use | Infrastructure Adoption | Superstructure Adoption |
|---|---|---|---|---|
| GEOS-5 atmospheric physics package | NASA GMAO | In routine use (required) | Time Manager, Config, LogErr | Runs as an ESMF component |
| NMM atmospheric physics package | NOAA NCEP | Working prototype (required) | | Runs as an ESMF component |

## Atmospheric Physics Elements

| Name | Institution | Code Use | Infrastructure Adoption | Superstructure Adoption |
|---|---|---|---|---|

| | | | | |
|---|---|---|---|---|
| GEOS-5 turbulence | NASA GMAO | In routine use (required) | Time Manager, Config, LogErr | Runs as an ESMF component |
| GEOS-5 moist processes | NASA GMAO | In routine use (required) | Time Manager, Config, LogErr | Runs as an ESMF component |
| GEOS-5 radiation | NASA GMAO | In routine use (required) | Time Manager, Config, LogErr | Runs as an ESMF component |
| GEOS-5 solar radiation | NASA GMAO | In routine use (required) | Time Manager, Config, LogErr | Runs as an ESMF component |
| GEOS-5 long wave radiation | NASA GMAO | In routine use (required) | Time Manager, Config, LogErr | Runs as an ESMF component |

## Atmospheric Analysis

| Name | Institution | Code Use | Infrastructure Adoption | Superstructure Adoption |
|---|---|---|---|---|
| Global Statistical Interpolation (GSI System) | NASA GMAO | Optional package in demo version; new production version in progress | | Runs as an ESMF component in available demo |
| Spectral Statistical Interpolation (SSI) analysis | NOAA NCEP | Working Prototype, SSI being replaced by GSI | | Runs as an ESMF component; coupled to CAM atmosphere using ESMF; system replaced by GSI |

## Atmospheric Tracer

| Name | Institution | Code Use | Infrastructure Adoption | Superstructure Adoption |
|---|---|---|---|---|
| Tracer Advection Component (TAC) | NASA GMAO | Working Prototype | Config, Time Manager | Runs as an ESMF component |

## Ocean and Wave

| Name | Institution | Code Use | Infrastructure Adoption | Superstructure Adoption |
|---|---|---|---|---|
| **ADCIRC** | DoD | Working prototype | Time Manager, Config, LogErr | Runs as an ESMF component |

| | | | | |
|---|---|---|---|---|
| **HYCOM** | DoD NRL | In routine use | LogErr | Runs as an ESMF coupled system without ESMF regrid |
| **MITgcm Ocean** | MIT | In routine use (option) | Time Manager, Config, LogErr | Runs as an ESMF component; used in multi-scale modeling where components are nested recursively |
| **MOM4** | NOAA GFDL | In routine use (option) | Time Manager | Runs as an ESMF component |
| **NCOM** | DoD NRL | Working prototype | | Runs as an ESMF component; couples with COAMPS |
| **POP** | DOE LANL | Working prototype | Time Manager | Runs as an ESMF component; grids cannot be correctly represented yet |
| **Poseidon** | GMU and NASA GMAO | In routine use (required) | Time Manager, Config, LogErr | Runs as an ESMF coupled system without ESMF regrid |
| **Simulating WAves Nearshore (SWAN)** | Delft Technical University and DoD NRL | Working prototype | | Runs as an ESMF component |
| GEOS-5 OGCM | NASA GMAO | In routine use (required) | Time Manager, Config, LogErr | Runs as an ESMF component |
| GEOS-5 data ocean | NASA GMAO | In routine use (required) | Time Manager, Config, LogErr | Runs as an ESMF component |

## Ocean Physics

| Name | Institution | Code Use | Infrastructure Adoption | Superstructure Adoption |
|---|---|---|---|---|
| GEOS-5 ocean biogeochemistry | NASA GMAO | In routine use (required) | Time Manager, Config, LogErr | Runs as an ESMF component |
| GEOS-5 ocean radiation | NASA GMAO | In routine use (required) | Time Manager, Config, LogErr | Runs as an ESMF component |

## Sea Ice

| Name | Institution | Code Use | Infrastructure Adoption | Superstructure Adoption |
|---|---|---|---|---|
| **CICE** | DOE LANL | Working prototype | | Runs as an ESMF component |
| GEOS-5 data sea ice | NASA GMAO | In routine use (required) | Time Manager, Config, LogErr | Runs as an ESMF component |

## Land and Surface

| Name | Institution | Code Use | Infrastructure Adoption | Superstructure Adoption |
|---|---|---|---|---|
| GEOS-5 land model | NASA GMAO | In routine use (required) | Time Manager, Config, LogErr | Runs as an ESMF component |
| GEOS-5 catchment basin | NASA GMAO | In routine use (required) | Time Manager, Config, LogErr | Runs as an ESMF component |
| GEOS-5 vegetation dynamics | NASA GMAO | In routine use (required) | Time Manager, Config, LogErr | Runs as an ESMF component |
| GEOS-5 lake model | NASA GMAO | In routine use (required) | Time Manager, Config, LogErr | Runs as an ESMF component |
| GEOS-5 land ice | NASA GMAO | In routine use (required) | Time Manager, Config, LogErr | Runs as an ESMF component |
| GEOS-5 salt water | NASA GMAO | In routine use (required) | Time Manager, Config, LogErr | Runs as an ESMF component |
| **Land Information Systems (LIS)** | NASA GMAO | In routine use | Time Manager, Config, LogErr | User code has ESMF interfaces (no setservices yet) |

## Hydrology/Watershed

| Name | Institution | Code Use | Infrastructure Adoption | Superstructure Adoption |
|---|---|---|---|---|
| **WASH123** | DoD ERDC | Working prototype | Time Manager | Runs as an ESMF component |

## Space Weather

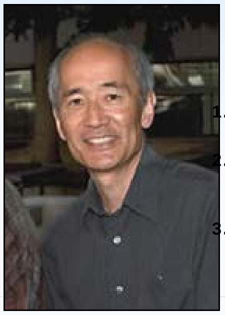
| Name | Institution | Code Use | Infrastructure Adoption | Superstructure Adoption |
|---|---|---|---|---|
| **Space Weather Modeling Framework (SWMF)** | University of Michigan | Working prototype (option) | | Runs as an ESMF coupled system without ESMF regrid |

## I/O Packages

| Name | Institution | Code Use | Infrastructure Adoption | Superstructure Adoption |
|---|---|---|---|---|
| NMM history output | NOAA NCEP | Working prototype (required) | | Runs as an ESMF component |
| GFS I/O component | NOAA NCEP | Working Prototype | | Runs as an ESMF component |

## DIRECTOR'S MESSAGE

**Welcome to the Earth Observing Laboratory's 2007 Annual Report.**



EOL is known as a community hub for the collection of data and transfer of knowledge pertaining to observations. The Laboratory also develops new measurement tools to extend community understanding of the atmosphere. EOL specifically fulfills three critical needs:

1. **To lead and serve the community in the provision of observational facilities, infrastructure, and services needed by the atmospheric and related sciences.**
2. **To play a leadership role in the development community-inspired next generation instrumentation and infrastructure while providing existing instruments and infrastructure in support of science.**
3. **To coordinate all aspects of field deployment from pre-project planning through the field phase and subsequent data stewardship.**

Central to EOL's success is our world-class scientific, engineering and project management staff that is respected by the community. Our staff responses to new directions in atmospheric research technology play a leadership role in the development and application of new technology to science objectives.

Scientist Cynthia Twohy makes some notes inside the NSF/NCAR G-V before the PACific Dust EXperiment (PACDEX) in April 2007. PACDEX was the first deployment that truly demonstrated the unique capabilities of the G-V as a long-range research aircraft. During that project the aircraft - stationed at its home base at the Rocky Mountain Metropolitan Airport - was quickly deployed to Japan via Alaska in response to news that a dust storm was gathering over Asia. The G-V was able to catch up with the plume before it started to travel across the Pacific, and for about a week was able to sample the plume as it made its way to North America.

EOL continues to make progress in all five NCAR strategic goals though our main focus is **Goal #5**. EOL supported a number of field campaigns, including METCRAX, PACDEX, CLIMODE, ISPA, CHATS, COPS and PASE in FY2007 and are preparing for some important deployments in 2008. EOL endeavors to identify ways to entrain new users. The official request procedure can appear daunting to someone who has never requested an NSF observing facility. Accordingly, it is our responsibility to help guide them through the process. This is one of the issues we addressed in September when we hosted the first-ever NSF Facilities Users' Workshop. In addition to reaching out to new users by delineating the request process, the workshop provided an opportunity for several hundred members of the NSF facilities' research community to meet and provide us with valuable guidance on core activities such as project planning, data stewardship, software tools, in-field service, and new instrument developments. The NSF Facilities Assessment database was discussed at a community workshop following the NSF Facilities Users' Workshop and will provide descriptive information on atmospheric science facilities and instrumentation in a consistent, easy-to-read format as a resource for the broad atmospheric science and related communities. EOL deployed the NSF/NCAR G-V in the first deployment (PACDEX) that truly demonstrated the unique capabilities as a long-range research aircraft. During PACDEX the aircraft - stationed at its home base at the Rocky Mountain Metropolitan Airport - was quickly deployed to Japan via Alaska in response to news that a dust storm was gathering over Asia. The aircraft was able to catch up with the plume before it started to travel across the Pacific, and for about a week was able to sample the plume as it made its way to North America. The G-V also entered a major upgrade phase in FY07 that will continue into FY09. HAIS instruments began arriving this year and will continue to be delivered until FY2009.

In support of **Goal #1**, Understanding the Earth & Sun System, an EOL scientist was the lead author on a landmark study that puts a new perspective on the "missing" carbon sink and could have political ramifications. A second Airborne Carbon in the Mountain Campaign (ACME) was conducted and three RACCOON (Regional Atmospheric Continuous CO2 Network in the Rocky Mountains) sites were added during the year.

In support of **Goal #2**, Improving Resilience to Weather, Climate and Atmospheric Hazards, EOL scientists collaborated with scientists in Africa to establish a continuous CO2 analysis site at Mt. Kenya Meteorological Observatory, which is World Meteorological Organization site.

EOL places major emphases on diversity and education and outreach activities (**Goal #3**). We will continue our efforts to support SOARS and the EOL Engineering Intern Program, as well as numerous education and outreach activities for K-12 students

and the general public.

EOL is committed to data processing, quality control, and archival for field projects as part of our expanding services that will be provided to the community **(Goal #4)**. This includes efforts to complete development of the Metadata Database and Cyberinfrastructure (EMDAC, formerly known as CODIAC) to access and browse products and data from field projects while integrating with the Community Data Portal.


Tours like this one, to the Marshall Facility where the S-Pol is located, are a staple of EOL's robust Education and Outreach program. EOL scientist Bob Rilling discusses radar operations with students from CU's Weather and Climate Data class.

NCAR is sponsored by the National Science Foundation.


*Postal Address: P.O. Box 3000, Boulder, CO 80307-3000 • Shipping Address: 1850 Table Mesa Drive, Boulder, CO 80305*

# 5. PROVIDING WORLD-CLASS OBSERVATIONAL FACILITIES AND SERVICES

Priority 1: Enabling Innovative Field Experiments and Measurement Campaigns

The accuracy, robustness, and performance of weather, climate, and chemistry models depend on sound theory and accurate measurements. EOL's leadership in the area of field program planning and implementation is considered the crown jewel of its achievements. EOL maintains a large suite of state-of-the-art NSF-funded Lower Atmospheric Observing Facilities (LAOF), without which collection and analysis of data and subsequently, understanding of atmospheric and earth processes would be impossible.

Maintaining a large degree of flexibility and responsiveness, EOL serves as the coordination point for scientific field campaigns, offering services ranging from advice and consultation during the initial stages of the planning process to the development of field design and project implementation plans, the provision of tailored and specialized logistics support, the fielding, operation and maintenance of scientific instrumentation in the field, real-time data communication development and support, organizational and operational management to achieve the scientific objectives as well as the coordination of educational activities related to field projects.

## National Radar Facility

EOL is developing a strategic partnership with Colorado State University to create a national radar facility. Both institutions support 10-cm, multiparameter Doppler radars that will be jointly operated in this new partnership. A key objective is to create a national test bed that other institutes and agencies can use for research and education. The radars will be in continuous operation, and university students will be encouraged to propose small (less than 20-hour) projects for collecting thesis-related research data. In FY08, the two institutes will formalize plans.

A key objective in creating the National Radar Facility is to create a national test bed that other institutes and agencies can use for research and education.

## Virtual Operations Center (VOC)

EOL has revised and updated the VOC proposal based on feedback from reviewers and a Town Hall Meeting which occurred at the annual AMS meeting in January 2007. EOL anticipates a funding decision by the NSF in early FY08. If successful in procuring funding, staff will begin to build prototypes for the VOC.

## NSF/NCAR Facilities Assessment

In the early part of FY 2007, the NSF/NCAR Facilities Assessment team developed an interactive database that will be populated with descriptions of systems, platforms, networks, and emerging technologies that are provided by community experts. The database will be supported on a web site and become a public resource with routine updating, and is intended to provide descriptive information on atmospheric science facilities and instrumentation in a consistent, easy-to-read format as a resource for the broad atmospheric science and related communities.

The Assessment has begun soliciting input from the community through submitting information on instruments and facilities or submitting revisions to resources already included. The 7 subcommittees met separately in May to review the information submitted so far, and there was a larger community workshop in late September, immediately following the planned NSF Facilities' Users' Workshop, to gain community input on gaps in the database and capabilities. EOL will continue to support the maintenance of the web site in FY08 and 09 and thereafter.

## Observing Facilities Assessment Panel (OFAP)

Twice a year, EOL hosts the Observing Facilities Assessment Panel (OFAP) and coordinates among panel members, PIs, facility providers, EOL staff and NSF to assess the feasibility and cost of NSF-funded field projects. The OFAP is an NCAR-driven community process that provides technical and operational assessment of requests associated with the use of NSF's Lower Atmospheric Observing Facilities (LAOF) in the field. The panel, which is composed of a diverse pool of scientists with broad experience in observational studies of earth system sciences, meets at NCAR to provide valuable feedback and evaluation to facility managers and the user community concerning experiment design, data management issues and the appropriate and efficient use of NSF resources as related to a specific field campaign. The comments and technical evaluation presented by the OFAP, together with feasibility analyses and cost estimates provided by Facility Managers, are considered before a final decision is made by NSF whether to approve a project.

Twice a year, EOL hosts the Observing Facilities Assessment Panel (OFAP), an NCAR-driven community process that provides technical and operational assessment of requests associated with the use of NSF's Lower Atmospheric Observing Facilities in the field.

## Field Deployments

### Meteor Crater Experiment (METCRAX)

In October 2006 EOL provided one ISS and seven ISFS in support of the METCRAX experiment, which investigated the meso- and micro-scale structure and evolution of the stable boundary layer within, above and in the vicinity of the Arizona Meteor Crater. The crater was chosen as it represents an ideal, simple-shaped, and small closed basin cut into a nearly homogeneous plane.

### CLIvar MOde Water Dynamics Experiment (CLIMODE)

EOL supported this University of Connecticut experiment on heat loss from the ocean into the atmosphere by providing one ISS on the R/V Knorr to study the dynamics of subtropical mode water of the North Atlantic. The experiment ran from February to March in 2007. The objective of this experiment was to develop better climate models by improving the understanding of ocean physics. Data gathered from the experiment will be checked for quality control by EOL and offered to the research community as a data product in FY 2007.

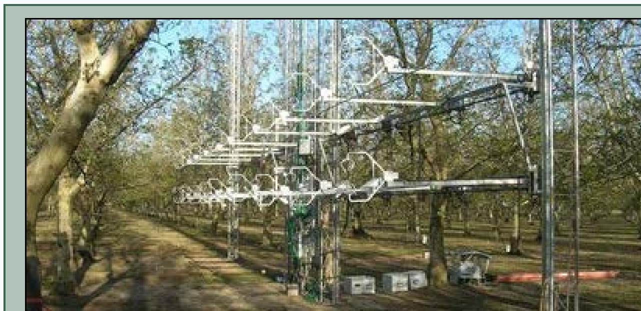
EOL scientist Bill Brown does a last minute check of atmospheric conditions before he launches a sounding balloon off the R/V Knorr during CLIMODE, an experiment which studied the loss of heat from the North Atlantic sea into the atmosphere.

### Inhibition of Snowfall by Pollution Aerosols (ISPA 2006)

ISPA studies the link between pollution aerosols and snowfall rates in the Mount Werner area near Steamboat Springs, Colorado. EOL provided the ISS-MAPR facility in early 2007 to obtain temperature and humidity profiles with altitude, cloud top height and temperature, depths of the snow layer, crystal fall speed and riming extent. Data gathered from the experiment will be checked for quality control and offered to the research community as a data product in FY 2007.

### Canopy Horizontal Array Turbulence Study (CHATS)

Turbulent transport within plant canopies is still not well understood and is, hence, poorly represented in large-scale climate models. Canopy turbulence is a complex but important aspect of biogeoscience, as it plays an essential role in transporting substances between their source location and the overlying atmosphere.  EOL supported this NCAR-led experiment by deploying an ISSF and the REAL lidar in a walnut grove in Dixon, California in March and April 2007. Data gathered from the experiment will be checked for quality control and offered to the research community as a data product in FY 2007.



EOL deployed its Integrated Surface Flux System (ISFS) in a walnut grove in Dixon, California for the CHATS experiment to study turbulent transport within plant canopies. (Steve Oncley)

### Convective and Orographically induced Precipitation Study (COPS)

EOL provided scientific and technical support in the COPS campaign to study convective processes in Germany's Black Forest during the summer of 2007. COPS' scientific goal is to improve the skill of quantitative forecasts of orographically-induced convective precipitation by obtaining a better understanding of the dynamical and microphysical processes responsible for deficiencies in QPF in moderate-mountain regions.


SOARS Student Theresa Aguilar stands by the Doppler on Wheels II as she watches a gust front roll in during the Convective and Orographically induced Precipitation Study (COPS) near the Black Forest in Germany, Summer, 2007.

COPS will provide a data set for identifying the reasons for deficiencies in QPF and for incorporating improved representations of sub-grid scale processes in mesoscale models.

**PACific Dust EXperiment (PACDEX)**

See section on the Role of Aerosol in Climate and Weather.

**Pacific Atmospheric Sulfur Experiment (PASE)**

In August and September of 2007, EOL provided the C-130 research aircraft to PASE, which is a comprehensive study of sulfur chemistry in a pristine marine trade wind system. The base of operations for this experiment was on Christmas Island, Kiribati, a remote area that offers a highly stable trade wind inversion with little chance of precipitation, high solar intensity and horizontal winds constant in direction and speed over several days.

### Future Field Deployments


The NSF/NCAR C-130 flies by a beach on Christmas Island during the PASE project in August, 2007.

**Ice In Clouds Experiment (ICE-L)**

EOL will provide the NSF/NCAR C-130 in November 2007. The scientific goal of the project, based at Jeffco Airport, is to show that under given conditions, direct ice nucleation measurements, or other specific measurable characteristics of aerosols, can be used to predict the number of ice particles formation by nucleation mechanisms in selected clouds. The investigators seek improved quantitative understanding of the roles of thermodynamic pathway, location within the cloud, and temporal dependency.

**HIAPER Pole-to-Pole Observations (HIPPO)**

The Collaborative Research: HIAPER Pole-to-Pole Observations (HIPPO) of Carbon Cycle and Greenhouse Gases Study will measure cross sections of atmospheric concentrations approximately pole-to-pole, from the surface to the tropopause, 4-6 times during different seasons over a 2.5 to 3-year period beginning in 2008. The scientific questions motivating HIPPO focus on understanding the global sources and sinks for $CO_2$, $CH_4$, and other carbon cycle gases, and more broadly determining large-scale rates of tracer transport in the atmosphere. This experiment would not be feasible without the G-V and will establish a new paradigm for facility allocation. It is first time that a multi-year allocation of an observational platform has been approved by NSF. Such allocations may become more common with the G-V.

**THORPEX Pacific Asian Regional Campaign (T-PARC)**

EOL will be providing Driftsonde support for the proposed T-PARC experiment in September of 2008. T-PARC is a multi-national field campaign that addresses the shorter-range dynamics and forecast skill of one region (Eastern Asian and the western North Pacific) and its downstream impact on the medium-range dynamics and forecast skill of another region (in particular, the eastern North Pacific and North America). The driftsonde and ELDORA are two primary platforms that have been requested for this experiment.

**Arctic Research of the Composition of the Troposphere from Aircraft and Satellites (ARCTAS)**

The proposed ARCTAS experiment will take place as two 1-month aircraft deployments, in March-April and June-July 2008. It will involve the NASA DC-8 as its primary platform, and EOL's new Difference Frequency Generation (DFG) spectrometer will acquire ambient measurements of formaldehyde, an important trace gas involved in ozone and hydrogen radical production. The spring deployment will target arctic haze, anthropogenic pollution in general, stratosphere-troposphere exchange, and sunrise photochemistry. The summer deployment will target boreal forest fires, stratosphere-troposphere exchange, and summertime photochemistry. ARCTAS is part of the international IPY/POLARCAT arctic field program for atmospheric composition.

## Priority 2: New instrumentation

Advances in research on weather, climate, water cycle, chemistry and dynamics of the upper troposphere/lower stratosphere, and biogeosciences all require capabilities beyond our current suite of airborne and ground-based instruments. EOL is tasked with developing this new generation of robust, inexpensive, easily deployable, and versatile instrument systems to address these needs. Our extensive pool of talented scientific and engineering staff continually conceptualize, develop and test new instrumentation for studying the links between atmospheric composition and the biogeosciences, with systems for quantifying the surface-atmosphere exchange of gases and aerosols on whole-plant, whole-canopy, and regional scales using mobile laboratories and deployments of our fleet of research aircraft.

EOL has been involved in a variety of efforts to support this strategic priority in FY 2007. CAPRIS, a new suite of radar and lidars that allow for unprecedented combination of coincident observations of precipitation, winds, cloud microphysics, water vapor, ozone and aerosol – all on one platform – is going through the NSF review process. The sophisticated gondola EOL developed in 2006 designed to fly approximately 25 miles into the atmosphere by a giant balloon to capture images of the Sun's outer surface at a higher resolution than ever before took its maiden voyage last month in Oklahoma.

## Community Airborne Platform Remote-Sensing Interdisciplinary Suite (CAPRIS)

The CAPRIS White Paper went through an extensive internal and external community review, and was resubmitted to NSF for review in April 2007. The latest changes include discussion of the science engineering and resources requirements, updates to the budgets based on the Lidar RFP process and partnership with MIT/Lincoln Labs on the development of the CM phased array antennas.

## Sunrise Gondola

EOL is working in conjunction with ESSL's High Altitude Observatory (HAO) to create the gondola for a lightweight, balloon-borne one-meter solar telescope that will circle Antarctica for about two weeks at an altitude of approximately 25 miles. Its advanced instrumentation will provide high-resolution images of the Sun's outer surface, or photosphere, enabling scientists to get unprecedented views of small-scale magnetic fields that drive solar variability and profoundly affect Earth's atmosphere.

A team of scientists and engineers in EOL and HAO built this 23-foot gondola (seen here with solar panels attached) as part of the Sunrise project, an international program to measure magnetic fields, dynamics, and thermal properties of the solar atmosphere. Carried approximately 25 miles (40 kilometers) into the atmosphere by a giant balloon, the gondola will contain a 1-meter diameter solar telescope that can capture high-resolution images of the Sun's outer surface.

To get a balloon up that high in the atmosphere with such sophisticated and sensitive instrumentation is no small feat. The entire system will weigh approximately 5000 pounds, which will require a 40 million cubic foot polyethylene balloon - in other words, the giganitc balloon will be nearly as big as a football field. Not only that, the gondola must keep the telescope aimed at a specific - and relatively tiny - area of the Sun. The telescope's angle must remain within 15 arc seconds, or *1/240th of a degree* while constantly twisting on a soaring balloon.

In FY 2007, completed the construction phase as well as the dynamic control system for the instrument and conduct a test flight in October of 2007. The balloon was launched by the National Scientific Balloon Facility from Fort Sumner, New Mexico. The short, 12-hour flight allowed the engineers an opportunity to test and fine tune the pointing control system. It is possible that the small optical telescope that will be installed for testing will produce some very useful UV flux measurements as well.

## Other Developments

### Wind Lidar

The proposal to develop a Wind Lidar was approved in FY 2007, and is exploring the ability of a lidar wind profiler to measure winds and possibly turbulence, with better time resolution, altitude resolution while reducing the effects of “clutter” (such as signals from the ground, birds, etc.) and interference from radio waves than is possible from current radar wind profilers and SODAR systems.

### CAMS Instrument for the G-V

EOL began development of the Compact Atmospheric Multi-species Spectrometer for the G-V (CAMS) in FY 2007. This new instrument will rely on the same state-of-the-art advancements employing DFG technology as our other airborne spectrometers, but with major upgrades and innovations for operation on the G-V platform. It is one of many important trace gas chemistry instruments being developed for the NSF/NCAR G-V for the 2010 DC-3 project (Deep Clouds, Convection & Chemistry) as well as other airborne studies.

### NO/NOy for the G-V

In FY 07 EOL funded the completion of this instrument, which will be used in many chemistry campaigns, and in 2010 will be an integral part in the proposed DC-3 experiment. In FY 2007 EOL and ACD established a Memorandum of Understanding and a working partnership regarding EOL support of ACD-built instruments, PI expectations in supporting non-ACD field deployments, and ownership of the acquired data. This represents an important partnership with ACD to support airborne instrumentation.

### Development of a plan for long-wave radiation for the G-V

In our efforts to continually produce state of the art observing technology, EOL staff is leading a development effort for an instrument to measure long-wave radiation emitted by the earth’s surface from the G-V platform. Measurements of terrestrial emissions are an essential element in understanding the earth’s radiative budget. In FY 2007 EOL will conduct a workshop to survey community needs for such instrumentation and devise a plan to improve upon what currently exists. Ultimately, this will lead to the development of new G-V instrument with this important capability.

#### SATCOM software products for the G-V

In F07 EOL is gathering input from the NCAR/NSF user community about what products they want and what is currently available in regards to Satcom software products. In FY08 we will begin efforts to develop or purchase what we need to provide the research community.

#### High Precision carbon dioxide isotopic ratio instrument

This long-standing development project that began in FY 2002 with NSF Biocomplexity Special Funds progressed rapidly in FY 2007. This instrument provides new in-situ information about carbon sinks in the atmosphere. It will augment more traditional measurements of this ratio from high precision isotopic ratio mass spectrometry, leading to an enhanced understanding of the carbon cycle. Throughout FY2007 extensive laboratory testing was conducted and field-testing is anticipated in FY 2008.

#### Development of a high efficiency waveguide DFG instrument

With partial support from the NCAR Director's Opportunity Fund in 2006, EOL scientists have been working with Japanese scientists and engineers from the NTT Photonics Laboratory, NTT Corporation in developing and assessing of new high performance optical frequency conversion technology based upon wave-guide DFG devices. This group published a paper on the first phase of this instrument development and assessment in FY 2007 and is currently working on an improved version. Research Engineers and Scientists in EOL anticipate significantly improved performance, both in terms of higher output powers and conversion efficiencies, from the new DFG device. If successful, this will open up many new detection methods for instruments on the G-V.

#### Water Reference Sounding System

This collaboration between NSF/EOL and South West Sciences Incorporated is aimed at exploring the feasibility of balloon-borne tunable diode laser (TDL) technology for in-situ water vapor measurements with verifiable accuracy. Such measurements are badly needed by the climate community. This activity has been postponed until the start of FY 2008.

## Priority 3: Installing Initial Instrument Suite and Beginning Operations of the NSF/NCAR G-V Aircraft

2007 marked the year that the NSF/NCAR G-V was deployed in a project that truly demonstrated its unique capabilities as a long-range research aircraft. The G-V also entered a major upgrade phase in FY07 that will continue into FY09. HAIS instruments began arriving this year and will continue to be delivered until FY2009.

### PACific Dust Experiment (PACDEX)

See section describing the Role of Aerosols in Climate and Weather.

### G-V Instrumentation

#### HAIS Instrumentation

The HIAPER Airborne Instrumentation Solicitation (or HAIS) instruments have started to arrive for installation and testing on the NSF/NCAR G-V. The first of these instruments (SID-2H, HARP, and VCSEL) are operating in PACDEX and making important contributions to that project. Test periods for others are scheduled in July 2007 and February 2008, with probably an additional test period needed in either late 2008 or early 2009. In addition to the instruments delivered for PACDEX, the AWAS, Fast Ozone, MTP, Ozone Photometer will be delivered in FY2007, the QCLS, CIMS, HSRL, 3V-CPI, AND GPS will be delivered in 2008 and the TOGA, ToF-AMS is scheduled to be delivered in FY2009.

This external wing store system, fabricated by EOL's Design and Fabrication Services, houses cloud physics instruments, video cameras, laser air motion sensors, and more under the wing of the NSF/NCAR G-V. (Carlye Calvin)

We are working with Gulfstream to develop 6 pylons similar to the ones installed for PACDEX plan to installation of those in January 2008. We also plan to add the large pods in 2008, but funds are unsecured.

Initial reports from PACDEX indicate that the plane is staying cooler than expected, so the cooling system upgrade will be postponed until FY09. Development of the optical ports is intended to be complete in FY08, and EOL will conduct two test periods for the instrumentation and infrastructure upgrades in July 2007 and in February 2008.

#### HIAPER Cloud Radar

The HIAPER cloud radar (HCR) is an airborne millimeter-wavelength radar that will serve the atmospheric science community by providing remote sensing capabilities to the NSF/NCAR G-V aircraft. During FY07, EOL completed the detailed design of the receiver, begin the detailed design of the data system and procure a transmitter. We anticipate completion of the remaining electronic design, mechanical design, fabrication and subsystem testing in FY08. System integration will start in FY08 and culminate in FY09, with flight testing to be completed in April 2009.

#### Laser Air Motion Sensor (LAMS) for the G-V

EOL scientists and engineers have been developing a new high-accuracy state-of-the art wind velocity instrument for the G-V over the past year. This instrument utilizes measurements of the Doppler shifts in backscattered near-IR laser radiation caused by the 3-D wind field. It will improve upon the accuracy of airborne wind velocity measurements over current technology based upon differential gust probes. The accuracy for the latter, which is severely compromised by aircraft flow perturbations, becomes a particular problem on the G-V. The new instrument solves this problem by remotely detecting the wind fields well in front of the airplane, resulting in anticipated flow velocity accuracies around 0.1 m/sec. In FY 2007 EOL anticipates completion of the single channel demo phase, including airborne testing, of this new instrument on the G-V. Upon completion of the first phase, EOL anticipates embarking on the full development of a three-channel system for measurements of all three-wind velocity components.


*Postal Address: P.O. Box 3000, Boulder, CO 80307-3000 • Shipping Address: 1850 Table Mesa Drive, Boulder, CO 80305*

## 3. CULTIVATING A SCIENTIFICALLY ENGAGED CITIZENRY

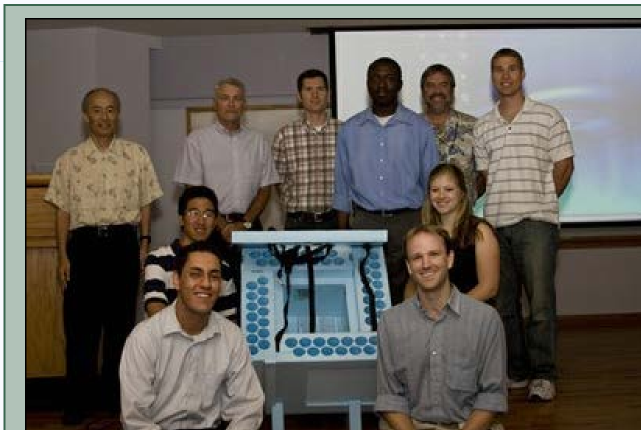
### Priority 1: Engaging a Broader and More Diverse Community in the Atmospheric and Geosciences

EOL recognizes that the overall health of our institution lay in ensuring that those with aptitude and determination have opportunities in the atmospheric science and engineering disciplines, and that they are welcomed and nurtured, regardless of gender, ethnic background, nationality, or physical ability. EOL addresses this NCAR strategic priority in a number of ways, including our highly successful Student Engineering program, now in its eighth year, our hiring practices, our EOL Women's Professional Development Group and our Education and Outreach efforts that reach the general public.

#### Undergraduate Engineering Internships

2007 has seen fantastic response to EOL's call for applications to our Summer Undergraduate Engineering program, which focuses EOL's outreach efforts on the engineering community in a manner analogous to what UCAR/NCAR currently does for young scientists.

EOL received resumes from mechanical, electrical and computer, aerospace, optical, environmental, chemical, and industrial engineering students.  A total of 99 applications were received, 15 from women.  Six students applied through the National Society of Black Engineers (NBSE).  The announcement was also posted with the Society of Hispanic Professional Engineers.


The Summer Engineering internship program ended with presentations given by the four interns, seen here with their mentors around the redesigned Driftsonde gondola.  Back row: Roger Wakimoto, Assistant Director to NCAR for the EOL, Jack Fox, DFS Manager, Scott Spuler of the LIDAR Group, intern Oluleye Olorude, Mark Lord of EOL's Research Aviation Facility, Tom Brimeyer, Program Coordinator.  Middle row: Interns Andrew Leung and Jaqueline Hibbard.  Bottom Row: Intern Tim Allarid and Program Coordinator Gordon Farquaharson.

Four interns were hired and worked with EOL engineers during the summer of 2007:  Tim Allarid, a mechanical engineering student, worked with the Design and Fabrication Services; Jacqueline Hibbard, an aerospace engineering student, worked at the Research Aviation Facility; Andrew Lueng, an electrical engineering student, assisted on upgrades to the ELDORA radar; and Oluleye Olorode, an electrical/optical engineering student, worked with the LIDAR group.  All interns gave presentations to the EOL Engineering Group as part of their internships.  Continuation of the undergraduate intern program will be a priority in FY08 and 09.

#### Expanding Your Horizons Workshop

EOL staff participated once again in the Expanding Your Horizons Conference at CU Boulder in February. The annual conference was held on February 24, 2007 in the CU engineering center, and was attended by close to 200 girls from schools along the Front Range. It is organized by the Boulder Branch of the American Association of University Women (AAUW) and the University of Colorado at Boulder with the goal to encourage pre-teen and teenaged girls to study math and science, to increase awareness of the options available in non-traditional careers, and to meet women whose careers depend on math, science, engineering and technology.


EOL Scientist Kate Young launches a weather balloon for

#### Diversity in EOL Hiring Process

EOL emphasizes the inclusion of diversity in its hiring practices and has instituted new internal practices in FY07 to ensure that a measurable and fair process is followed for every new hire.  We have established checks and balances to ensure proper advertisement of new positions in order to solicit the widest variety of applicants.  Hiring managers must complete a form outlining how and where the job was advertised, what effort was made to solicit applications from females and underrepresented minorities, and justification for final interview pool and hire.  EOL firmly believes these efforts to ensure diversity within its ranks will strengthen our organization as a whole.

#### EOL Women's Professional Development Group

The EOL Women's group continues to bring together women at all levels in the laboratory - mechanics, technicians, administrators, scientists, data managers,

managers, etc., to provide a forum in which women can share experiences and discuss lab topics of mutual interest. Management is interested to foster this communication in order to work on making EOL a supportive place in which women professionals work.

the Expanding Your Horizons workshop. This event is organized by the Boulder Branch of the American Association of University Women (AAUW) and the University of Colorado at Boulder with the goal to encourage pre-teen and teenaged girls to study math and science, to increase awareness of the options available in non-traditional careers, and to meet women whose careers depend on math, science, engineering and technology.

### Wonders of Science Saturday

EOL Scientist Junhong Wang teaches an aspiring scientist how to read the data collected from a weather balloon during the Wonder of Science Saturday event at the 29th Street Mall in Boulder, Colorado.

NCAR scientists also participated in the Wonder of Science Saturday, an event held at Boulder's 29th Street Mall, in September 2007. This event provided the public with an opportunity to learn about different scientific organizations in the area, and its primary focus was on science education of children and adults. EOL performed a series of radiosonde weather balloon launches that gave people a rare opportunity to learn first-hand about the technology used to capture atmospheric profiles of pressure, temperature, relative humidity, and wind, and view data collected in real-time.

## Priority 2: Supporting and Enhancing Formal Science Education at all Levels

EOL attaches a high value to Education and Outreach and currently infuses all EOL programs, whether in the laboratory or field with an E&O component. EOL encourages a general interest in earth science, and particularly tries to foster advanced understanding in the science and process of atmospheric research measurements. EOL accepts its responsibility to encourage the growth of the next generation of observational engineers and scientists, and continually seeks new ways to do this. Our major event in 2007 that supports this priority was our first-ever NSF Facilities Users' Workshop.

### NSF Facilities Users' Workshop

EOL hosted the first NSF Facilities Users' workshop was held the week of September 24-28, 2007 at NCAR. One of the major issues addressed this workshop was reaching out to new users by delineating the request process since the official request procedure can appear daunting to someone who has never requested an NSF observing facility. The workshop also provided an opportunity for several hundred members of the NSF facilities' research community to meet and provide us with valuable guidance on core activities such as project planning, data stewardship, software tools, in-field service, and new instrument developments. Representatives from funding agencies and potential partners in instrument development were also invited.

Dr. Clifford Jacobs, head of the UCAR and Lower Atmospheric Facilities

### High School Laser Class

EOL received an Activity Grant from the Optical Society of America (OSA) to support an Education and Outreach activity at a high school in Arvada, Colorado. Staff worked with a teacher of a laser class to get resources such as optics, and lasers and the class put together a laser show. Students of this class got the opportunity to attend monthly meetings in order to get a feel for what's going on in the world of optics, and what a professional environment is like.

Oversight Section of the National Science Foundation's Division of Atmospheric Sciences, addresses participants in the first-ever NSF Facilities Users' Workshop, held in Boulder Colorado in September 2007.

### Pilot High School Student Program

EOL values educational outreach at all levels and is currently conducting a small pilot program that exposes local high school students of high academic caliber to various EOL activities and specialized projects. In FY07, EOL hired a Boulder High School senior, to work with engineers on data collected from the driftsonde during the T-AMMA campaign in Africa last year. Pending evaluation of this program EOL plans to continue with this educational outreach in FY 2008-2009.

### Student Visits

EOL staff has continued to support formal science education in 2007, with six visits so far to local elementary, middle and high schools for weather lessons, balloon launches and tours of the Integrated Sounding System (ISS). Familiarizing young students with opportunities in atmospheric science will continue to be an activity EOL supports in FY08 and 09.

## Priority 3: Maintaining an Innovative and Creative Workplace

EOL knows we cannot fulfill our scientific, engineering and service objectives without capable, intelligent, dedicated and effective personnel. We find a variety of ways to keep our staff challenged, including our pilot sabbatical program for scientific staff.

### Instituting Sabbatical for Scientific Staff

EOL instituted an internal sabbatical for ladder-track scientific staff intended to increase their productivity through uninterrupted research or laboratory work, including research leading to publication, publication writing, instrument development, development of major science plans and participation as scientists in a field project. Staff could also include time to write e.g., one or more chapters of a thesis or dissertation, depending on circumstances. At the present, there is a pilot process in place and in FY08 we will be reviewing how the program is working and will make adjustments to it as necessary.

Director's Message
Table of Contents
**Strategic Goals**: Science, Facilities & Technology
Archives and Supplemental Info

# 1. UNDERSTANDING THE EARTH & SUN SYSTEM

## Priority 1: Exploring Atmospheric, Earth System, and Solar Processes, Variability and Change

### Landmark Paper on the "Missing" Carbon Sink

Among the 2007 highlights in this area is a landmark paper by Britt Stephens et al. published in Science, which puts a new perspective on the “missing” carbon sink. This paper greatly diminishes the apparent discrepancy between overall emissions and the rate of increase of atmospheric CO2. This research indicates that uptake in tropical forests is actually much larger than previously thought, while CO2 uptake in northern latitudes is lower than previously thought.

### START 08

The Stratosphere-Troposphere Analyses of Regional Transport (START) experiment, run in FY06, looks at transport processes that impact the chemical-microphysical distribution of the extratropical upper troposphere/lower stratosphere (UTLS) region. START08 planning launched this year. With a collaborative team of university and NCAR scientists in place, an experiment design and plan proposal were submitted to the Observing Facility Assessment Panel (OFAP) in early 2007, which received NSF approval in August 2007.

## Priority 2: Investigating the Interactions of the Atmosphere, the Broader Earth System and Human Society

Developing a fuller understanding of the complex interactions among the Earth’s atmosphere, oceans, land masses, ice masses, and biosphere; the interconnection of human activities with the Earth’s physical, chemical, and biological processes is a major focus of our national center. EOL is tasked mainly with the mission to develop innovative instrumentation and data acquisition technology and lead scientific campaigns that make such understanding possible. Even so, EOL scientists often find themselves in the thick of data analysis that contribute directly to the goal of improving our understanding of the atmosphere and earth system, specifically by investigating the interactions of the atmosphere and the broader earth system.

### Terrain-influenced Monsoon Rainfall Experiment (TiMREX)

TiMREX is a proposed joint U.S.-Taiwan multi-agency field program that will be conducted from 15 May to 30 June 2008 in the northern South China Sea, western coastal plain and mountain slope regions of southern Taiwan. The goal of TiMREX is to improve understanding of the physical process associated with the terrain-influenced heavy precipitation systems and the monsoonal environment in which they are embedded through intensive observations, data assimilation and numerical modeling studies.

EOL Technician Jeff Bobka maps out a potential S-POL Radar site for the TiMREX Field Program during a site survey visit to Taiwan. (Wen-Chau Lee)

### Biogeochemistry Initiative

EOL collaborated with investigators at CU, CSU, and in CGD, MMM, and TIIMES to conduct the ACME ’07 campaign using the University of Wyoming King Air. This was the second Airborne Carbon in the Mountains Campaign, focusing in Colorado and Wyoming, with flights taking place from early spring through fall 2007. EOL also collaborated with TIIMES and investigators from Harvard, NOAA, and Scripps Institution of Oceanography to plan and conduct the HIPPO campaign on the NCAR G-V. This campaign investigating the global carbon cycle will conduct profiling flights over North America in 2008, and during 5 global loops from 2009-2011. EOL and TIIMES staff continued to operate the Regional Atmospheric Continuous CO2 Network in the Rocky Mountains (Rocky RACCOON) network of CO2 analyzers and collaborate with University of Utah and University of Wisconsin to investigate regional carbon cycling the Rocky Mountains.

### The Role of Aerosols in Climate and Weather

In April and May of 2007, EOL ventured into NCAR’s strategic priority to study the role of aerosols in climate and weather by deploying the NSF/NCAR G-V in support of the PACific Dust EXperiment (PACDEX) to study the Eurasian-Pacific-North American dust plume. The transport of dust and anthropogenic aerosols (e.g., black carbon, organics and sulfates, and air pollution from Eurasia, across the Pacific Ocean, into North America) is one of the most widespread and major pollution

events on the planet.
This plume passes through the Pacific Ocean extratropical cloud systems, which are important climate regulators through their large radiative cooling effect. The effect of this mixed dust-pollution plume on the Pacific cloud systems and the associated radiative forcing is an outstanding problem for understanding climate change and has not been explored. The primary reason has been the lack of an airborne platform that can sample the evolution of this plume in situ all the way across the Pacific Ocean.


Outside the hangar in Anchorage Alaska, with the Chugach mountain range at its back, the NSF/NCAR G-V receives last minute preparations before its flight to Japan to follow a dust plume during the PACific Dust EXperiment (PACDEX). (Photo by Jeff Stith)

The experiment represents the first true deployment of the G-V as originally envisioned. The aircraft is equipped with the first HAIS instrument packages and will not plan on recovering at Jeffco during its cross-Pacific mission. Analysis of data collected during the experiment will be a high priority for EOL scientists during FY08 and 09.

## Priority 3: Improving the Prediction of Weather, Climate and other Atmospheric Phenomena

Over the last several decades, the skill of numerical weather prediction is generally considered to have increased at an average rate of about one day per decade. Thus, the skill of today's four-day forecast is equivalent to the skill of a three-day forecast of a decade earlier. The rate of improvement is even slower for the forecast variables needed most by society, such as the prediction of heavy rainfall. This relatively slow, *linear* rate of improvement is not sufficient to keep place with the demand for accurate weather information in the world today, where an *exponentially* growing world population places an ever-increasing number of people in areas at risk for weather disasters.

### THORPEX Pacific Asian Regional Campaign

In FY07, EOL began to analyze data gathered during T-AMMA (FY 2006) to investigate and improve the performance of the driftsonde as a research tool and to investigate hurricane genesis and the genesis environment. Areas of likely activity include investigating why such a pronounced large-scale wave structure was found at the 20-km height of the balloon-gondola, but not in the operational analysis.

The driftsonde will be undergoing major developments in preparation for the proposed T-PARC campaign in FY08. In addition, ELDORA has also been requested by the PIs to collect data in the genesis region.


Data is being analyzed from the T-AMMA project to investigate and improve the performance of the driftsonde, shown above, as a research tool. (Terry Hock)

NCAR is sponsored by the National Science Foundation.


*Postal Address: P.O. Box 3000, Boulder, CO 80307-3000 • Shipping Address: 1850 Table Mesa Drive, Boulder, CO 80305*

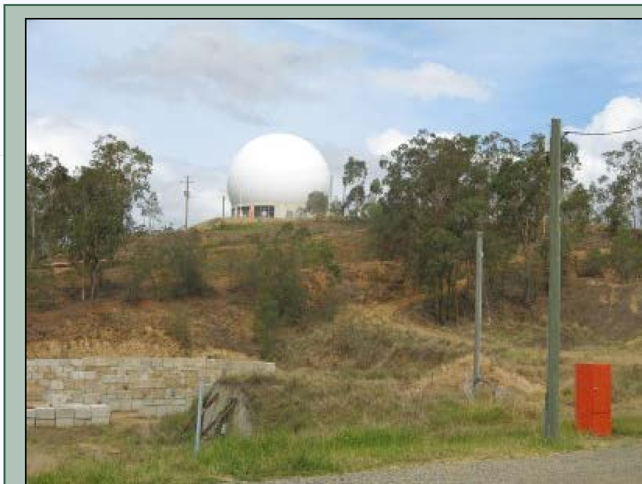
## 2. RESILIENCE TO WEATHER, CLIMATE AND ATMOSPHERIC HAZARDS

### Priority 2: Building Capacity for Coping with Weather and Climate Hazards

To help society cope with weather and climate hazards, decision makers must be made aware of threats and vulnerabilities so that options of mitigation and adaptation can be developed. EOL has contributed to this strategic priority in 2007 by installing a brand-new radar processor, developed at EOL for the Australian Bureau of Meteorology Research Center in Brisbane, Australia.

#### NCAR's CP-2 Radar in Brisbane, Australia

The CP-2 radar was set up by a team of EOL engineers in Brisbane, Australia. and began functioning in August 2007. As part of a 2002 Memorandum of Understanding between the Bureau of Meteorology (BOM), Australia and UCAR, a formal agreement was established to transfer CP-2 to BOM and setup and operate it in Brisbane, Australia for long-term scientific collaboration in the areas of nowcasting, hydrology, and weather modification. EOL engineers installed a brand new radar processor that was developed at EOL. The Australians have built a permanent structure to house the radar for continuous 24/7 operations.


The CP-2 radar was set up by a team of EOL engineers in Brisbane, Australia for long-term scientific collaboration in the areas of nowcasting, hydrology, and weather modification. The Australians have built a permanent structure to house the radar for continuous 24/7 operations.

The Brisbane area is an excellent location for studying flash flood producing rainstorms over moderate topography as well as sub-tropical oceanic systems. The area has a first-class array of rain gauge and lightning detection systems. CP-2 will be available for both operational and research activities. The Queensland government has recently started to explore the potential for cloud seeding to enhance rainfall and plans a feasibility study starting later this year in the Brisbane area. The Queensland program provides a unique opportunity to address some of the outstanding cloud micro physical issues such as growth of hygroscopic particles into drizzle drops and glaciation and graupel growth in silver iodide seeded clouds identified in previous rainfall enhancement experiments. The CP-2 radar with its advanced measurement capabilities would collect a dual polarization, and dual wavelength radar observations for cloud micro physical research during the Queensland program.

### Priority 3: Establishing Research Connections in Emerging Nations

People everywhere are affected by weather, climate change and other atmospheric phenomena. Continued improvements in scientific capabilities in emerging nations creates opportunity for scientific progress and increases the likelihood that science can improve the effectiveness of local and regional decision making on environmental and development issues. While a good number of EOL's activities center around our international collaborations, two activities stand out as prime examples of our commitment to support NCAR's strategic priority to establish research connections in emerging nations.

#### India workshop

In February 2007, EOL staff members and a representative from NOAA/NSSL traveled to New Delhi to participate in a five-day workshop with the Indian National Center for Medium Range Weather Forecasting and many other Indian scientists. The goals of the workshop were twofold: 1) to give India advice regarding the development of an airborne science platform; and 2) to begin initial planning for a Bay of Bengal tropical cyclone experiment aimed at improving forecasts of cyclone intensity and landfall. Both India and the US will be entraining interested scientists in the next phase of planning - likely to be an international meeting in late Fall 2007.

Representatives from NCAR/MMM and UOP/COMET also attended as discussions were held defining tasks in the next UCAR/NCAR MOU with India detailing specific interactions among our scientific institutions on topics ranging from regionalizing WRF to training the Indian Meteorological Department in modern forecasting techniques.

#### CO2 Analyzers in Africa

EOL scientists are also pursuing collaborations with scientists in Africa to establish continuous CO2 analysis sites. Within the last year, scientists have worked to establish CO2 sites in order to fill in the gap of data in CO2 exchange in Africa, and to further understanding of Africa’s role in global CO2 exchange. In April 2007, EOL staff attended the Sahel Conference in Burkina Faso to establish relationships with African scientists, and to explore the possibility of setting up one of EOL’s CO2 analyzers. In FY07, EOL scientists, in collaboration with local scientists as well as other international scientists, decided to install the CO2 analyzer at the Mt. Kenya Meteorological Observatory, which is World Meteorological Organization site. Pending research permits. EOL plans to install the analyzer

NCAR is sponsored by the National Science Foundation.

either in November 2007 or early 2008.


*Postal Address: P.O. Box 3000, Boulder, CO 80307-3000 • Shipping Address: 1850 Table Mesa Drive, Boulder, CO 80305*

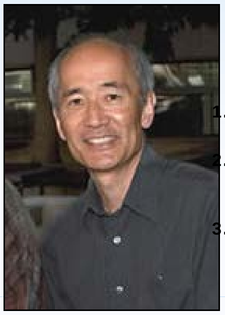
The National Center for Atmospheric Research
NCAR
sponsored by NSF

2007 EOL Annual Report



## DIRECTOR'S MESSAGE

**Welcome to the Earth Observing Laboratory's 2007 Annual Report.**



EOL is known as a community hub for the collection of data and transfer of knowledge pertaining to observations. The Laboratory also develops new measurement tools to extend community understanding of the atmosphere. EOL specifically fulfills three critical needs:

1. **To lead and serve the community in the provision of observational facilities, infrastructure, and services needed by the atmospheric and related sciences.**
2. **To play a leadership role in the development community-inspired next generation instrumentation and infrastructure while providing existing instruments and infrastructure in support of science.**
3. **To coordinate all aspects of field deployment from pre-project planning through the field phase and subsequent data stewardship.**

Central to EOL's success is our world-class scientific, engineering and project management staff that is respected by the community. Our staff responses to new directions in atmospheric research technology play a leadership role in the development and application of new technology to science objectives.

Scientist Cynthia Twohy makes some notes inside the NSF/NCAR G-V before the PACific Dust EXperiment (PACDEX) in April 2007. PACDEX was the first deployment that truly demonstrated the unique capabilities of the G-V as a long-range research aircraft. During that project the aircraft - stationed at its home base at the Rocky Mountain Metropolitan Airport - was quickly deployed to Japan via Alaska in response to news that a dust storm was gathering over Asia. The G-V was able to catch up with the plume before it started to travel across the Pacific, and for about a week was able to sample the plume as it made its way to North America.

EOL continues to make progress in all five NCAR strategic goals though our main focus is **Goal #5**. EOL supported a number of field campaigns, including METCRAX, PACDEX, CLIMODE, ISPA, CHATS, COPS and PASE in FY2007 and are preparing for some important deployments in 2008. EOL endeavors to identify ways to entrain new users. The official request procedure can appear daunting to someone who has never requested an NSF observing facility. Accordingly, it is our responsibility to help guide them through the process. This is one of the issues we addressed in September when we hosted the first-ever NSF Facilities Users' Workshop. In addition to reaching out to new users by delineating the request process, the workshop provided an opportunity for several hundred members of the NSF facilities' research community to meet and provide us with valuable guidance on core activities such as project planning, data stewardship, software tools, in-field service, and new instrument developments. The NSF Facilities Assessment database was discussed at a community workshop following the NSF Facilities Users' Workshop and will provide descriptive information on atmospheric science facilities and instrumentation in a consistent, easy-to-read format as a resource for the broad atmospheric science and related communities. EOL deployed the NSF/NCAR G-V in the first deployment (PACDEX) that truly demonstrated the unique capabilities as a long-range research aircraft. During PACDEX the aircraft - stationed at its home base at the Rocky Mountain Metropolitan Airport - was quickly deployed to Japan via Alaska in response to news that a dust storm was gathering over Asia. The aircraft was able to catch up with the plume before it started to travel across the Pacific, and for about a week was able to sample the plume as it made its way to North America. The G-V also entered a major upgrade phase in FY07 that will continue into FY09. HAIS instruments began arriving this year and will continue to be delivered until FY2009.

In support of **Goal #1**, Understanding the Earth & Sun System, an EOL scientist was the lead author on a landmark study that puts a new perspective on the "missing" carbon sink and could have political ramifications. A second Airborne Carbon in the Mountain Campaign (ACME) was conducted and three RACCOON (Regional Atmospheric Continuous CO2 Network in the Rocky Mountains) sites were added during the year.

In support of **Goal #2**, Improving Resilience to Weather, Climate and Atmospheric Hazards, EOL scientists collaborated with scientists in Africa to establish a continuous CO2 analysis site at Mt. Kenya Meteorological Observatory, which is World Meteorological Organization site.

EOL places major emphases on diversity and education and outreach activities (**Goal #3**). We will continue our efforts to support SOARS and the EOL Engineering Intern Program, as well as numerous education and outreach activities for K-12 students

and the general public.

EOL is committed to data processing, quality control, and archival for field projects as part of our expanding services that will be provided to the community **(Goal #4)**. This includes efforts to complete development of the Metadata Database and Cyberinfrastructure (EMDAC, formerly known as CODIAC) to access and browse products and data from field projects while integrating with the Community Data Portal.

Tours like this one, to the Marshall Facility where the S-Pol is located, are a staple of EOL's robust Education and Outreach program. EOL scientist Bob Rilling discusses radar operations with students from CU's Weather and Climate Data class.

NCAR is sponsored by the National Science Foundation.



*Postal Address: P.O. Box 3000, Boulder, CO 80307-3000 • Shipping Address: 1850 Table Mesa Drive, Boulder, CO 80305*

## TABLE OF CONTENTS

NCAR is sponsored by the National Science Foundation.



*Postal Address: P.O. Box 3000, Boulder, CO 80307-3000 • Shipping Address: 1850 Table Mesa Drive, Boulder, CO 80305*

Director's Message

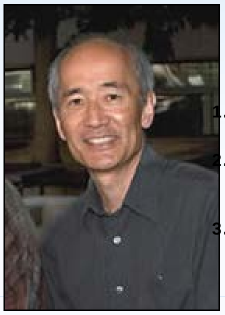
Table of Contents

**Strategic Goals**: Science, Facilities & Technology

Archives and Supplemental Info

# DIRECTOR'S MESSAGE

**Welcome to the Earth Observing Laboratory's 2007 Annual Report.**



EOL is known as a community hub for the collection of data and transfer of knowledge pertaining to observations. The Laboratory also develops new measurement tools to extend community understanding of the atmosphere. EOL specifically fulfills three critical needs:

1. **To lead and serve the community in the provision of observational facilities, infrastructure, and services needed by the atmospheric and related sciences.**
2. **To play a leadership role in the development community-inspired next generation instrumentation and infrastructure while providing existing instruments and infrastructure in support of science.**
3. **To coordinate all aspects of field deployment from pre-project planning through the field phase and subsequent data stewardship.**

Central to EOL's success is our world-class scientific, engineering and project management staff that is respected by the community. Our staff responses to new directions in atmospheric research technology play a leadership role in the development and application of new technology to science objectives.

Scientist Cynthia Twohy makes some notes inside the NSF/NCAR G-V before the PACific Dust EXperiment (PACDEX) in April 2007. PACDEX was the first deployment that truly demonstrated the unique capabilities of the G-V as a long-range research aircraft. During that project the aircraft - stationed at its home base at the Rocky Mountain Metropolitan Airport - was quickly deployed to Japan via Alaska in response to news that a dust storm was gathering over Asia. The G-V was able to catch up with the plume before it started to travel across the Pacific, and for about a week was able to sample the plume as it made its way to North America.

EOL continues to make progress in all five NCAR strategic goals though our main focus is **Goal #5**. EOL supported a number of field campaigns, including METCRAX, PACDEX, CLIMODE, ISPA, CHATS, COPS and PASE in FY2007 and are preparing for some important deployments in 2008. EOL endeavors to identify ways to entrain new users. The official request procedure can appear daunting to someone who has never requested an NSF observing facility. Accordingly, it is our responsibility to help guide them through the process. This is one of the issues we addressed in September when we hosted the first-ever NSF Facilities Users' Workshop. In addition to reaching out to new users by delineating the request process, the workshop provided an opportunity for several hundred members of the NSF facilities' research community to meet and provide us with valuable guidance on core activities such as project planning, data stewardship, software tools, in-field service, and new instrument developments. The NSF Facilities Assessment database was discussed at a community workshop following the NSF Facilities Users' Workshop and will provide descriptive information on atmospheric science facilities and instrumentation in a consistent, easy-to-read format as a resource for the broad atmospheric science and related communities. EOL deployed the NSF/NCAR G-V in the first deployment (PACDEX) that truly demonstrated the unique capabilities as a long-range research aircraft. During PACDEX the aircraft - stationed at its home base at the Rocky Mountain Metropolitan Airport - was quickly deployed to Japan via Alaska in response to news that a dust storm was gathering over Asia. The aircraft was able to catch up with the plume before it started to travel across the Pacific, and for about a week was able to sample the plume as it made its way to North America. The G-V also entered a major upgrade phase in FY07 that will continue into FY09. HAIS instruments began arriving this year and will continue to be delivered until FY2009.

In support of **Goal #1**, Understanding the Earth & Sun System, an EOL scientist was the lead author on a landmark study that puts a new perspective on the "missing" carbon sink and could have political ramifications. A second Airborne Carbon in the Mountain Campaign (ACME) was conducted and three RACCOON (Regional Atmospheric Continuous CO2 Network in the Rocky Mountains) sites were added during the year.

In support of **Goal #2**, Improving Resilience to Weather, Climate and Atmospheric Hazards, EOL scientists collaborated with scientists in Africa to establish a continuous CO2 analysis site at Mt. Kenya Meteorological Observatory, which is World Meteorological Organization site.

EOL places major emphases on diversity and education and outreach activities (**Goal #3**). We will continue our efforts to support SOARS and the EOL Engineering Intern Program, as well as numerous education and outreach activities for K-12 students

and the general public.

EOL is committed to data processing, quality control, and archival for field projects as part of our expanding services that will be provided to the community **(Goal #4)**. This includes efforts to complete development of the Metadata Database and Cyberinfrastructure (EMDAC, formerly known as CODIAC) to access and browse products and data from field projects while integrating with the Community Data Portal.

Tours like this one, to the Marshall Facility where the S-Pol is located, are a staple of EOL's robust Education and Outreach program. EOL scientist Bob Rilling discusses radar operations with students from CU's Weather and Climate Data class.




*Postal Address: P.O. Box 3000, Boulder, CO 80307-3000 • Shipping Address: 1850 Table Mesa Drive, Boulder, CO 80305*

The National Center for Atmospheric Research sponsored by NSF
NCAR
2007 EOL Annual Report



## 4. PROVIDING INNOVATIVE INFORMATION SERVICES

Priority 2: Developing and Providing Advanced Services and Tools

### EOL Metadata Database and Cyber Infrastructure (EMDAC)

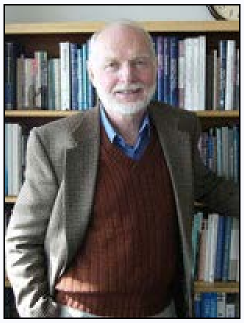
In 2007 EOL will continue to develop EMDAC, providing a next-generation user interface and enhancing the links between EMDAC and the UCAR Community Data Portal (CDP). We will develop tools to make it easier for EOL facilities to manage their datasets via EMDAC, and provide education on their use. To further improve its efficiency, stability and ease of use, we will incorporate EOL's Mass Store Retrieval tool into EMDAC.

In FY 2007 EOL will develop a single integrated codebase for the Field Catalog, providing a secure and robust platform for future projects. In FY08 and FY09 we will solicit feedback from users in order to continue evolving EMDAC to meet user requirements, and will enhance current infrastructure to streamline overall internal data management activities.

### C-130 SATELLITE COMMUNICATION

EOL installed a Satcom system onboard the G-V that provides a new paradigm for operating and communicating with research aircraft. The installation of the new Satcom system on the G-V underscored the importance of such communications capabilities on the C-130, which currently is involved in the majority of field research requiring aircraft. We were recently able to install a state-of-the-art Inmarsat Satcom system on the C-130, which creates a bandwidth comparable to the GV.

## DIRECTOR'S MESSAGE



RAL Director, Brant Foote

Welcome to the Research Applications Laboratory's Annual Report for FY2007. Our mission is to conduct directed research that contributes to the depth of fundamental scientific understanding, to foster the transfer of knowledge and technology for the betterment of life on earth, and to support technology transfer that expands the reach of atmospheric science. We are, at present, an organization with an annual budget of more than $30M and a staff comprised of nearly 200 scientists, software engineers, and management/administration personnel. Although NCAR as a whole is largely funded by the National Science Foundation, RAL receives the vast majority of its funding from other sources such as domestic and international government agencies and private companies interested in exploiting the latest advanced weather technologies.

In 2005 we reorganized the Laboratory into five programs dealing with research and applications in topics related to aviation, homeland security, hydrometeorology, weather systems and assessments, and numerical testbeds. The activities within each of these programs are detailed on the RAL website. In this Annual Report, however, we take the opportunity to present our program in a different way, highlighting the many areas in which our work supports and advances the NCAR Strategic Plan.

Given our focus on applied atmospheric research and technology transfer, it is natural that much of our work contributes to Strategic Goal 2, Priority 2: "Building capacity for coping with weather and climate hazards." It is also important to note, though, that many parts of our program map easily into other goals and priorities of NCAR's Strategic Plan. RAL scientists are engaged in fundamental investigations of earth-atmosphere interactions, in improving community models, in connecting science to decision making and public policy, in building scientific and technical capacity in developing countries, in creating new mathematical and statistical tools, and in improving instruments used to observe the atmosphere. In each of these activities, RAL works to bring science and technology to bear on problems that affect society.

### Highlights

This Annual Report provides short narratives on nearly 40 programs conducted at RAL. Here I highlight five programs that significantly advance NCAR's strategic priorities.

#### Improving prediction of weather, climate and other atmospheric phenomenon

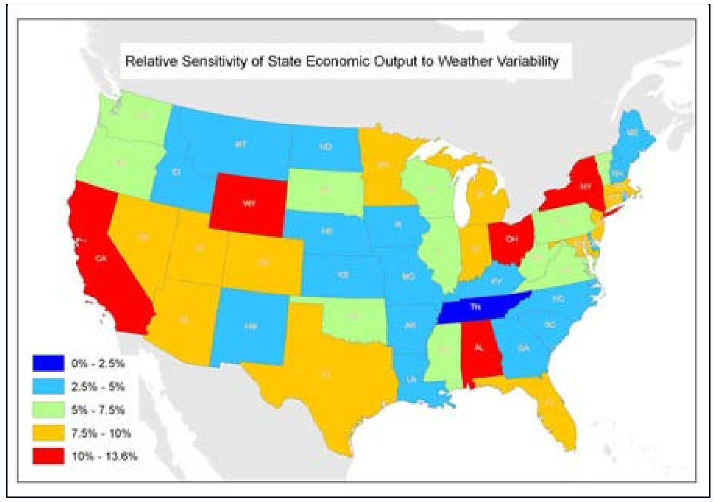
Highlight: Climate Forecasting Applications for Bangladesh

A RAL/ASP post-doc, Thomas Hopson, has worked with Peter Webster and colleagues at the Georgia Institute of Technology and researchers at the Asian Disaster Preparedness Centre to improve flood forecasts for Bangladesh. Using ECMWF forecast products and NASA and NOAA precipitation estimates to produce short-range (1- to 10-day) and long-range (1- to 6-month) forecasts--as well as a statistical model to create 20-25 day forecasts--the team is now issuing operational forecasts designed to provide extended-lead-time to those most likely to be affected by flooding of the Ganges and Bramaputhra Rivers. Good forecasts alone, however, don't necessarily save lives. Dissemination of forecasts to a largely rural population lacking access to electricity, as well as advanced communication technologies, has long been a problem. To address this challenge, the Asian Disaster Preparedness Centre staff teamed with local organizations and the country's Flood Forecasting and Warning Centre to establish a pilot dissemination network in 2006. A series of training workshops was conducted for the people within the pilot regions so they could effectively utilize the CFAB probabilistic discharge forecast information. Improved flood forecasts effectively communicated are credited with saving thousands of lives during the severe floods of July and September 2007.

#### Investigating weather and climate information needs and decision making

Highlight: Societal Impacts Program

In 2007 the Societal Impacts Program, a collaborative effort with ISSE, completed an "Overall U.S. Sector Sensitivity Assessment" which examined the sensitivity and vulnerability of state-level economic productivity to weather across 11 economic "super" sectors. Results indicate that U.S. sensitivity to weather variability is estimated to be about 3.4% of gross domestic product or $260 billion annually. This is the first study of its kind to combine economic and weather data using valid economic methods to assess sector, state, and national economic sensitivity



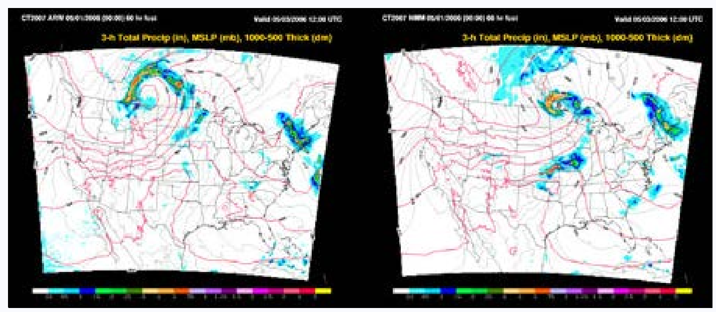

weather variability. Building on this work, SIP staff will focus on specific sectors of the economy to assess the use and value of current and improved weather forecasts.

SIP staff continue to develop and implement the Weather and Society*Integrated Studies (WAS*IS) workshops. This effort trains and empowers practitioners, researchers, and stakeholders to forge new relationships and to use new tools for more effective socio-economic applications and evaluations of weather products. A total of 145 WAS*IS graduates now comprise a growing community of researchers, operational forecasters, academics, and private sector individuals working to infuse social science research and understanding into the weather enterprise

**Community Modeling**

[Highlight: Developmental Testbed Center (DTC)]

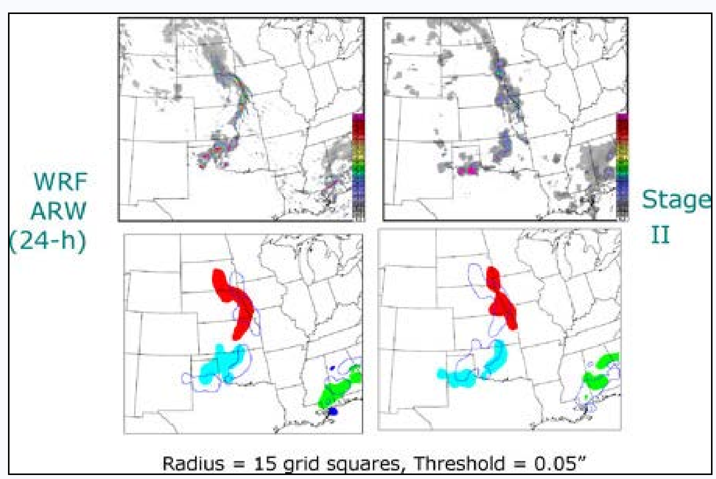
The effort to develop the new Weather Research and Forecasting (WRF) model for the atmospheric community has long been an NCAR priority. While the development effort largely resides in ESSL, the effort to test and evaluate model configurations resides with the DTC. The DTC works primarily to facilitate the transfer of new numerical weather prediction (NWP) technologies from research to operations, thereby accelerating the improvement of numerical weather prediction for the nation. This past year, the DTC conducted an extended core test of WRF's two dynamic solvers: the Advanced Research WRF (ARW) developed by NCAR/MMM, and the Nonhydrostatic Mesoscale Model (NMM) developed by NCEP, to determine whether the small differences in forecast skill between the two dynamic cores for a 24-hour lead time also pertain to longer lead times (i.e., 60 hours). In addition to extending the forecasts out to 60 hours, the DTC is working to determine whether forecast skill is dependent on the computing platform used to generate the forecasts. The DTC remains very focused on serving the community by hosting an active visitor program, conducting WRF tutorials, and providing a support system to aid users in accessing and using WRF codes.


3-h total precipitation (shaded), mean sea level pressure, and 1000-500 mb thickness fields for 60-h forecasts valid at 12 UTC on 3 May 2006. Right panel shows the ARW forecast and left panel shows the NMM forecast. Both WRF configurations used NAM initial and lateral boundary conditions and the same suite of physics parameterizations. For this particular forecast cycle, the ARW and NMM forecasts show rather different evolutions of the cyclone for this extended lead time.

**Conducting computer science, computational science, applied mathematics, statistics, and numerical methods research and development**

[Highlight: Verification research and development]

Much of the work we do at RAL is focused on improving weather forecasts. But how do we know if a new forecast is better than an existing one? Forecast verification by nature is a mathematical activity, and development of improved verification methods requires the application of advanced mathematical, statistical, and computational approaches. To develop and disseminate new forecast verification approaches, RAL scientists conduct research in several areas, including statistical methods, exploratory data analysis, statistical inference, pattern recognition, and evaluation of user needs. Their goal is to produce statistically-valid approaches (e.g., object-based evaluation of precipitation and convective forecasts, distribution-based schemes, etc.) that can provide more meaningful and relevant information about forecast performance, both for those who develop forecasts and for the decision makers who use them. This past year the Verification Group



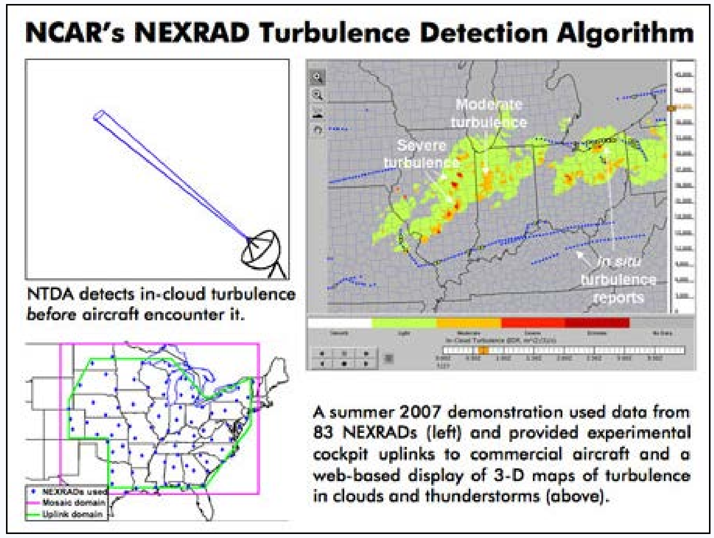
implemented its Method for Object-based Diagnostic Evaluation (MODE) tool within a new verification toolkit it developed for the DTC and the broader NWP community. It also launched an intercomparison project (ICP) for spatial forecast verification methods, involving scientists from around the world who are developing new methods for evaluation of spatial forecasts. A workshop to discuss initial results of the project is planned for Spring 2008.

Example of an application of the MODE, a tool included in MET, as an advanced verification technique provided to the NWP community. By comparing the locations of objects identified using the MODE technique between the forecast (left) and analysis (right) fields, one may identify errors that are difficult or impossible to detect using traditional verification metrics.

**Provide world-class ground, airborne, and space-borne observational facilities and services**

[Highlight: The NEXRAD Turbulence Detection Algorithm (NTDA)]

RAL scientists have worked for more than 15 years to improve the detection of turbulence. Over the past several years they have developed the NEXRAD Turbulence Detection Algorithm (NTDA), a new approach to processing data from the National Weather Service's network of Next Generation Radars (NEXRADs). While aviation users commonly use reflectivity from onboard radars or ground-based radar mosaics to gauge the intensity of a storm, the NTDA detects the wind variations that can shake an aircraft. By directly measuring the in-cloud turbulence intensity, the NTDA will provide airline dispatchers, air traffic managers, and pilots an important new source of information for tactical turbulence avoidance. NTDA has won final approval from the NEXRAD Technical Advisory Committee (TAC) and the NEXRAD Software Recommendation and Evaluation Committee, and the software package has been delivered to the NEXRAD Radar Operations Center. Final testing and deployment of the algorithm on the nation's radars is expected to occur in Summer 2008.




---

***Other Relevant Links***

- [2006 RAL Strategic Plan]
- [2006 RAL Annual Report]
- [Previous ASRs (Annual Scientific Reports)]

***RAL Director's Message***



*Postal Address: P.O. Box 3000, Boulder, CO 80307-3000 • Shipping Address: 1850 Table Mesa Drive, Boulder, CO 80305 • Contact*

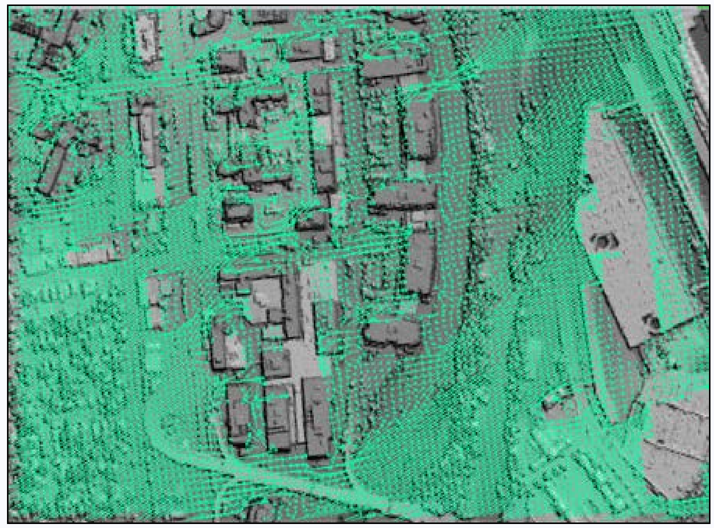
## IMPROVING PREDICTION OF WEATHER, CLIMATE, AND OTHER ATMOSPHERIC PHENOMENA

### Highlight: Pentagon and Urban Shield

The Pentagon, and its 25,000+ occupants, represents a potential target for a terrorist attack using chemical, biological, or radiological material released into the atmosphere. In response to this concern, the Department of Defense has engaged RAL to develop a building-protection system called Pentagon Shield (PS). The PS system assimilates meteorological and contaminant observations from remote and *in-situ* sensors into a complex linked system of models which operate together to represent processes from the mesoscale to the building scale. In the event of a hazardous-material release, the system calculates the properties of the contaminant source (e.g., location), the current characteristics of the contaminant plume, and the future path of the plume.

#### FY07 Accomplishments

A prototype building protection system was installed at the Pentagon in the beginning of the fiscal year. The system incorporates observational data feeds from Doppler radar and Doppler lidar, analyses of 3-dimensional wind fields from Doppler radial winds using VDRAS and VLAS, and numerical weather prediction capabilities from regional to metro scale using the Real-Time Four-Dimensional Data Assimilation System (RTFDDA). It blends observational and model data to provide redundant, continuous spatial and temporal coverage of non-building flow at a horizontal resolution on the order of 100 meters. Inclusion of building-flow effects through the use of two computational fluid dynamics (CFD) models provides characteristic flow fields at a scale of several meters within urban areas. By linking multiple, complex data-assimilation and forecast models to operate synchronously as a single system, to depict the urban boundary layer from the mesoscale to the street-canyon/building scale, the building protection system provides a new ability to detect chemical and aerosol/particulate releases and predict the transport and dispersion of those releases.



Ground level winds in Crystal City VA, just west of Reagan National Airport, from the building aware model. A variety of building flow effects including wake flow reversal and channeling are shown.

The prototype building protection system has been in operation throughout the year and has undergone extensive testing by both the development team and Pentagon staff. In August the domain area was expanded from 4km2 to 8km2 to support additional DoD facilities.

The main task during FY07 has been the development of Urban Shield, a further expansion of the modeling domain to cover a 168km2 area. This has required the development of a distributed computing environment for the building flow diagnostic model, which consists of 21 8km2 tiles computing the flow effects of thousands of buildings. The Urban Shield domain will be used to support emergency response efforts for both the DoD and Arlington County.

#### Plans for 2008

The current emphasis is on deployment and operation and maintenance of the Urban Shield system. Anticipated enhancements during FY08 include upgrading the transport and dispersion model to account for dense-gas effects and include a variety of release source models; inclusion of TDWR data in the VDRAS system; and porting the transport model to run on high-speed GPU hardware.

### Highlight: Flash Flood Forecasting in Bangladesh

In 2000, the U.S. Agency for International Development (USAID) funded the Climate Forecasting Applications for Bangladesh (CFAB) project to provide advanced warning of severe flooding within the country of Bangladesh. CFAB is an innovative program that has made significant scientific and technological progress in flood forecasting and in communicating those forecasts to the Bangladeshi public. This effort is based at the Georgia Institute of Technology, and involves an NCAR/RAL investigator, and colleagues at the Asian Disaster Preparedness Center in Bangkok, Thailand.

While Bangladesh has its own well-developed river forecasting center, it has long been handicapped by very-limited and inconsistent river-discharge data-sharing between India and Bangladesh. As a result, two of its primary rivers, the Brahmaputra and the Ganges, were effectively ungauged basins above their entry point into Bangladesh from India, and advance warning of severe flooding events could only begin once observations were taken of the floodwaters crossing the India-Bangladesh border. To address this problem, CFAB issues operational forecasts designed to provide extended-lead-time information about the upper-catchment discharges of the Brahmaputra and Ganges Rivers before they enter Bangladesh. This is accomplished by utilizing ECMWF forecast products and NASA and NOAA precipitation estimates to produce short-range (1- to 10-day) and long-range (1- to 6-month) forecasts. Medium-range forecasts (20- to 25-day) use a statistical model to bridge these two time scales.

Disseminating forecasts has been a significant logistical challenge. To address this challenge, the Asian Disaster Preparedness Centre staff teamed with Disaster Management Committee chairmen in Bangladesh, with local non-governmental organizations, CARE, and the country's Flood Forecasting and Warning Centre to establish a pilot dissemination network in 2006. A series of training workshops was conducted for the people within the pilot regions so they could effectively utilize the CFAB probabilistic discharge forecast information. Such training was crucial to building acceptance and trust of these citizens whose lives and livelihoods are so dependent on accurate and accurately interpreted forecast information.

**FY2007 Accomplishments**

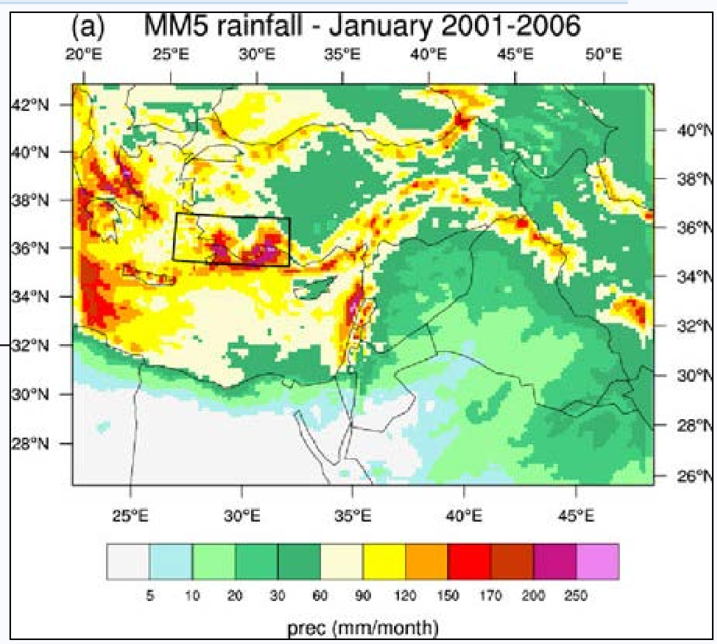
The dissemination network was activated in 2007 in time to test the benefits of the short-range forecasting system for two severe flooding events. The late July event was one of the largest flooding events on record, inundating much of the northern regions of Bangladesh (and India). A report of the effectiveness of CFAB in mitigating the severity of the impacts on the people throughout Bangladesh, preceding and during the event, is given here by Selvaraju Ramasamy with the Asian Disaster Preparedness Centre: "The forecast was communicated to all our partners and local communities through Disaster Management Committee (DMC) chairmen in the pilot unions. The local partners, non-government organization (NGO) networks and DMC members were advised to inform the poorest of the poor, especially those people living in river islands ("chars"). The Flood Forecasting and Warning Centre (FFWC) incorporated the CFAB forecasts into their model and produced water level forecasts for 18 locations in Bangladesh. On the 28th and 29th, meetings were organized in villages near Rangpur (northern Bangladesh), where the Teesta River was flowing just a few inches below the rim. Local communities informed us that the river level at that time was even above the 1998 level. However, they perceived that the river water level would fall, but our forecasts showed a rising trend. We engaged the local partner NGOs to prepare an evacuation plan urgently, which we further discussed with them. The forecast helped our local partners and DMC chairman to prepare evacuation plans and mobilize the resources for response activities in advance." As a result of the advance forecasts, areas that would be hardest hit were evacuated in advance; other areas not forecast to be inundated by flood waters had the warning time they needed to mobilize food and safe drinking water for a week to 10 days, protect their rice seedlings and fishing nets, and raise and protect their fish pods. For the first time 10-day advance official forecasts of significant chances of exceeding danger level in all the gauge stations along the Brahmaputra River were successfully communicated to the public. The dissemination network ultimately reached approximately 110,000 persons in five vulnerable regions within Bangladesh that have little access to advanced communication technology, let alone electricity.

**FY2008 Plans:**

The CFAB team will work to assimilate satellite remotely-sensed river discharge higher up in the Ganges and Brahmaputra watersheds to improve forecast skill and accuracy. The existing forecast warning dissemination network will also be expanded to include additional regions of Bangladesh.

Experience gained through the Bangladesh program will be used in a new effort in Africa. Hopson and David Yates of NCAR plan to work with Ben Lamptey (former RAL post-doc now with the Ghana Met Service), Prof. Robert Brakenridge at Dartmouth, and Prof. MeKonnen Gebremichael at the Univ. of Connecticut to extend the river discharge forecasting scheme to a number of river basins in Africa, with particular emphasis on the Volta River of West Africa and the Awash River in Ethiopia.

## Climate Downscaling with MM5 / WRF: The Climatological Four Dimensional Data Assimilation (C-FDDA) System




The Real Time Four-Dimensional Data Assimilation System developed at RAL generates a mesoscale re-analysis that is consistent with both observations and model dynamics. Even though it was originally developed for dynamic initialization of mesoscale forecasts with gridded data sets that contained fully developed mesoscale processes, the continuous data-assimilation process in RTFDDA is also ideal for generation of mesoscale climatographies. The RTFDDA technology, when applied in this way, is called the Climate-FDDA (C-FDDA) system.

**FY2007 Accomplishments:**

The current C-FDDA infrastructure, which involves performing model simulations, computation of statistical products, and model validation, is used in a number of applications:

- *The Global Climatological Analysis Tool (GCAT)* allows the U.S. National Ground Intelligence Center to generate a climatography for a region of interest with typical boundary layer conditions used to define likely directions and speeds of hazardous-material transport for different seasons and times of day

Climatographic database for the Defense Threat Reduction Agency's (DTRA) Joint Effects Model (JEM): C-FDDA will be used to create a global mosaic of moderate resolution (~40 km) climatographies for the 1979-2005 period. This database will be used by state, and local emergency managers for predicting the effects of accidental or intentional releases of hazardous material, as well as by military commanders for whom an understanding of "typical" atmospheric conditions in a given place on a given day will be useful in preparing strategic battle plans

- *Eastern Mediterranean Studies*: C-FDDA is also being used to study the hydro-climatology of the eastern Mediterranean and the adjacent countries of the Middle East, where the balance between water supply and demand could be significantly altered by climate change. Because precipitation data are not assimilated, and because many aspects of model physics typically need to operate properly for precipitation to be correctly simulated, this will be a good test of C-FDDA's ability to define unobserved or poorly observed fields. We assess the success of the model by comparing the model-simulated precipitation with gage, radar, and satellite-derived estimates of rainfall in terms of the average monthly totals for January. Results are presented below in Figure 1 for six Januaries, from 2001 to 2006.

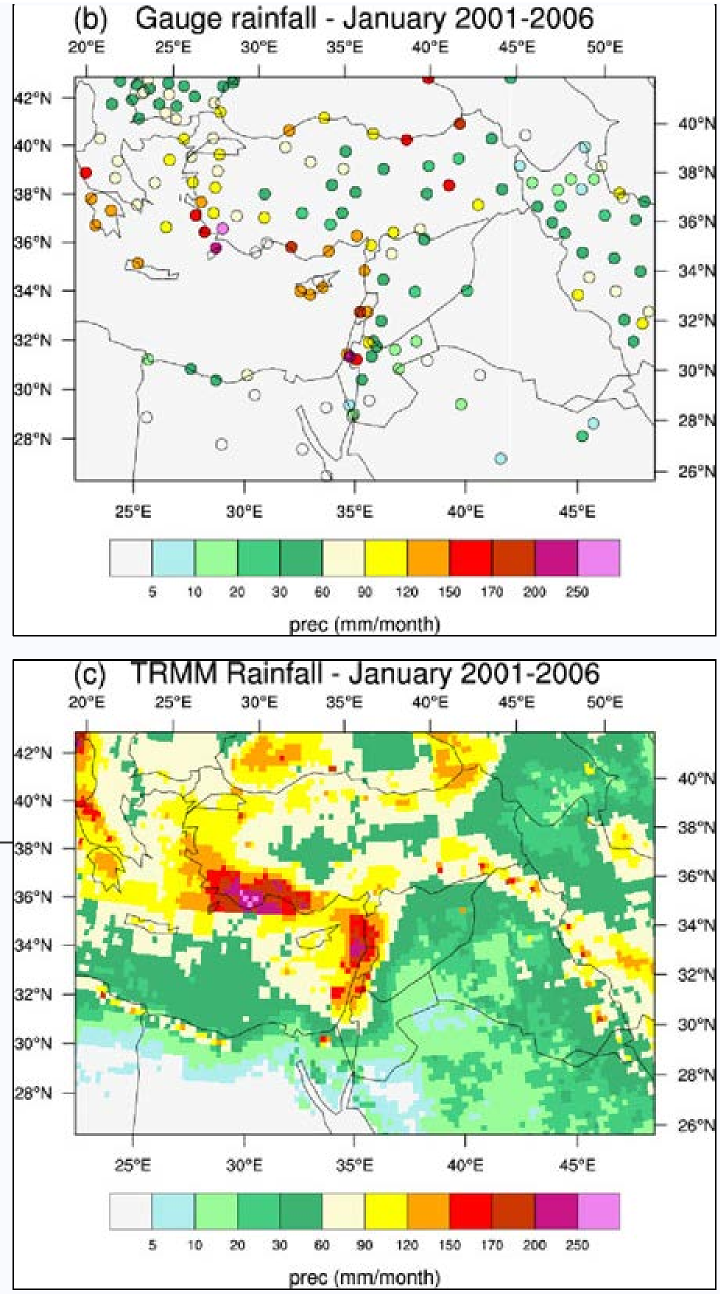



Figure a shows the average January precipitation amount based on MM5 simulations, for the inner computational domain at 15 km horizontal grid spacing. The rain gauge data in Fig. b are consistent with the MM5 estimates, and the coastal amounts of precipitation from the satellite/gauge merged data set show a similar pattern (Fig. c). Visual comparison of the amount and geographic distribution of monthly rainfall between model and the observations reveals considerable skill in the model simulation.

**FY2008 Plans:**

The results presented above are a first step toward downscaling global model simulations of future climates for the Eastern Mediterranean sea and surrounding land area. The preliminary simulation will be repeated later without the use of observations but using "grid nudging" towards the driving analysis to keep the model analysis from drifting. This process of model verification and adaptation for the area will then be repeated with WRF for the entire winter season, when most of the precipitation occurs. After this step, the model that better represents the regional and local climate will be selected and run for the same period using lateral-boundary conditions from a simulation of the present global climate by the NCAR Community Atmospheric Model (CAM) driven by observed sea-surface temperatures and land use. Lastly, the regional model will be run with the lateral-boundary conditions provided by future climate simulations conducted for the Fourth IPCC assessment report with the coupled ocean-land-atmosphere Community Climate System Model, CCSM. This regional-model output will be compared with the regional-model simulation of the present climate in order to assess the impact of future climate forcing scenarios on the components of the water cycle in this geographic area.

### Microphysical Observations and Modeling

It is widely recognized that uncertainties and approximations in the microphysics parameterizations within numerical models are a significant contributor to forecast error and that microphysics parameterization in models needs to be vastly improved in order to significantly improve the skill of precipitation forecasts. An effort to develop multi-species microphysics schemes with accurate particle size distribution models and multiple moment schemes that are refined and verified with observations is progressing. The work involves coordinated system development with MMM through retrospective studies using operational and special field observations, and developing a new bulk microphysical parameterization for the Weather Research and Forecasting (WRF) model. Key areas for model improvement through upgraded microphysical schemes are: 1) quantitative precipitation forecasts and 2) cold pool and outflow formation and evolution.

**FY2007 Accomplishments:**

In recent years polarimetric radar and disdrometer measurements have been used to develop procedures for retrieving particle size distributions (PSDs) in storms. Analyses focused on convective storms reveal that drop distributions are well represented by a constrained-gamma model in which the shape and slope parameters of an assumed three-parameter gamma distribution are related.

This essentially reduces the gamma drop size model to two parameters. For forecasting applications the parameters of choice are the liquid water content and the drop median volume diameter. The constrained-gamma is being refined by improving the method for estimating poorly sampled large drop concentrations, especially those at the leading edge of convection.

A new bulk microphysical scheme for WRF has been developed at RAL, incorporating a new snow PSD based on aircraft observations that represents snow particles as a sum of exponential and gamma distributions. The scheme is unique in that bulk snow density varies inversely with diameter instead of having a constant density as assumed in nearly all other schemes. Moreover, the scheme allows hydrometeors to have a generalized gamma form providing an opportunity to determine sensitivity to distribution shape parameter values as found in observational studies of convective storms. Squall line simulations, including the 12-13 June 2002 IHOP storm, have been run in WRF using this scheme with a model grid spacing of 1.0 km.

RAL scientists conducted a detailed microphysical study of two winter storms occurring during the IMPROVE II field program. An unexpected finding was that freezing drizzle formed outside convective updrafts and ice crystals formed in convective cores. These observations suggest that ice nuclei depletion and ice formation via supersaturation need to be included in microphysical parameterizations in order to properly simulate these types of storms.

The distribution of snowflakes in winter storms along the Front Range in eastern Colorado were examined using a video disdrometer. The snowflakes were dominated by roughly spherical particles having quasi-exponential or superexponential size distributions. Upon melting, raindrop distributions were more peaked. A nearly inverse linear relation between snowflake bulk density and particle median volume diameter was derived. Disdrometer measurements were also used to derive temperature-dependent aggregate terminal velocity relations. For a particular snowflake size it was determined that terminal velocities increase as temperatures increase. At –10ºC an aggregate with an equivalent volume diameter of 10 mm has a mean fall speed of about 0.9 m s–1. At –1ºC the fall speed is 1.5 m s–1. The increase with temperature is attributed greater riming.

### FY2008 Plans:

Expected activities for the coming year include:

- Collecting and analyzing observations that directly address key uncertainties in microphysical parameterization schemes in forecast models
- Improving the representation of processes in microphysical schemes based on observations
- Conducting case studies
- Verifying the storm simulations with observations

## The Colorado REFRACTT Demonstration

The NSF-sponsored **R**efractivity **E**xperiment **F**or H20 **R**esearch **A**nd **C**ollaborative operational **T**echnology **T**ransfer (REFRACTT) was conducted in NE Colorado from June – August 2006. This experiment provided a unique opportunity to collect high resolution, 2-D water vapor fields derived from refractivity data collected by three research Doppler radars and one operational NWS NEXRAD radar. There were two overarching goals of REFRACTT: 1) improve our understanding of near-surface water vapor variability and the role it plays in the initiation of convection and thunderstorms and 2) build operational advocacy for the refractivity moisture retrieval technique for ultimate installation on the U.S. national network of NEXRADs.

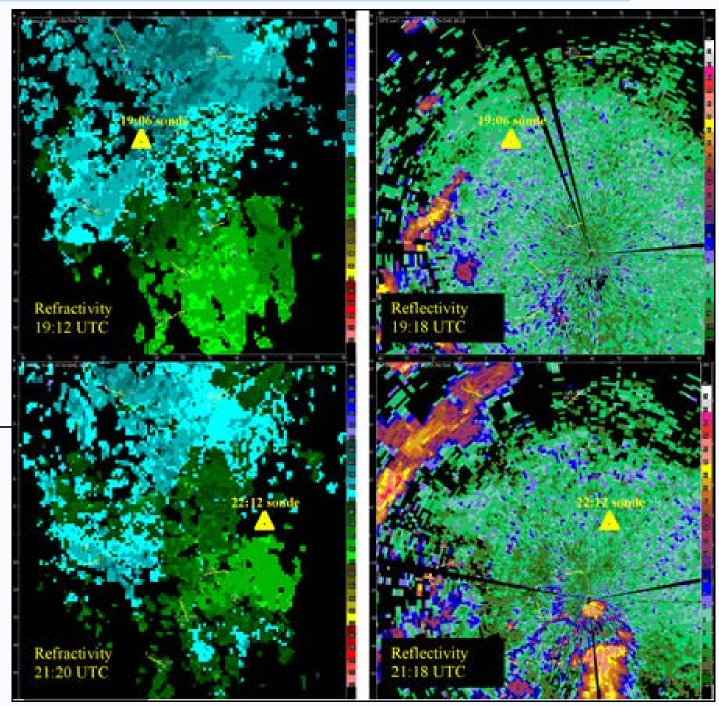



Figure 1. Refractivity and reflectivity plots from 20 July 2006. Yellow triangles show the location of MGAUS soundings launched at 19:06 UTC (red profile in Fig. 2) and 22:12 UTC (blue profile in Fig. 2). The refractivity fields depict the moisture variability in the near-surface portion of the boundary layer. Higher near-surface moisture values (blue) can been seen in the NW portion of the domain, while lower moisture can be seen in the SE portion of the domain.

### FY2007 Accomplishments:

Following the conclusion of real-time REFRACTT operations, data inventory and quality control were begun. The most important challenge was to reprocess the real-time radar refractivity data from the four REFRACTT radars using the best set of calibration datasets and ground target information collected during 2006. Frederic Fabry of McGill University, the author of the radar refractivity technique, assisted Rita Roberts and Eric Nelson in this process. Results from reprocessing the REFRACTT data using these improved calibration files include increased areal coverage of refractivity from the Denver NEXRAD data and elimination of a suspicious, persistent northwest-southeast gradient in *N* that was observed in realtime operations but is no longer present in the reprocessed data.

The considerable effort spent on data quality control and re-calibration of the refractivity fields was in preparation for case study analysis of convection initiation and assimilation of the refractivity data into a numerical model. Approximately six cases from REFRFACTT-2006 have been identified for detailed analysis on the variability of water

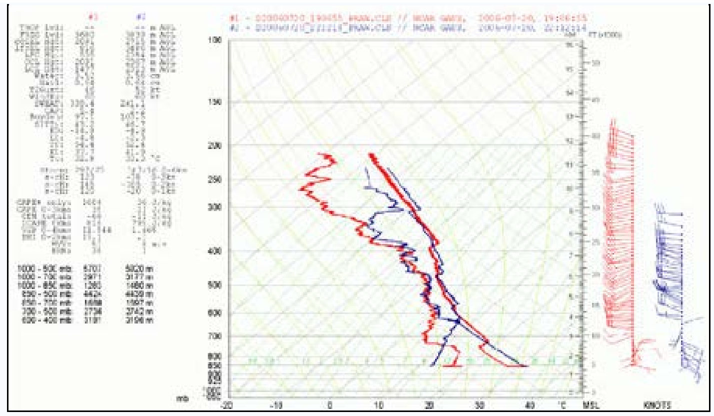


Figure 2. Mobile GAUS soundings from 19:06 and 22:12 UTC illustrate the different moisture profiles and magnitudes at the two different locations within the REFRACTT domain. The lowest 50 mb mean moisture measurements are in good agreement with the moisture measurements retrieved using the refractivity (N) technique. In this case the near-surface moisture (refractivity) field is representative of the moisture present through the depth of the boundary layer.

vapor in the near-surface boundary layer in the pre-storm environment and its role in the initiation of new convection. One of the cases is being highlighted in a paper on REFRACTT-2006 that we are preparing for submission to the Bulletin of the American Meteorological Society (Figures 1 and 2).

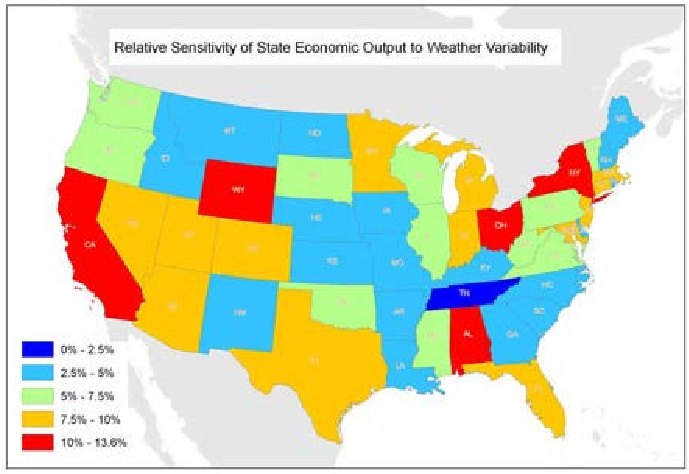
The larger multi-radar domain of moisture information available from REFRACTT enables us to expand upon the refractivity-related research conducted using only the S-Pol radar refractivity fields collected during IHOP. Refractivity observations have the potential to improve numerical prediction of storm initiation and evolution when assimilated into a numerical model. The radar refractivity observations provide a unique dataset that, when assimilated along with the radial velocity and reflectivity, can enhance low-level moisture analysis in numerical models and hence has the potential to improve prediction of convective initiation. Some preliminary studies have been done assimilating IHOP refractivity data into a numerical model with promising results. Current efforts are underway by Jenny Sun and Eunha Lim to assimilate observations collected during the REFRACTT-2006 for a convective event that occurred on August 1, 2006 when a large scale influx of moisture into NE Colorado was observed prior to the onset of an intense line of thunderstorms.

### FY2008 Plans:

Specific research planned for the next year includes documentation of moisture variability and transport during the hours leading up to convection to assess the relative impact of these changes on pre-conditioning the environment towards convection, storm initiation and storm evolution. This includes characterizing the moisture variability along surface convergence boundaries and with terrain-induced features. We propose to incorporate the findings from these studies into storm initiation predictor fields that can be included in the RAL heuristic thunderstorm nowcasting system.

## STRATEGIC PRIORITY: INVESTIGATING WEATHER AND CLIMATE INFORMATION NEEDS AND DECISION MAKING

### Highlight: Societal Impacts Program




All aspects of the U.S. public and economy are directly and indirectly affected by weather. However, few definitive assessments of the use of weather information and weather impacts have been performed, and the information that has been generated from previous studies is hard to locate and synthesize. The Societal Impacts Program (SIP), funded by NOAA's U.S. Weather Research Program (USWRP) and NSF, addresses these gaps by developing and supporting a closer relationship between weather researchers, operational forecasters, relevant end-users, and social scientists concerned with the impacts of weather and weather information on society. SIP activities include primary research, outreach and education, and development and support for the weather impacts community. SIP researchers at NCAR include participants from RAL, ISSE, and MMM, and from COMET in the UCAR Office of Programs.

**FY2007 Accomplishments:**

Current research activities by SIP staff have focused on completing the Overall U.S. Sector Sensitivity Assessment, which examined the sensitivity and vulnerability of state-level economic productivity to weather across 11 economic "super" sectors. Results show that all states and sectors show some sensitivity to weather. State sensitivity ranges from 2.5% (of gross state product) annual variability in Tennessee to 13.6% annual variability in New York, and sector sensitivity ranges from 2.2% annual variability in wholesale trade to 12.1% annual variability in agriculture. Overall U.S. sensitivity to weather variability is estimated to be about 3.4% of gross domestic product or $260 billion annually. This is the first study of its kind to combine economic and weather data using valid economic methods to assess sector, state, and national economic sensitivity weather variability. Building on this work, SIP staff initiated work on sector-specific studies with an emphasis on assessing the use and value of current and improved weather forecasts in addition to sectoral impact of weather. This work is initially focused on the transportation sector.

In other research, an internet-based survey of 1520 U.S. households nationwide was conducted to elicit information on people's sources, perceptions, uses, and values for weather forecasts. People's understanding of, use of, and preferences for weather forecast uncertainty information were also elicited in the survey. Preliminary results indicate that the average household accesses weather forecast information from various sources 115 times a month. Results also show that a majority of people are willing to receive forecasts that contain uncertainty information and that people have preferences for how uncertainty information is conveyed.

Funding from the U.S. Voluntary Cooperation Program Contribution managed by NOAA's NWS International Activities Office was used to develop the "Primer on Economics for National Meteorological and Hydrological Services". This Primer on economic theory, methods, and applications is primarily intended for members of the weather community with the goal of increasing their understanding of economic methods and their applicability in evaluating both the impacts of national meteorological and hydrological services (NMHS) and the associated benefits and costs of those services.

SIP staff continue to collaborate with university researchers in developing and implementing the Weather and Society*Integrated Studies (WAS*IS) workshops. This effort trains and empowers practitioners, researchers, and stakeholders to forge new relationships and to use new tools for more effective socio-economic applications and evaluations of weather products. A total of 145 WAS*IS graduates now comprise a growing community of researchers, operational forecasters, academics, and private sector individuals working to infuse social science research and understanding into the weather enterprise.

**FY2008 Plans:**

SIP staff will focus on the following activities:

- Completion of the Overall U.S. Sector Sensitivity Assessment
- Continued assessment of weather impacts and forecast values in the transportation sector
- Analysis and publication of results from the U.S. household survey on sources, uses, and preferences for weather forecasts

and weather forecast uncertainty information.

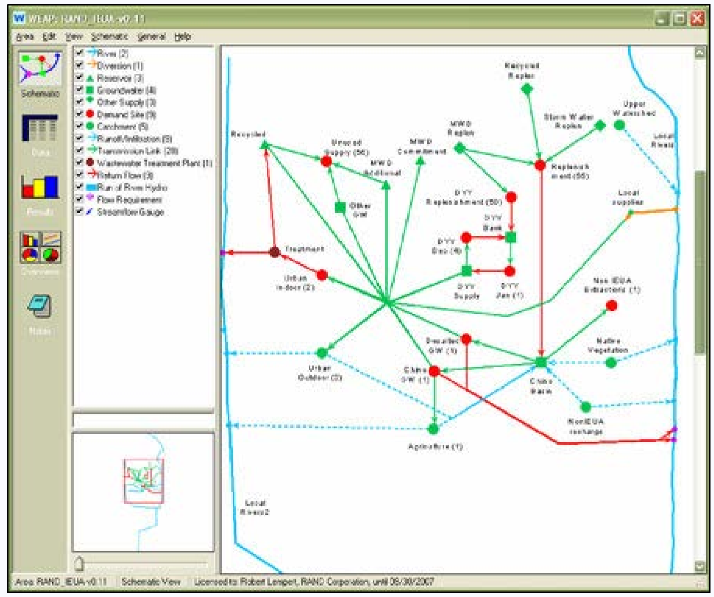
- Examination of the societal impacts and economic values for activities of NOAA's Hydrometeorological Testbed Center in the American River area of California.
- Assessment of the use and communication of extreme weather warning information by forecasters, public officials, the media, and members of the public with a focus on how they receive, interpret, and use warning information
- Preliminary assessment of the reliability, accuracy, and consistency of extreme weather data. Development of an overview of best practices for interacting with users to introduce new decision support technologies into their working environments.
- Publication of an article reviewing the WAS*IS program in the November 2007 issue of the *Bulletin of the American Meteorological Society*

## Decision Support for Water Resource Managers

RAL scientists are working in several arenas to create improved decision support tools and systems for water resource managers.

### FY2007 Accomplishments:

A team of researchers from NCAR, the Stockholm Environment Institute's US Center (SEI-US), and the University of California, Davis and Berkeley, has developed an integrated water resource modeling framework, the Water Evaluation and Planning System, that can be used to investigate medium- to long- term water resource planning and management issues throughout the Sacramento Basin. This framework makes use of climate data derived from a new Bayesian analysis technique that yields frequency distribution functions (FDFs) of regional climate change based on projections from multiple Atmosphere-Ocean models. These FDFs then guide the use of a K-nearest neighbor (K-nn) resampling technique to generate a large ensemble of local weather sequences that reflect this plausible range of regional climate changes. These weather sequences serve as input to water management models (e.g. WEAP) to evaluate possible climate change impacts on a regional or local water system. In one case-study to date, the method has been applied to the Inland Empire Utilities Agency (IEUA) in Southern California to look at probabilistically-weighted water management futures (Figure 1).



A schematic of the Inland Empire Utility Agency (IEUA) in WEAP21.

A second program, funded by NOAA, looks at the competition between water demands from cities in the Colorado Front Range and traditional agricultural water users. The feverish competition for water in this area may result in the transfer of a great deal of water before management innovations can be fully developed or the playing field more fairly balanced between small farming interests and cities with their extensive legal and financial resources. Researchers from RAL and C.U. are examining the competing interests for water resources with an eye to protecting future-opportunity interests for rural users, as well as the public's interests in recreation, environmental protection and general quality of life. Work also focuses on exploring new legal forms for water transfer using market mechanisms and increased flexibility, including short-term reversible leases or "water banks", and longer-term commitments to move water under specified conditions. In 2007 the team brought together a number of representative stakeholders at a workshop at Colorado State University to further discuss these issues.

A third effort, joint with SERE/ISSE, remains focused on an-going collaboration with the American Water Works Association's Research Foundation (AwwaRF). Following the publication of their very successful climate change primer for the drinking water utility industry, the NCAR researchers are working to implement a locally-relevant, structured process to help utilities address climate change impact and adaptation options. Several water utilities in California, Colorado, Massachusetts, New York, and North Carolina are participating in this effort.

### FY2008 Plans:

An extensive literature review and outreach to western water interests and relevant professional societies has confirmed that there are enormous gaps in our knowledge of the biological impacts of water transfers from agricultural to urban uses, and surprisingly, no known research agenda to address these gaps. In particular, there are continental-scale estimates and micro-scale research, but regionally little in the way of a "big picture" helpful for identifying thresholds, avoiding problems, or anticipating consequences. In 2008 the NCAR/CU researchers will team with the US Geological Survey and the US Fish and Wildlife Service to write a paper that will address these overarching issues.

A new NOAA grant will support the development of a regional model of water management possibilities that could help create long-term agricultural water security in eastern Colorado. The WEAP model will be used to provide a balance of planning capacity with fast processing of flexible scenarios, incorporating critical place-specificity in climate, hydrology, water law, institutional and infrastructural inputs, and supporting geographic information systems for visualization of possibilities. This work is expected to provide an informational platform which competing water interests can use to work toward sustaining small farms with improved economics and opportunity, and supporting rural economies.

Work will also begin to generate ensembles of synthetic daily weather data for sites within the Pacific Gas and Electric Company (PG&E) service area. Climate data will be simulated using the K-nearest neighbor (KNN) resampling technique, used to mimic potential future climate change in a statistically rigorous manner relevant for PG&E. Historical temperature data, which will be provided by PG&E, are used by the KNN method, which in-turn is informed by an analysis of global climate models. We will document the method used to simulate the data and provide a statistical analysis of the historical and simulated data.

RAL and SERE will also continue to work with partnering utilities involved in the AwwaRF/NCAR collaboration, formalizing the structured process that will help them address climate change impact and adaptation options. The decision analytic approach includes: 1) a problem definition phase; 2) the development and/or modification of system-specific Integrated Water Resource Management (IWRM) models; 3) development of probabilistic climate change scenarios; and 4) implementation of the structured process to examine alternative investment and adaptation strategies in light of the likely range of future climate-related changes in local hydrologic conditions.




*Postal Address: P.O. Box 3000, Boulder, CO 80307-3000 • Shipping Address: 1850 Table Mesa Drive, Boulder, CO 80305 • Contact*

## TABLE OF CONTENTS

***Other Relevant Links***

2006 RAL Strategic Plan
2006 RAL Annual Report
Previous RAL ASRs (Annual Scientific Reports)

***Table of Contents***



*Postal Address: P.O. Box 3000, Boulder, CO 80307-3000 • Shipping Address: 1850 Table Mesa Drive, Boulder, CO 80305 • Contact*

Director's Message
Table of Contents
**Strategic Goals**: Science, Facilities & Technology
Archives and Supplemental Info

## NCAR STRATEGIC PRIORITY 4: COMMUNITY MODELING

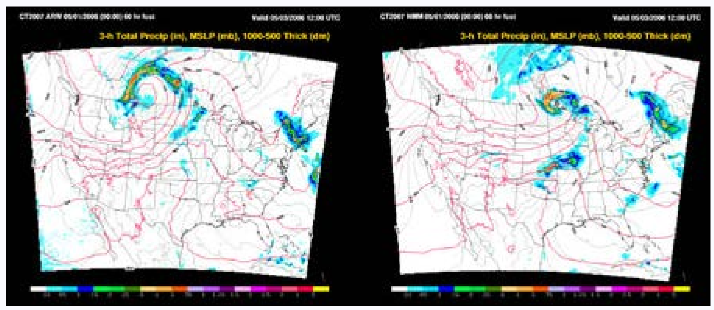
### Highlight: Developmental Testbed Center (DTC)

The Developmental Testbed Center (DTC) is a national facility created in 2003 to facilitate the interaction of the operational and research communities in accelerating the improvement of Numerical Weather Prediction (NWP) for the U.S. The DTC effort at NCAR includes:

- A program for testing and evaluating various WRF model configurations so that the operational community can plan for changes and upgrades to the operational models and the research community has access to the latest NWP systems for testing and research.
- A visitor program that invites members from the operational and research communities to participate in the testing and evaluation of WRF.
- A user support system that provides documentation, tutorials, and helpdesk capabilities to aid users in both the research and operational communities in accessing and using WRF codes.

**FY2007 Accomplishments:**

*WRF Testing and Evaluation:* The current WRF Software Framework (WSF) supports two dynamic solvers: the Advanced Research WRF (ARW) developed by NCAR/MMM, and the Nonhydrostatic Mesoscale Model (NMM) developed by NCEP. In light of the results from the DTC's 2006 Core Test, NOAA requested the DTC undertake an extended Core Test to determine whether the small differences in forecast skill between the two dynamic cores for 24 hour lead time also pertain to longer lead times (i.e., 60 hours). Preparations for this intensive testing of the NMM and ARW were completed near the end of FY07 and the actual runs are currently underway. In addition to extending the forecasts out to 60 hours, the DTC will be performing a platform comparison to test whether forecast skill is dependent on the computing platform used to generate the forecasts.



3-h total precipitation (shaded), mean sea level pressure, and 1000-500 mb thickness fields for 60-h forecasts valid at 12 UTC on 3 May 2006. Right panel shows the ARW forecast and left panel shows the NMM forecast. Both WRF configurations used NAM initial and lateral boundary conditions and the same suite of physics parameterizations. For this particular forecast cycle, the ARW and NMM forecasts show rather different evolutions of the cyclone for this extended lead time.

*WRF Code Management:* Based on extensive discussions between DTC staff, WRF developers, and the panel for the DTC Technical Review held in September 2007, the concept of a WRF Reference Code maintained by the DTC has evolved to a concept of WRF Reference Configurations. The configuration concept is much better suited to the current status of the WRF Code Repository and will likely also extend to how the DTC handles supporting the Operational Code or rather Operational Configurations to the user community.

*WRF Tutorials* The DTC conducted a WRF-NMM Tutorial in February 2007 and then joined efforts with MMM to conduct the first joint WRF Tutorial in July 2007 covering both the NMM and ARW dynamic cores. These tutorials include lectures on the pre-processor, model, and post-processing tools, as well as practical sessions that allow the participants to gain hands-on experience building and running each component of the end-to-end system. The tutorial participants once again represented a broad cross-section of both the national and international community.

*DTC Verification System:* During FY07, the DTC undertook the critical task of assembling a state-of-the-art verification toolkit, the Model Evaluation Tools (MET). This work is highlighted in a separate section of this RAL Annual Report.

*DTC Visitor Program:* The DTC released an "Announcement of Opportunity" for its 2007-2008 Visitor Program in March 2007. The DTC received 27 proposals and 10 of these proposals were selected for funding. These projects address much needed work in the areas of physics parameterizations, ensembles, verification techniques, and idealized capability for the NMM dynamic core.

**FY2008 Plans:**

*WRF Testing and Evaluation:* The DTC will complete the runs for its extended Core Test, analyze the results, and provide a report summarizing the results. This testing activity will likely lead to the first designations of Reference Configurations. The DTC will also undertake planning and execution of another Core Test comparing the forecast skill of the two dynamic cores for higher resolution forecasts (e.g., grid spacing on the order of 1 km). And finally, the DTC is planning to add data assimilation to its end-to-end system for testing and evaluation.

*WRF Reference Code Management:* The DTC will continue to develop the concept of Reference and Operational Configurations by putting together a written document describing the process for designating these configurations, the information and support that will be provided for these configurations, and how decisions will be made with respect to retiring configurations.

*WRF Tutorials:* Bi-annual WRF Tutorials are planned for FY08 (i.e., winter and summer offerings). The winter tutorial will cover basically the same material covered during summer 2007, whereas the summer 2008 tutorial will likely be extended from one week to two weeks in length to accommodate a wider range of information.

*DTC Verification System:* During FY08, the DTC plans to offer the first official release of MET to the community. Work will continue to extend the capabilities of MET to include a broader spectrum of verification capabilities, development of an online tutorial, and inclusion of MET in the WRF Tutorial in July 2008. Members of the verification community will also be invited to join DTC staff for a workshop to be held in spring 2008 to discuss new capabilities for MET and the development of a verification system in which MET could reside.

*DTC Visitor Program*: Another "Announcement of Opportunity" is expected to be issued in February 2008.

## Data Assimilation Testbed Center

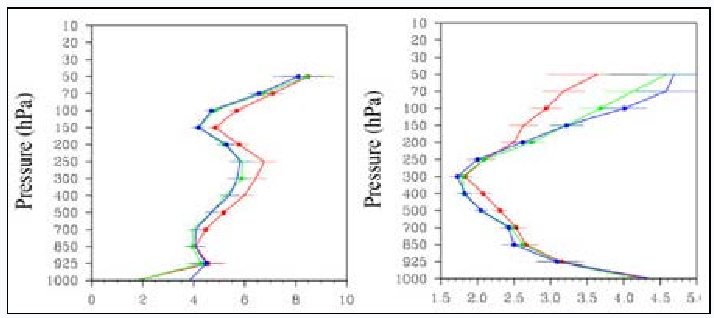
Established in August 2006, the Data Assimilation Testbed Center is collocated with the WRF Developmental Testbed Center within NCAR/RAL's Joint Numerical Testbed (JNT). The DATC provides data assimilation resources and expertise to the NCAR and external research communities.

### FY2007 Accomplishments

In its first year, the DATC has performed detailed assessments of data assimilation capabilities in a number of testbeds:

*Testing the Impact of COSMIC in Antarctica*

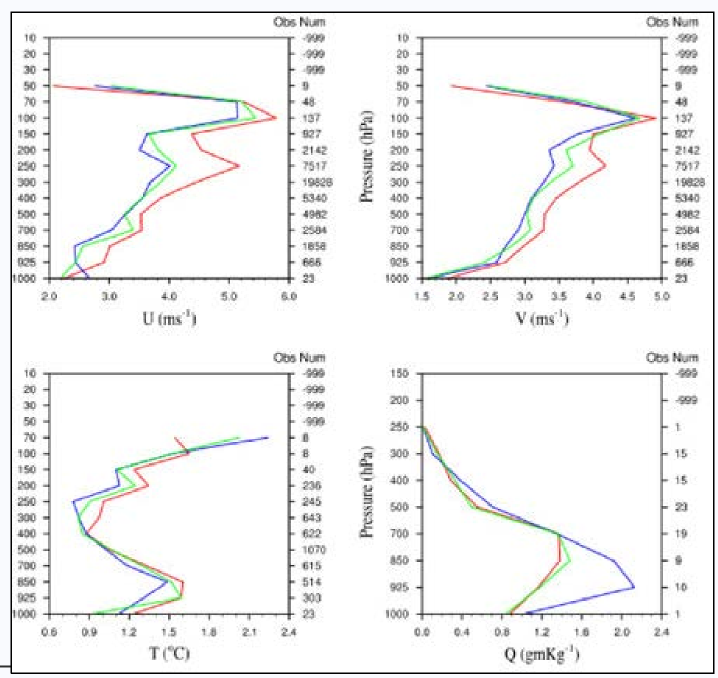
Using data from the Antarctic Mesoscale Prediction System (AMPS) project, the DATC has performed a month-long evaluation of the impact of COSMIC local refractivity observations on Antarctic weather forecasts. The WRF-ARW model and WRF-Var were cycled continuously through the month of October 2006 (start of the Antarctic field season) and forecasts were integrated out to 72hrs four times a day using conventional observations with and without COSMIC data assimilated. The study found a significant positive impact of COSMIC refractivity assimilation on wind forecasts and tropospheric temperature and surface pressure. One negative result appears to be a degradation of stratospheric temperature forecasts, potentially due to excess gravity wave activity at the highest levels of the model and/or an overly simplistic representation of ozone in WRF. This study provided a rational and scientific basis for the operational implementation of COSMIC data in AMPS and also indicated areas of the WRF model that require further attention. Results from AMPS WRF-Var work were presented at the 2007 WRF Workshop and at the 2nd Antarctic Meteorological Observation, Modeling, and Forecasting Workshop in Rome, Italy, in June 2007.




36hr WRF forecast verification against Antarctic sondes: Conventional observations only (red), conventional plus COSMIC (green), and retuned conventional plus COSMIC (blue).

*Testing WRF-ARW cycling with WRF-Var in AFWA's S. W. Asia Theater*

To prepare for the Air Force Weather Agency's anticipated worldwide regional implementation of WRF-ARW and WRF-Var, the DATC has established an AFWA testbed using global observations. Initial studies are focused on optimal data assimilation/forecast configurations on a South-West Asia regional domain. Currently, the data assimilation is performed every six hours, with the cycle being broken every twelve hours to blend back to NCEP's global forecast system. The possibility of full-cycling (i.e. continuously cycling WRF-Var and WRF-ARW without reverting back to the global model data) has been tested in DATC in 2007. Figure 2 compares the 24hr forecast skill of update-cycling, full-cycling, and no data assimilation (i.e. WRF-ARW run from interpolated GFS analyses). Clearly, both cycling permutations produce superior forecasts to those run without regional data assimilation, with update-cycling producing the most accurate forecasts. These results provide a benchmark for further full-cycling experiments to be performed later in 2007 to assess the impact of AMSU and AIRS radiances, COSMIC, and tuned error covariance.




### FY2008 Plans

In 2008, the DATC will continue detailed testing of data assimilation capabilities in a variety of applications. The Antarctic, Korean, and Taiwanese WRF NWPs testbeds will be supplemented by the first reanalysis testbed, a 10-year Arctic system reanalysis based on a 10-year (2000-2010) period and the WRF-ARW enhanced with polar physics.

24hr forecast verification (against all available conventional observations) for a) U-Wind, b) V-wind, c) Temperature, and d) Specific humidity. No data assimilation (red), update-cycling (blue), and full-cycling (green) experiments are shown.

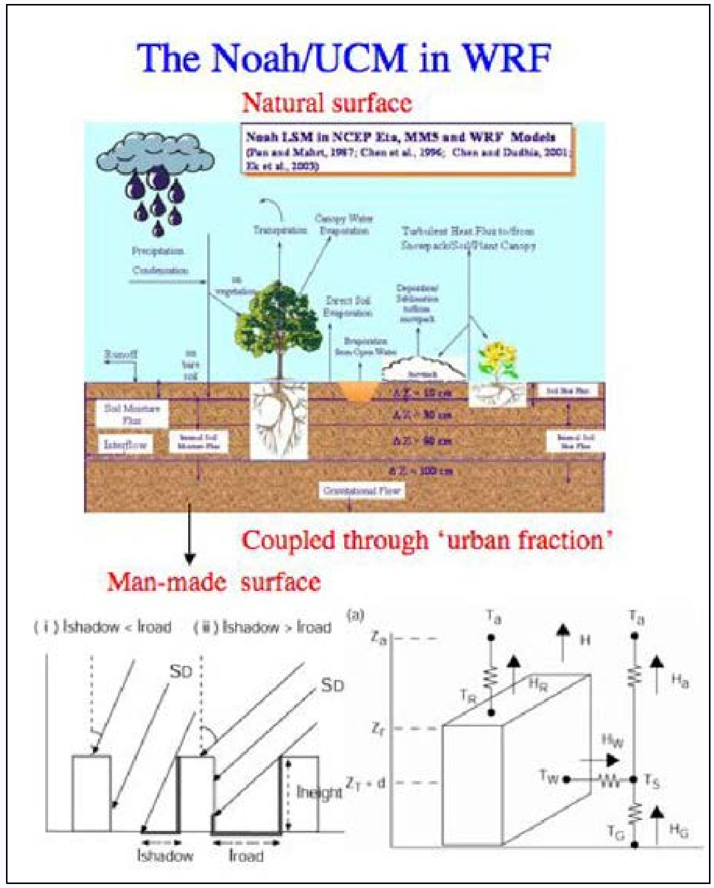
The DATC will also begin to test and support the JCSDA's GSI algorithm in 2008, initially to NCAR colleagues and visitors. This effort is part of the larger plan to work with the JCSDA (including NASA, the Navy, NOAA, and AFWA) in developing next-generation assimilation algorithms suitable for both research and operational communities.

## Land Surface Modeling

RAL scientists work to understand, through theoretical and observational studies, the complex interactions (biophysical, hydrological, and bio-geochemical) between the land-surface and the atmosphere at micro- and mesoscales. The ultimate goal is to integrate such knowledge into numerical mesoscale weather prediction and regional climate models to improve prediction of the impacts of land-surface processes on regional weather, climate, and hydrology. Land surface modeling efforts were funded in FY07 by NSF, the Air Force Weather Agency (AFWA), NOAA, NASA, DTRA, and the CFD Research Corporation.

### FY2007 Accomplishments:

As part of a major collaborative effort among NCAR, NECP, NASA/GSFC, AFWA and several university groups, RAL scientists supported the development of the Unified Noah land surface model (LSM) for the numerical weather prediction community and its implementation in the Weather Research and Forecast (WRF) model. To meet the need for accurate weather prediction over urban areas (especially important for the air-quality modeling community), an advanced single-layer urban canopy model was coupled to Noah (Fig. 1) and released in WRF V2.2. In a new project started in FY07, supported by the Defense Threat Reduction Agency (DTRA), we are working towards improving the land-use data set in the DTRA Joint Effects Model/Hazard Prediction and Assessment Capability (JEM/HPAC) system and in WRF.




(Top) The coupled Noah/urban canopy model (UCM) in the community mesoscale WRF model. (Bottom) Application of the WRF/Noah/Urban coupled modeling system over Salt Lake City and surrounding complex.

The team also applied the Noah-urban modeling system, with 1-km grid spacing, in WRF, where the resulting forecast fields were used to drive a CFD-model-based transport and dispersion model for a case study during the Joint Urban 2003 field experiment conducted in Okalahoma City. Verification results indicate that the use of the WRF forecasts by the quasi-steady CFD-Urban model has resulted in a significant improvement (by four or five times) in the accuracy of transport and dispersion calculations, compared with input from a single sounding instead of WRF.

Although the important role of soil moisture in the development of deep-convection has been recognized, it remains the most difficult variable to obtain because there is no routine high-resolution observation of soil moisture at the continental scale. Thus, a High-Resolution Land Data Assimilation System (HRLDAS) has been developed to support the WRF/Noah coupled land surface modeling system and ATEC range forecasts. It uses observed hourly precipitation, solar radiation derived from satellite, and analyzed surface wind and temperature to force a land-surface model to simulate the evolution of soil moisture. In this system, the NCEP/NOAA hourly 4-km rainfall analysis, based on NEXRAD and rain-gauge observations, is used so that errors in soil moisture caused by precipitation and radiation bias in coupled modeling systems could be avoided. Long-term HRLDAS simulations were conducted over the U.S. Southern Great Plains region to support RAL land-atmospheric interaction studies for IHOP 2002.

### FY2008 Plans:

- Use MODIS vegetation products and photosynthesis-based model (GEM) to improve the representation of vegetation transpiration processes in the Noah land surface model.
- Implement a multi-layer urban canopy model in the WRF/Noah coupled modeling system and improve the representation of building morphology.
- Using Kalman filter technique to assimilate the profile of soil moisture and temperature in the high-resolution land data assimilation system.

- Investigate the coupling between surface hydrology, biogenic emission and vegetation processes using the Noah, GEM, canopy model, and MEGAN models.




*Postal Address: P.O. Box 3000, Boulder, CO 80307-3000 • Shipping Address: 1850 Table Mesa Drive, Boulder, CO 80305 • Contact*

## 4. PROVIDING INNOVATIVE INFORMATION SERVICES

**NCAR Strategic Priority: Conducting Computer Science, Computational Science, Applied Mathematics, Statistics, and Numerical Methods R&D**

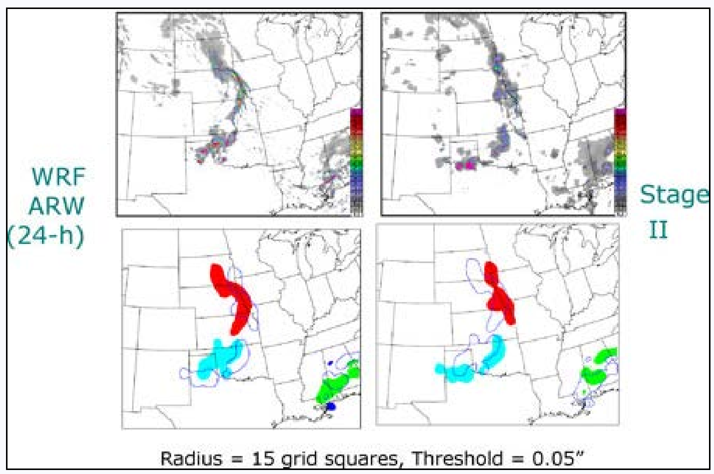
### Highlight: Verification Research and Development

Forecast verification and evaluation activities typically are based on relatively simple metrics regarding the meteorological performance of forecasts and forecasting systems. Metrics such as the Probability of Detection, Root Mean Squared Error, and Equitable Threat Score provide information that is useful for monitoring changes in performance of single aspects of forecast performance with time. However, they generally do not provide information that can be used to improve the forecasts, or that can be used by end users (including forecasters) for decision making. Moreover, it is possible for forecasts that are quite useful – including high resolution forecasts – to have very poor scores when evaluated by using these standard metrics. In response to these limitations, the RAL Verification Group develops improved verification approaches and tools that provide more meaningful and relevant information about forecast performance. The focus of this effort is on diagnostic, statistically valid approaches, including object-based evaluation of precipitation and convective forecasts and other approaches (e.g., distribution-based) that can provide more useful information – for forecast developers as well as forecast *users* – about forecast performance.

Development and dissemination of new forecast verification approaches requires research and application in several areas, including statistical methods, exploratory data analysis, statistical inference, pattern recognition, and evaluation of user needs.

**FY07 Accomplishments:**

The Method for Object-based Diagnostic Evaluation (MODE), developed by RAL and MMM scientists and software engineers, provides one approach for diagnostic evaluation of spatial forecasts that directly measures the performance of the forecasts in terms of specific attributes – spatial displacement, intensity, storm size, and so on – and attributes may be designed to represent the use of the forecast for specific applications (Figure 1).



Example of an application of the MODE, a tool included in MET, as an advanced verification technique provided to the NWP community. By comparing the locations of objects identified using the MODE technique between the forecast (left) and analysis (right) fields, one may identify errors that are difficult or impossible to detect using traditional verification metrics.

During the past year MODE was implemented as a tool in the Model Evaluation Tools (MET) developed by the Developmental Testbed Center (DTC ) and has been disseminated to the numerical weather prediction (NWP) community. New methods were also developed to summarize output of the MODE tool which could be useful for decision makers as well as for forecast developers for whom the information may suggest an error in timing in the model, which could lead to model improvements.

The team has also organized and coordinated an intercomparison project (ICP) for spatial forecast verification methods, involving scientists from around the world who are developing new methods for evaluation of spatial forecasts. The project will include applications of all of the methods to the same real and idealized datasets, and comparisons of the capabilities of the various methods, with a goal of determining which methods should be applied to achieve different goals, and to identify the kinds of information that each method can provide. The ICP is also expected to lead to discussions within the verification and NWP communities regarding development of a protocol for judging when new verification methods are ready to be applied in operational settings.

We continued strong efforts in advocacy through participation in, and leadership of the WMO's Joint Working Group on Verification (JWGV), numerous conferences and workshops, statistical support for forecast evaluation studies undertaken by the RAL Developmental Testbed Center (DTC), and applications of MODE by various scientists at NCAR and in the wider atmospheric science community. The RAL verification group also organized and hosted a verification workshop on state-of-the-art verification methods in February 2007, which included international verification and NWP experts.

**FY2008 Plans:**

Attributes of the MODE approach will be more thoroughly investigated, including extensive examination of the impacts of variations in spatial scale, as represented by the parameters used to define objects. New diagnostic methods will be developed to summarize object attribute comparisons, to provide greater understanding of model performance. The approach for incorporating the time dimension in MODE analyses will be further investigated and enhanced.

The verification method intercomparison project (ICP) will continue, and a white paper summarizing the various methods will be submitted to a journal. We also plan to hold a workshop among the participants during the spring to begin discussions of the results of the ICP evaluations.

MODE will be applied to additional datasets and types of forecasts. An initial effort will be made to examine ensemble forecasts of precipitation from an object perspective. MODE will also be applied to convective and precipitation forecasts as part of NCAR's program on Short Term Explicit Prediction.

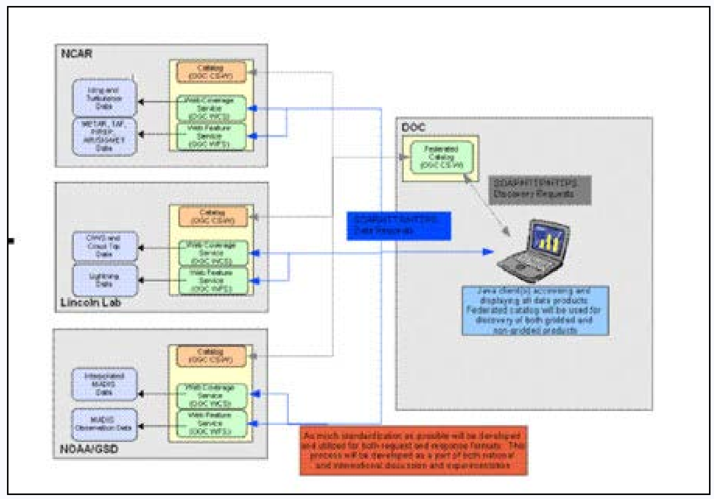
The concept of user-focused verification will be further developed and presented to the forecasting and verification communities.

**Long-Term Goals:**

The long-term goals of the verification research program are to (a) develop a stable version the MODE approach that can be applied in evaluations of a variety of weather, air quality, climate, and other forecast variables, including precipitation, convection, and other variables that can be represented spatially; (b) enhance the MODE approach to take into account the time dimension and other capabilities desired for applications of the technique; (c) develop user-relevant verification approaches in the context of the needs of specific end users; (d) develop new user-relevant verification approaches for evaluation of probabilistic and ensemble forecasts; (e) develop and disseminate new methods for making statistical inferences about verification measures (i.e., methods to take into account the uncertainty in verification measures); and (f) continue to facilitate activities of the international verification community, and further advance the application of improved verification measures in operational settings.

## NextGeneration Network Enabled Weather

Since its inception nine years ago, the Aviation Digital Data Service (ADDS) has emphasized user-friendly and intuitive weather graphics to provide users with enhanced weather situational awareness. Within the ADDS system, there exists a fundamental infrastructure for serving weather data in a network-centric manner. The ADDS Flight Path Tool (FPT), for example, enables human users to visualize specific portions from immense volumes of data using a highly interactive software application. The software renders the graphics from the digital data after it is passed over the Internet. In contrast, most Internet weather resources create graphics internally then distribute the final graphical product to users.




While graphical presentations of weather data are useful to human users, there is also a need for machine-to-machine data dissemination to provide data to decision support tools and systems that manage air traffic. The challenge is to provide four-dimensional weather data using standard formats for the request and delivery.

To address this problem, NCAR-RAL has teamed with MIT-Lincoln Labs and NOAA-Global Systems Division to explore standards-based, net-centric data access. The goal of this research is to create a virtual weather database spanning more than one physical location, organization, and data system. To date, these three organizations are involved in various distribution and data access mechanisms but all using their own, internally-developed formats. Starting in late 2007, each laboratory intends to research open standards and technologies to share their data sources.

**FY2007 Accomplishments:**

The majority of this year's effort has been to instantiate a gridded weather products server using a Web Coverage Service (WCS), a specification of the Open Geospatial Consortium (OGC). The OGC is an international standards body with over 300 active member organizations and is responsible for developing and maintaining standards related to geospatial data and access mechanisms. Using the WCS specification, NCAR-RAL now distributes a variety of three-dimensional gridded weather products including analyses and forecasts of icing, turbulence, winds, and temperatures.

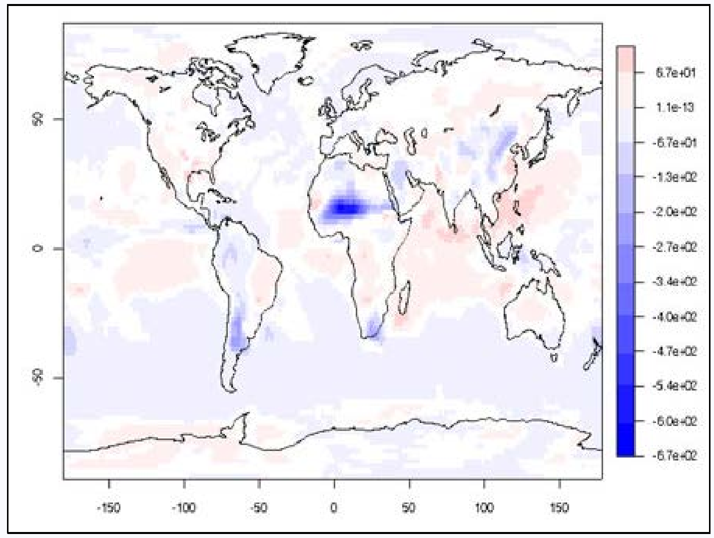
Additionally, the data available through the WCS services were exposed in a catalog as an OGC Catalogue Service (CS-W). This allows the automated discovery of data as it comes in and provides information about the data that may be accessed through the WCS services. This includes information such as the quality of the data, the organization that originally created or gathered it, the data format in which it is available, and its geographic extent.

**FY2008 Plans:**

Future work will include non-gridded products (such as METARs, PIREPs, AIR/SIGMETs, and TAFs) and related standards to distribute them. These new products as well as the gridded products will be accessible via a single NNEW catalog that allows the products of each organization to be treated transparently as a virtual database. The means to integrate JMBL data sources into the virtual database will be explored, as JMBL will most likely be a part of international weather data distribution.

### Modeling Weather Extremes

In the third and fourth Assessment Reports of the Intergovernmental Panel on Climate Change, discussions of the impacts of climate change on severe thunderstorms have been limited to comments regarding the difficulty of using storm report databases to determine if changes have taken place historically.  Because convective storms occur on very fine spatial scales, it is not possible to directly resolve such phenomena from coarse-scale global datasets.  However, large-scale indicators can be employed to study trends in environments that are conducive to such severe weather. Initial work in this area has focused on identification of useful measures of large-scale environments that are relevant for severe thunderstorm formation based on NCAR global model reanalysis data. These data have been used to investigate trends in the large scale environmental characteristics, as well as spatial and extreme value distribution attributes. The approaches developed for the reanalysis data will be extended to Global Climate Model (GCM) projections of future climate, to determine the expected characteristics of severe weather environments associated with future climate change scenarios.



Trends in annual CAPE (J/kg) * shear (m/s) 95th percentile values at individual grid points as estimated using linear models applied to CAPE and shear values estimated using global model reanalysis data over a 42-year period. CAPE is the convective available potential energy and Shear is the magnitude of the vector difference between the surface and 6-km estimated wind. The grid resolution is approximately 1.875 degrees longitude by 1.915 degrees latitude, yielding 17,856 grid points, on a 192 x 94 grid. Temporally, values are available every 6 hours over 42 years (1958 through 1999). Only areas with significant trends are shown; the False Discovery Rate was set to 0.05.

This work has led to identification of several statistical challenges as well as new areas for research. Statistical challenges include methods for modeling extreme values in a spatial context; addressing the issue of multiple comparisons inherent in working with gridded data; and making inferences about changes in distribution parameters.

#### FY2007 Accomplishments

The global dataset of convective parameters that has been created using the NCAR model reanalyses was further analyzed during FY07. The reanalysis dataset has been analyzed to include two important severe weather indicators, Convective Available Potential Energy (CAPE) and vertical shear.  Analyses of trends in CAPE, Shear, and functions of these variables, such as CAPE x Shear, were applied to the global set of gridpoints included in this dataset. A false discovery rate (FDR) procedure was employed to account for the effects of multiple hypothesis testing and to make the analysis spatially robust (Figure 1).  Two manuscripts based on these analyses are in preparation, and several presentations have been made.

The focus of this work has begun to shift to consider the evaluation of convective extremes in projections of a changed climate. Output of the NCAR Community Climate System Model (CCSM3), AB1 scenario, are being used to represent the current climate and will be used to compare to results associated with the reanalysis data. These analyses are being done in collaboration with H. Brooks at the NOAA National Severe Storms Laboratory and P. Marsh at the University of Oklahoma.

#### FY2008 Plans

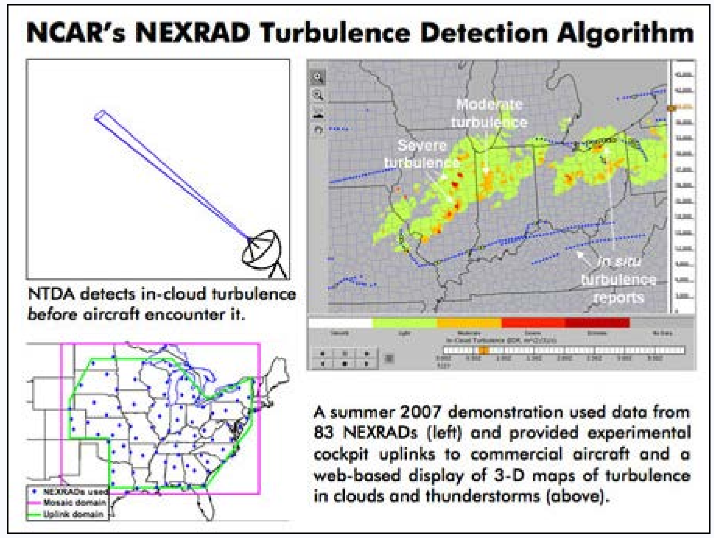
The techniques developed with the reanalysis data will be applied to output of the CCSM3 to determine whether the characteristics of CAPE and Shear based on GCM output for an unchanged climate are consistent with the characteristics of these parameters in the reanalysis data. Subsequently (assuming consistency is found), the parameters will be analyzed using CCSM3 output for changed climate scenarios to study how the frequency and intensity of environments conducive to severe weather activity can be expected to change under a future climate scenario. The aim of this work is to determine the current distributions of environments conducive to severe weather, and study how these environments are changing.  Initial steps include determining whether the climate models produce the correct spatial patterns found in the reanalysis data, and in particular, if they correctly place the extrema both spatially and temporally.  Once the consistency of these characteristics is verified, it will be possible to address the differences between current and future climates.  Finally, we will investigate approaches for making inferences about changes in the extreme value distribution parameters for the severe weather indicators. Development of these approaches will allow regional assessments of the characteristics of these indices of the potential for severe weather environments.

***Strategic Goal 4***

## 5. PROVIDING WORLD-CLASS OBSERVATIONAL FACILITIES AND SERVICES

### NCAR Strategic Priority: Developing New Instrumentation

#### Highlight: Advanced Weather Radar Techniques for Aviation




RAL is working under the sponsorship of the FAA's Aviation Weather Research Program to develop radar products that will utilize current and future capabilities of weather radars to support the detection and prediction of aviation hazards. This leads to two very different tasks: implementing and obtaining approval for operational deployment of new radar algorithms; and conducting research and development of radar products that will utilize future capabilities of weather radars.

**FY2007 Accomplishments**

RAL scientists have worked for more than 15 years to improve the detection of turbulence. Over the past several years they have developed the NEXRAD Turbulence Detection Algorithm (NTDA), a new approach to processing data from the National Weather Service's network of Next Generation Radars (NEXRADs). While aviation users commonly use reflectivity from onboard radars or ground-based radar mosaics to gauge the intensity of a storm, the NTDA detects the wind variations that can shake an aircraft. By directly measuring the in-cloud turbulence intensity, the NTDA will provide airline dispatchers, air traffic managers, and pilots an important new source of information for tactical turbulence avoidance. The performance of the NTDA was evaluated via comparison with research aircraft data and automated *in situ* turbulence reports from commercial aircraft, and it was shown to have good skill. RAL scientists and engineers also prototyped a 3-D Mosaic of NTDA turbulence measurements and are currently collaborating with National Severe Storms Laboratory on further development and implementation of an operational, real-time version that will cover the contiguous U.S. Finally, a RAL investigation into the NEXRAD spectrum width measurement technique revealed a problem with its accuracy that can limit the NTDA's ability to discriminate null from light or light-to-moderate turbulence. Following presentations at a conference and a TAC meeting, the FAA has formally requested that the accuracy requirements for NEXRAD spectrum width be tightened and that the implementation of a RAL-developed technique that provides improved accuracy be considered.

Techniques are also under development to determine whether precipitation detected with dual-polarization radars is rain, snow, mixed-phase, or freezing drizzle. Activities this past year focused on evaluating both polarimetric and non-polarimetric radar products for detecting the freezing level (essentially establishing the lower boundary of potential icing layers in the atmosphere) and the designation of freezing drizzle conditions in the terminal area. These products are being developed in conjunction with a polarimetric radar-based Hydrometeor Classification Algorithm (HCA) for detecting winter weather hazards for the aviation community. Results from case studies show good skill.

**FY2008 Plans:**

NTDA has won final approval from the NEXRAD Technical Advisory Committee (TAC) and the NEXRAD Software Recommendation and Evaluation Committee, and the software package has been delivered to the NEXRAD Radar Operations Center. Final testing and deployment are expected to occur in Summer 2008. A pilot program with United Airlines to test the uplink of the NTDA to the cockpit is expected to be expanded. Changes to the WSR-88D NEXRAD radars (super-resolution, range-velocity mitigation techniques, dual-pol, etc.) will necessitate a maintenance upgrade, the NTDA-2. This product, which will also contain an improved data quality algorithm, will be implemented and will begin the approval process for inclusion in the NEXRAD system. The NTDA 3-D mosaic will continue to undergo development and testing.

RAL scientists and engineers, in conjunction with the In Flight Icing team, will begin implementation of real-time versions of the freezing level and freezing drizzle algorithms. This will allow for the evaluation and ultimately inclusion of these products into icing hazard detection algorithms such as RAL's Current Icing Potential (CIP).

The national network of WSR-88Ds is targeted to be upgraded for dual-polarimetric capabilities beginning in FY08. Specific long-term project goals are to develop remote sensing capabilities for discriminating between rain and snow, designating icing conditions in the terminal area (freezing drizzle and rain) and in-cloud, quantifying winter precipitation in support of aircraft deicing operations, and estimating precipitation-impacted visibility.

### Objective Plume Detection

### HIAPER Instrumentation

The Microwave Temperature Profiler (MTP) is a passive radiometric sensor that measures brightness temperature at multiple frequencies and elevation angles. Retrieval algorithms applied to the measurements yield temperature profiles above and below the aircraft. Earlier versions of the MTP were developed and deployed by Jet Propulsion Laboratory (JPL) which is tasked to build a customized MTP for the NCAR G-V aircraft (HIAPER). JPL and NCAR staff are working together to certify and install the sensor on the G-V. The JPL Principal Investigator, Michael Mahoney, will also provide training to NCAR staff on sensor operation and maintenance, as well as data processing, quality control, and analysis.

### FY2007 Accomplishments:

A critical design review (CDR) was held in October, 2006. Substantial progress has been made this year on sensor hardware development and fabrication of the aerodynamic fairing for the sensor. The prototype instrument is approximately 1 month from completion. Mahoney and the NCAR P.I., Julie Haggerty, have met several times this year for training on data acquisition and analysis software.

### FY2008 Plans:

Upon completion of the prototype sensor early November, 2007, a mechanical load analysis of the sensor and fairing will be conducted by NCAR/DFS to ensure that the system will meet FAA certification requirements. Following the load analysis, the instrument and housing will be assembled by December, 2007, and associated documents will be submitted for FAA certification. This schedule will allow for delivery and certification of the MTP in time for the HIAPER Experiment Test Flights (HEFT) in February, 2008. The first scientific deployment of the MTP will occur in the Spring of 2008 in the START08 program.




*Postal Address: P.O. Box 3000, Boulder, CO 80307-3000 • Shipping Address: 1850 Table Mesa Drive, Boulder, CO 80305 • Contact*

The National Center for Atmospheric Research

Research Applications Laboratory | RAL

2007 Lab Annual Report

**RAL Director's Message**

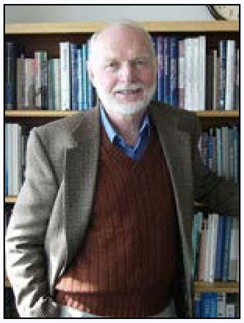
Director's Message

Table of Contents

**Strategic Goals**: Science, Facilities & Technology

Archives and Supplemental Info

## DIRECTOR'S MESSAGE



RAL Director, Brant Foote

Welcome to the Research Applications Laboratory's Annual Report for FY2007. Our mission is to conduct directed research that contributes to the depth of fundamental scientific understanding, to foster the transfer of knowledge and technology for the betterment of life on earth, and to support technology transfer that expands the reach of atmospheric science. We are, at present, an organization with an annual budget of more than $30M and a staff comprised of nearly 200 scientists, software engineers, and management/administration personnel. Although NCAR as a whole is largely funded by the National Science Foundation, RAL receives the vast majority of its funding from other sources such as domestic and international government agencies and private companies interested in exploiting the latest advanced weather technologies.

In 2005 we reorganized the Laboratory into five programs dealing with research and applications in topics related to aviation, homeland security, hydrometeorology, weather systems and assessments, and numerical testbeds. The activities within each of these programs are detailed on the RAL website. In this Annual Report, however, we take the opportunity to present our program in a different way, highlighting the many areas in which our work supports and advances the NCAR Strategic Plan.

Given our focus on applied atmospheric research and technology transfer, it is natural that much of our work contributes to Strategic Goal 2, Priority 2: "Building capacity for coping with weather and climate hazards." It is also important to note, though, that many parts of our program map easily into other goals and priorities of NCAR's Strategic Plan. RAL scientists are engaged in fundamental investigations of earth-atmosphere interactions, in improving community models, in connecting science to decision making and public policy, in building scientific and technical capacity in developing countries, in creating new mathematical and statistical tools, and in improving instruments used to observe the atmosphere. In each of these activities, RAL works to bring science and technology to bear on problems that affect society.

### Highlights

This Annual Report provides short narratives on nearly 40 programs conducted at RAL. Here I highlight five programs that significantly advance NCAR's strategic priorities.

#### Improving prediction of weather, climate and other atmospheric phenomenon

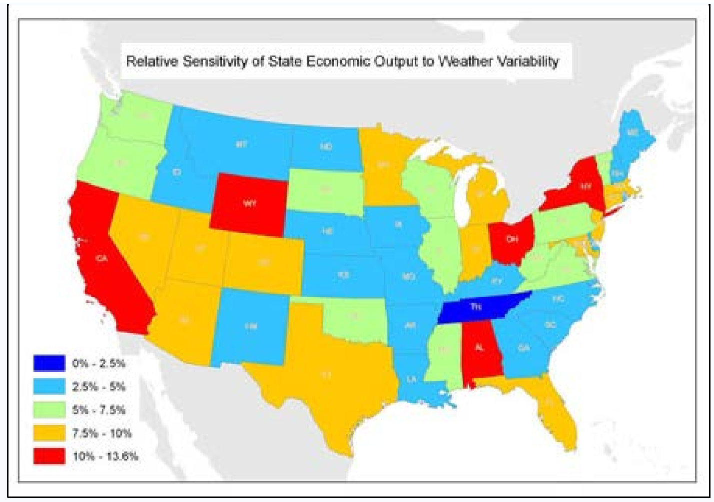
Highlight: Climate Forecasting Applications for Bangladesh

A RAL/ASP post-doc, Thomas Hopson, has worked with Peter Webster and colleagues at the Georgia Institute of Technology and researchers at the Asian Disaster Preparedness Centre to improve flood forecasts for Bangladesh. Using ECMWF forecast products and NASA and NOAA precipitation estimates to produce short-range (1- to 10-day) and long-range (1- to 6-month) forecasts--as well as a statistical model to create 20-25 day forecasts--the team is now issuing operational forecasts designed to provide extended-lead-time to those most likely to be affected by flooding of the Ganges and Bramaputhra Rivers. Good forecasts alone, however, don't necessarily save lives. Dissemination of forecasts to a largely rural population lacking access to electricity, as well as advanced communication technologies, has long been a problem. To address this challenge, the Asian Disaster Preparedness Centre staff teamed with local organizations and the country's Flood Forecasting and Warning Centre to establish a pilot dissemination network in 2006. A series of training workshops was conducted for the people within the pilot regions so they could effectively utilize the CFAB probabilistic discharge forecast information. Improved flood forecasts effectively communicated are credited with saving thousands of lives during the severe floods of July and September 2007.

#### Investigating weather and climate information needs and decision making

Highlight: Societal Impacts Program

In 2007 the Societal Impacts Program, a collaborative effort with ISSE, completed an "Overall U.S. Sector Sensitivity Assessment" which examined the sensitivity and vulnerability of state-level economic productivity to weather across 11 economic "super" sectors. Results indicate that U.S. sensitivity to weather variability is estimated to be about 3.4% of gross domestic product or $260 billion annually. This is the first study of its kind to combine economic and weather data using valid economic methods to assess sector, state, and national economic sensitivity



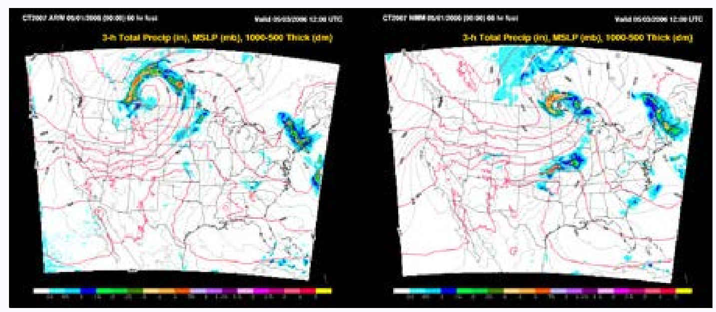

weather variability. Building on this work, SIP staff will focus on specific sectors of the economy to assess the use and value of current and improved weather forecasts.

SIP staff continue to develop and implement the Weather and Society*Integrated Studies (WAS*IS) workshops. This effort trains and empowers practitioners, researchers, and stakeholders to forge new relationships and to use new tools for more effective socio-economic applications and evaluations of weather products. A total of 145 WAS*IS graduates now comprise a growing community of researchers, operational forecasters, academics, and private sector individuals working to infuse social science research and understanding into the weather enterprise

**Community Modeling**

[Highlight: Developmental Testbed Center (DTC)]

The effort to develop the new Weather Research and Forecasting (WRF) model for the atmospheric community has long been an NCAR priority. While the development effort largely resides in ESSL, the effort to test and evaluate model configurations resides with the DTC. The DTC works primarily to facilitate the transfer of new numerical weather prediction (NWP) technologies from research to operations, thereby accelerating the improvement of numerical weather prediction for the nation. This past year, the DTC conducted an extended core test of WRF’s two dynamic solvers: the Advanced Research WRF (ARW) developed by NCAR/MMM, and the Nonhydrostatic Mesoscale Model (NMM) developed by NCEP, to determine whether the small differences in forecast skill between the two dynamic cores for a 24-hour lead time also pertain to longer lead times (i.e., 60 hours). In addition to extending the forecasts out to 60 hours, the DTC is working to determine whether forecast skill is dependent on the computing platform used to generate the forecasts. The DTC remains very focused on serving the community by hosting an active visitor program, conducting WRF tutorials, and providing a support system to aid users in accessing and using WRF codes.

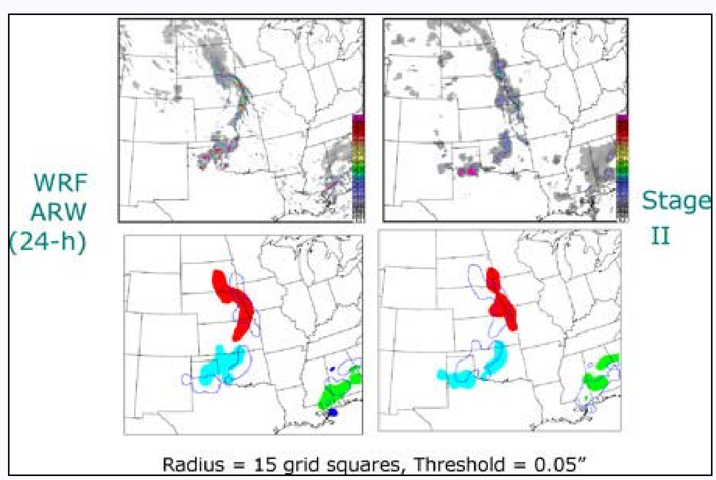



3-h total precipitation (shaded), mean sea level pressure, and 1000-500 mb thickness fields for 60-h forecasts valid at 12 UTC on 3 May 2006. Right panel shows the ARW forecast and left panel shows the NMM forecast. Both WRF configurations used NAM initial and lateral boundary conditions and the same suite of physics parameterizations. For this particular forecast cycle, the ARW and NMM forecasts show rather different evolutions of the cyclone for this extended lead time.

**Conducting computer science, computational science, applied mathematics, statistics, and numerical methods research and development**

[Highlight: Verification research and development]

Much of the work we do at RAL is focused on improving weather forecasts. But how do we know if a new forecast is better than an existing one? Forecast verification by nature is a mathematical activity, and development of improved verification methods requires the application of advanced mathematical, statistical, and computational approaches. To develop and disseminate new forecast verification approaches, RAL scientists conduct research in several areas, including statistical methods, exploratory data analysis, statistical inference, pattern recognition, and evaluation of user needs. Their goal is to produce statistically-valid approaches (e.g., object-based evaluation of precipitation and convective forecasts, distribution-based schemes, etc.) that can provide more meaningful and relevant information about forecast performance, both for those who develop forecasts and for the decision makers who use them. This past year the Verification Group



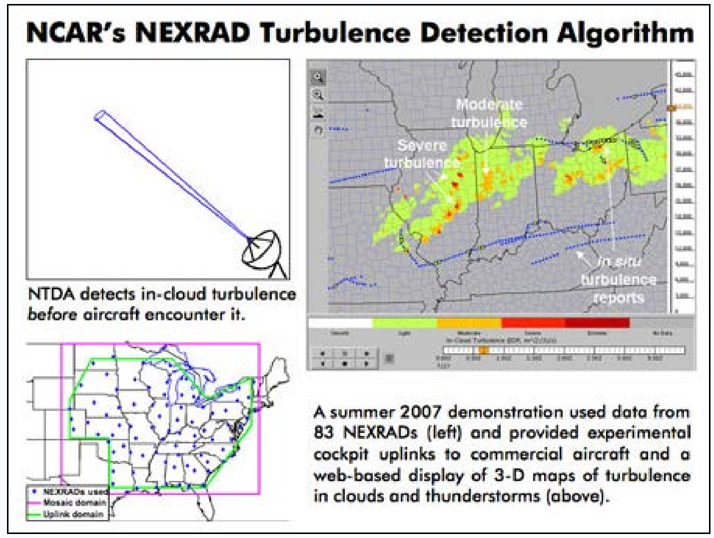
implemented its Method for Object-based Diagnostic Evaluation (MODE) tool within a new verification toolkit it developed for the DTC and the broader NWP community.  It also launched an intercomparison project (ICP) for spatial forecast verification methods, involving scientists from around the world who are developing new methods for evaluation of spatial forecasts.  A workshop to discuss initial results of the project is planned for Spring 2008.

Example of an application of the MODE, a tool included in MET, as an advanced verification technique provided to the NWP community. By comparing the locations of objects identified using the MODE technique between the forecast (left) and analysis (right) fields, one may identify errors that are difficult or impossible to detect using traditional verification metrics.

### Provide world-class ground, airborne, and space-borne observational facilities and services

Highlight:  The NEXRAD Turbulence Detection Algorithm (NTDA)

RAL scientists have worked for more than 15 years to improve the detection of turbulence.  Over the past several years they have developed the NEXRAD Turbulence Detection Algorithm (NTDA), a new approach to processing data from the National Weather Service's network of Next Generation Radars (NEXRADs). While aviation users commonly use reflectivity from onboard radars or ground-based radar mosaics to gauge the intensity of a storm, the NTDA detects the wind variations that can shake an aircraft. By directly measuring the in-cloud turbulence intensity, the NTDA will provide airline dispatchers, air traffic managers, and pilots an important new source of information for tactical turbulence avoidance. NTDA has won final approval from the NEXRAD Technical Advisory Committee (TAC) and the NEXRAD Software Recommendation and Evaluation Committee, and the software package has been delivered to the NEXRAD Radar Operations Center.  Final testing and deployment of the algorithm on the nation's radars is expected to occur in Summer 2008.

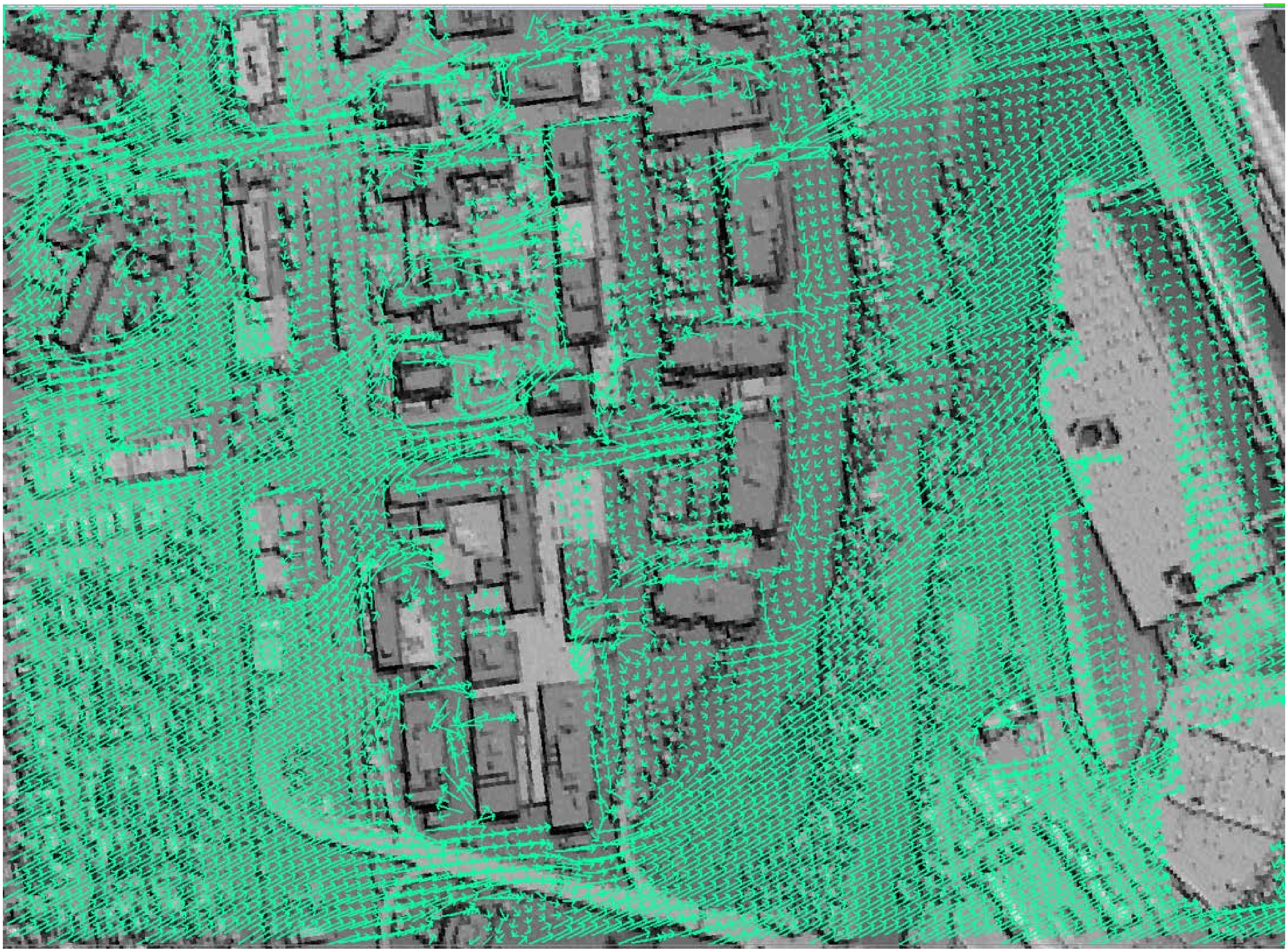



---

#### *Other Relevant Links*

- 2006 RAL Strategic Plan
- 2006 RAL Annual Report
- Previous ASRs (Annual Scientific Reports)

***RAL Director's Message***



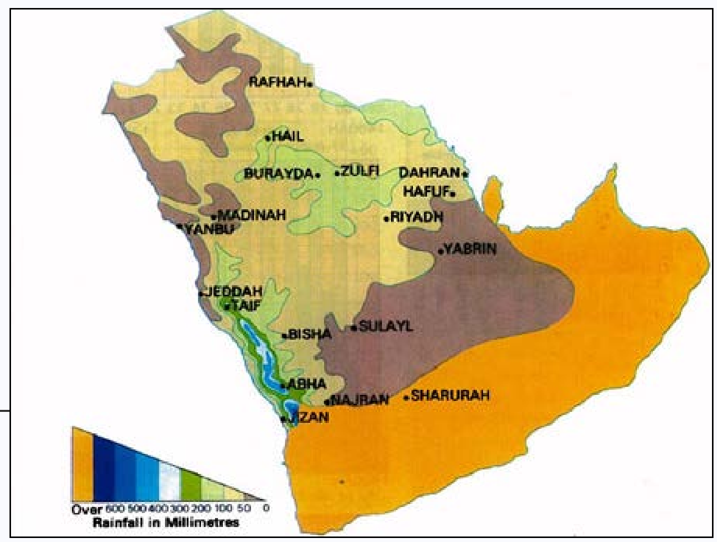
## 1. IMPROVE UNDERSTANDING OF THE ATMOSPHERE, EARTH SYSTEM, AND SUN



### NCAR Strategic Priority 2: Investigating the Interactions of the Atmosphere, the Broader Earth System, and Human Society

#### Aerosols and Precipitation – Feasibility Studies on Rainfall Enhancement

Over the past several years, the collection and analysis of data on aerosols, clouds and storms has been an important element of rainfall enhancement programs RAL conducts throughout the world. While the primary concern of all these efforts is precipitation, the effects of aerosols as agents of significant climatic perturbations, particularly with respect to precipitation, have received increasing attention over the past decade or so. Understanding the potential for an indirect aerosol effect, which involves changes in cloud microphysical processes, has become an additional factor to consider in documenting cloud and precipitation characteristics in regions proposed for weather modification activities.




Map of Saudi Arabia showing the distribution of annual rainfall (mm).

#### FY2007 Accomplishments:

*West Africa*
A rainfall enhancement assessment study was conducted in Mali, West Africa. Aerosol and cloud microphysical measurements collected during the field program combined with NASA satellite and NRL aerosol model forecasts show that even though a major source of aerosols is related to dust transport from the Sahara, the Saharan dust is mostly confined to the northern areas of Mali (even during monsoon conditions) with only an occasional penetration of dust further south. These studies also showed that local variations in aerosols embedded on the background levels may play an important role in the effects of aerosols on clouds. Storm trends have also been analyzed, improving our understanding of where, when, and how storms develop in this region. Future studies, planned for FY08, will examine a more complete data set to evaluate these characteristics in the context of the whole rainy season.

*Saudi Arabia*
Using three weather radars and two research aircraft over a six-month field effort, RAL scientists collected data that substantially aid our understanding of the climatology of Saudi Arabia, as well as the character of precipitating storms in the area. Dryness is the prevailing climatic characteristic of Saudi Arabia except in the Asir region, which receives annual rainfall >400-500 mm due to its unique geographical configuration and the local mountains. Rainfall in most of Saudi Arabia is <200 mm, highly irregular (i.e., large natural variability), and hence is not dependable. The geographic distribution of annual rainfall across Saudi Arabia is shown in the figure to the right. Analyses of the field data will continue into FY08, and more extensive field studies of air chemistry, aerosol, cloud microphysics, precipitation, and storm characteristics in the region will be conducted.

#### FY2008 Plans:

*West Africa*

The next step in the 2007 Mali study is the analysis of the collected aircraft and radar data to better determine the natural aerosol and precipitation characteristics in Mali clouds, and the effect of cloud seeding on these processes and vice versa. In addition, more training sessions for scientists and technicians in Mali and in neighboring Burkina Faso, are planned for FY08. Work will continue to sustain and extend the upgrades to observational networks in West Africa that were begun in FY07.

*Saudi Arabia*

The 2006-2007 study on aerosols, clouds, precipitation systems, and the feasibility of cloud seeding in north-central Saudi Arabia was the first step toward establishing scientific contacts, developing the infrastructure, and collecting data aimed at understanding these processes. Continuing the studies in the same area, expanding them to other areas of Saudi Arabia, and building samples of seeded and non-seeded storms are planned for FY08.

*Istanbul, Turkey*

A new program to assess the feasibility of rainfall enhancement in Turkey will begin in FY08. Airborne data are to be collected during three months of the winter, their peak season for precipitation, to study the distribution of aerosols, cloud physical properties, and the development of precipitation.

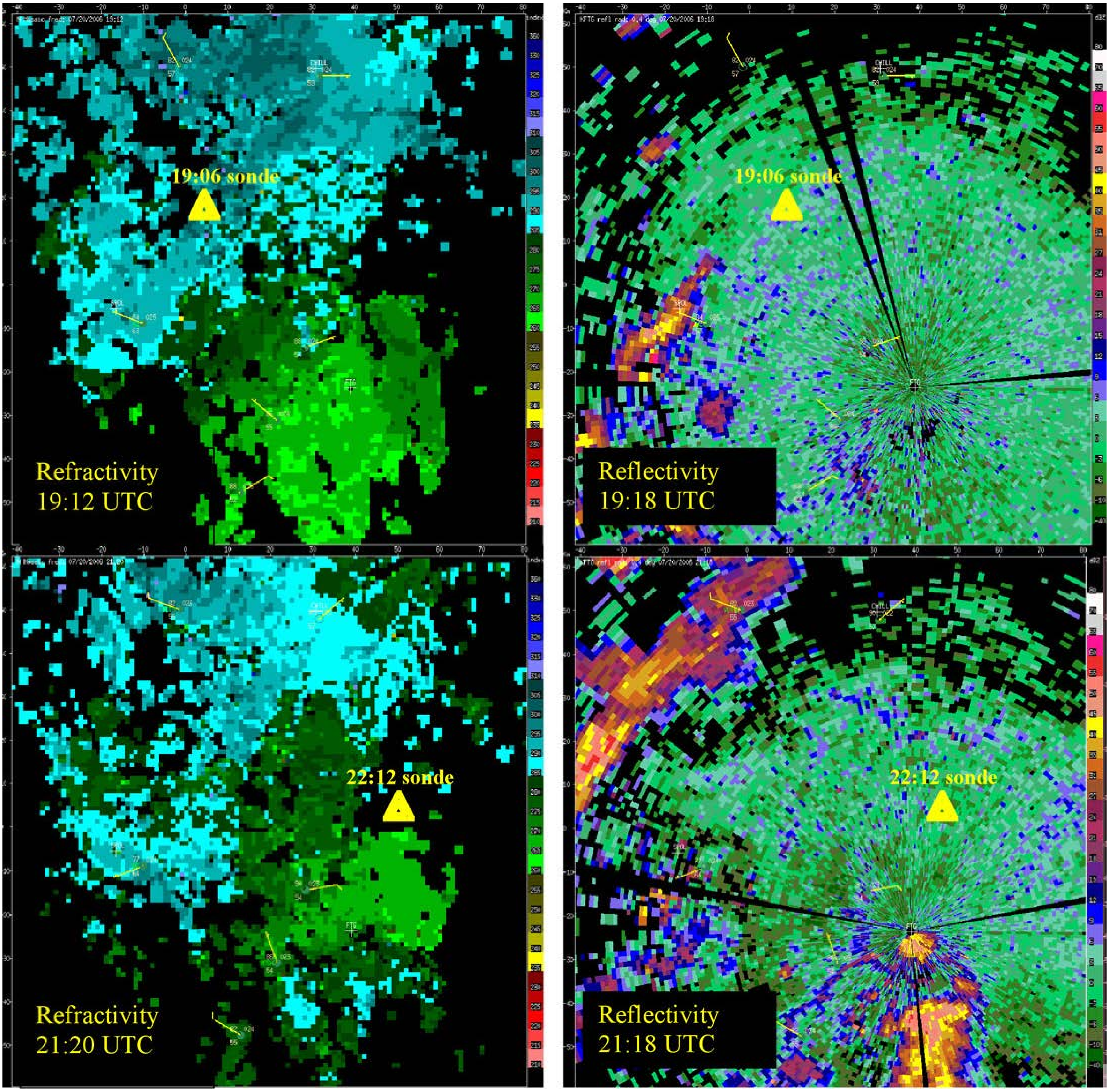
*Queensland, Australia*

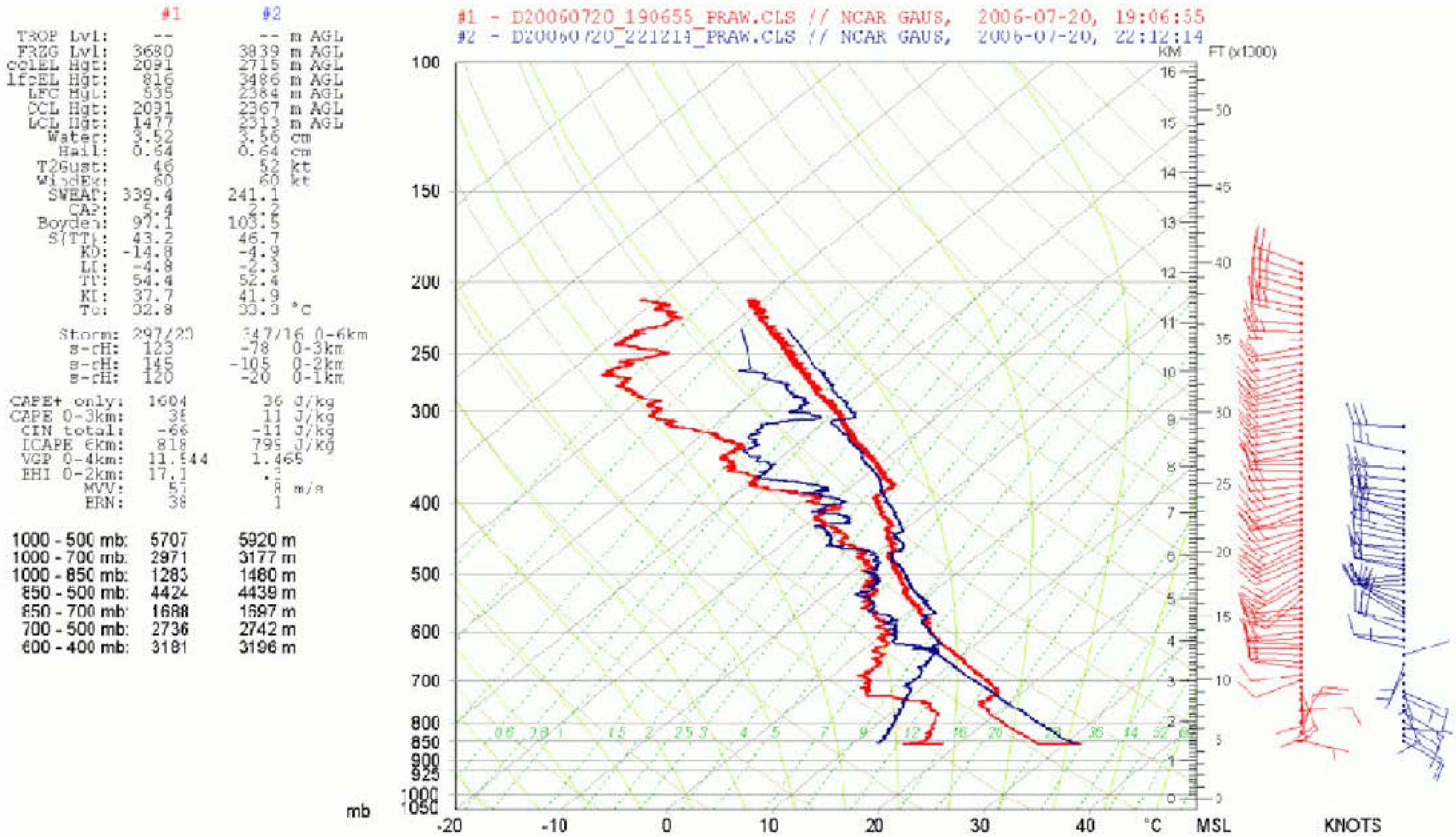
RAL has launched a new effort in Queensland to scientifically investigate when--and how well--cloud seeding works to enhance rainfall from convective clouds. For the first time in any rainfall enhancement experiment, dual-polarization, dual-wavelength and advanced weather radars will all be implemented in the field. In combination with the airborne measurements, these measurement systems make it possible to trace the physical chain of events from the natural or seeded small particles to droplet and ice crystal growth, subsequent precipitation development in clouds, and ultimately rain on the ground in both natural and seeding clouds. In addition, this will be the first time in decades that such a range of scientific expertise (e.g., several Australian institutions and universities, South African colleagues, and NCAR scientists and engineers) has been brought together in one program of this type.



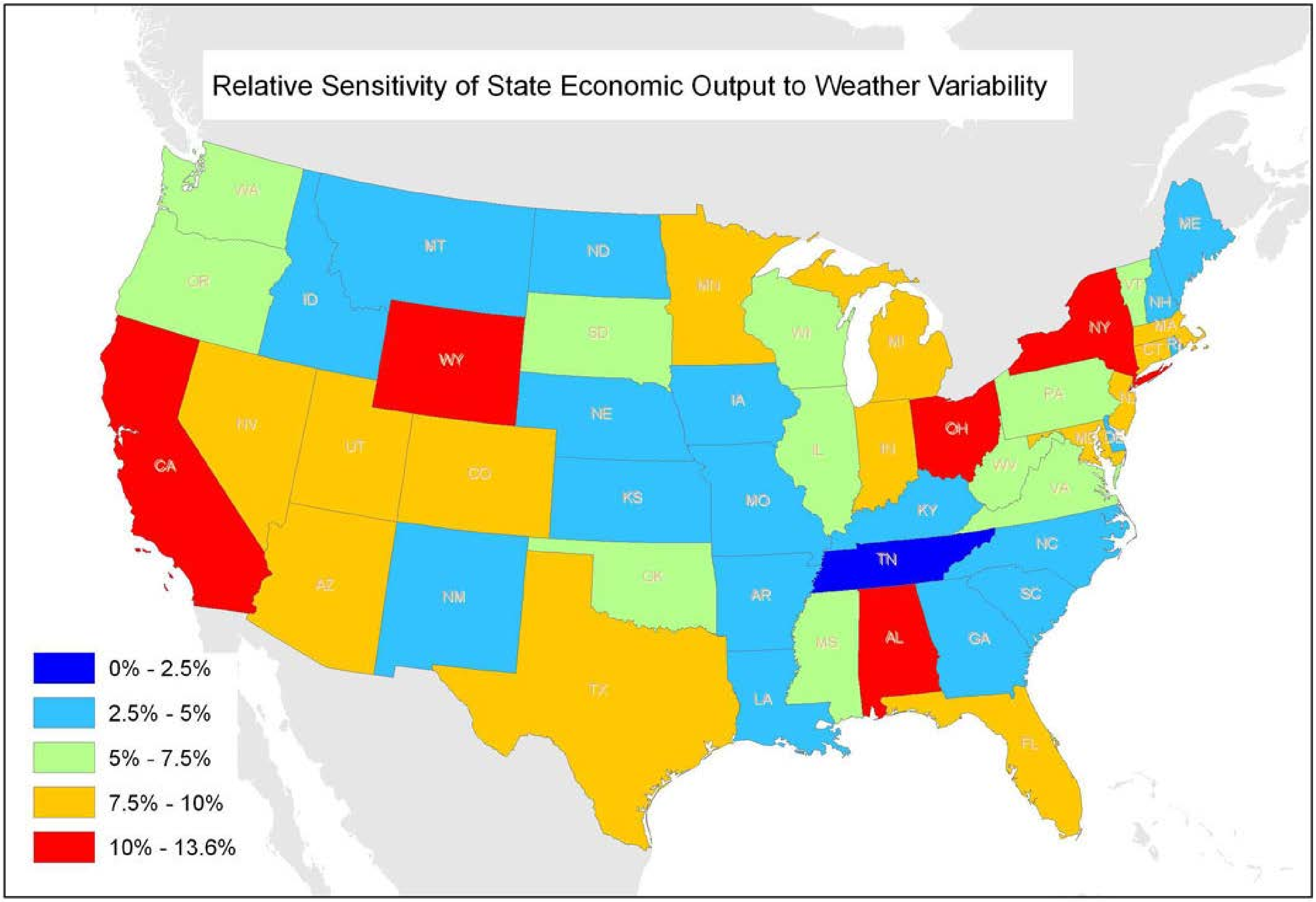


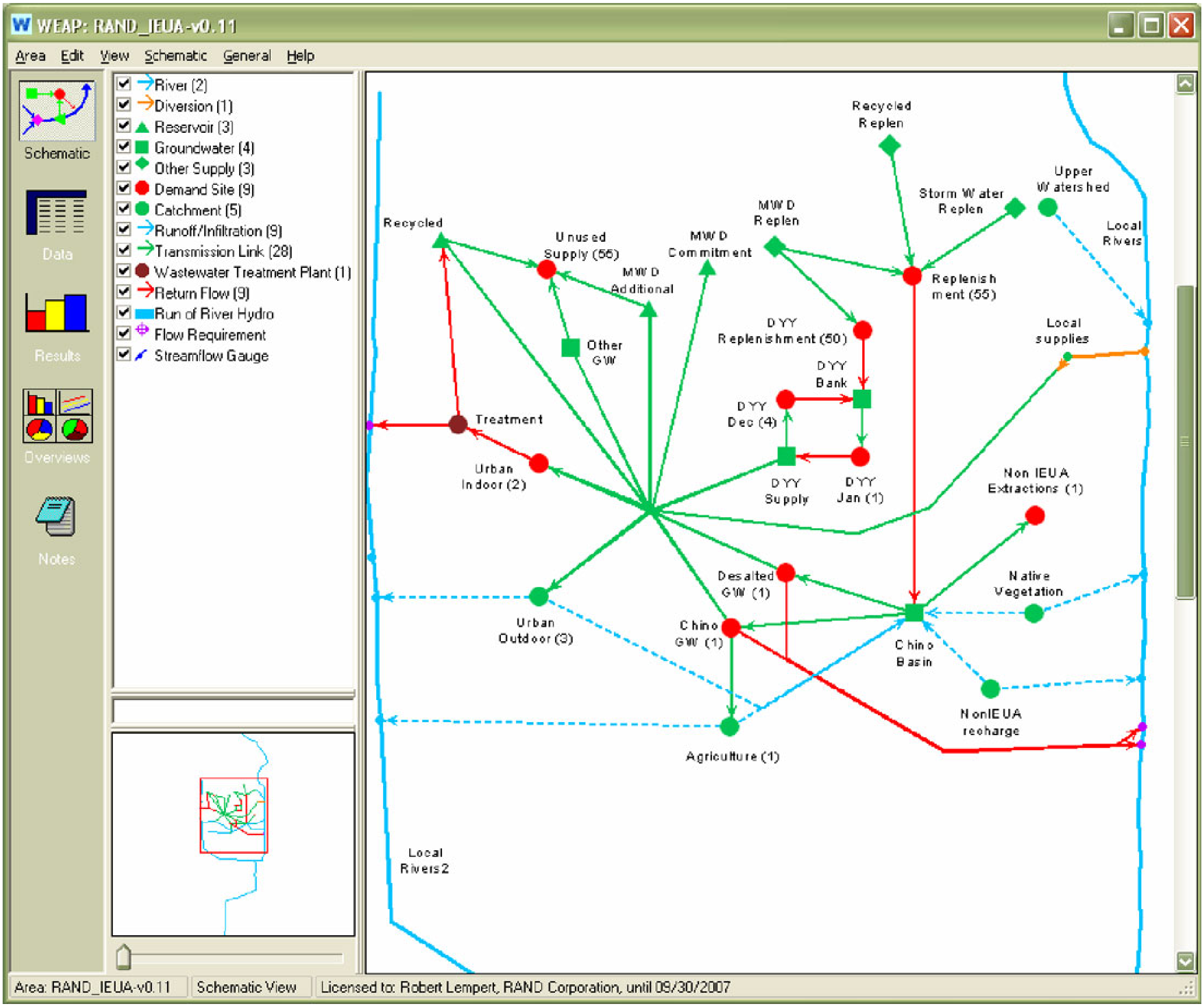
*Postal Address: P.O. Box 3000, Boulder, CO 80307-3000 • Shipping Address: 1850 Table Mesa Drive, Boulder, CO 80305 • Contact*


19:06 sonde
Refractivity
19:12 UTC
19:06 sonde
Reflectivity
19:18 UTC
22:12 sonde
Refractivity
21:20 UTC
22:12 sonde
Reflectivity
21:18 UTC



#1 - D20060720_190655_PRAW.CLS // NCAR GAUS, 2006-07-20, 19:06:55
#2 - D20060720_221214_PRAW.CLS // NCAR GAUS, 2006-07-20, 22:12:14
#1 #2
TROP Lvl: -- -- m AGL
FRZG Lvl: 3680 3839 m AGL
colEL Hgt: 2091 2715 m AGL
lfcEL Hgt: 816 3486 m AGL
LFC Hgt: 535 2384 m AGL
CCL Hgt: 2091 2367 m AGL
LCL Hgt: 1477 2313 m AGL
Water: 3.52 3.56 cm
Hail: 0.54 0.64 cm
T2Gust: 46 52 kt
WindEx: 60 60 kt
SWEAT: 339.4 241.1
CAP: 5.4 2.2
Boyden: 97.1 103.5
S(TT): 43.2 46.7
KO: -14.8 -4.9
LI: -4.8 -2.3
TT: 54.4 52.4
KI: 37.7 41.9
Tc: 32.8 33.3 °C
Storm: 297/20 347/16 0-6km
s-rH: 123 -78 0-3km
s-rH: 145 -105 0-2km
s-rH: 120 -20 0-1km
CAPE+ only: 1604 36 J/kg
CAPE 0-3km: 38 11 J/kg
CIN total: -66 -11 J/kg
ICAPE 6km: 818 795 J/kg
VGP 0-4km: 11.544 1.465
EHI 0-2km: 17.1
MVV: 57 8 m/s
BRN: 38 1
1000 - 500 mb: 5707 5920 m
1000 - 700 mb: 2971 3177 m
1000 - 850 mb: 1283 1480 m
850 - 500 mb: 4424 4439 m
850 - 700 mb: 1688 1697 m
700 - 500 mb: 2736 2742 m
600 - 400 mb: 3181 3196 m
mb
°C
KM
FT (x1000)
MSL
KNOTS


Relative Sensitivity of State Economic Output to Weather Variability
WA
OR
CA
ID
MT
ND
WY
SD
MN
WI
MI
NY
ME
NH
VT
MA
CT
RI
NE
IA
IL
IN
OH
PA
NJ
MD
DE
WV
VA
KY
NV
UT
CO
KS
MO
TN
NC
SC
AZ
NM
OK
AR
MS
AL
GA
LA
TX
FL
0% - 2.5%
2.5% - 5%
5% - 7.5%
7.5% - 10%
10% - 13.6%


WEAP: RAND_IEUA-v0.11
Area Edit View Schematic General Help
Schematic
Data
Results
Overviews
Notes
River (2)
Diversion (1)
Reservoir (3)
Groundwater (4)
Other Supply (3)
Demand Site (9)
Catchment (5)
Runoff/Infiltration (9)
Transmission Link (28)
Wastewater Treatment Plant (1)
Return Flow (9)
Run of River Hydro
Flow Requirement
Streamflow Gauge
Recycled Replen
Upper Watershed
Storm Water Replen
MWD Replen
Local Rivers
Recycled
Unused Supply (55)
MWD Commitment
MWD Additional
Replenishment (55)
DYY Replenishment (50)
Local supplies
Other GW
DYY Bank
DYY Dec (4)
Treatment
Urban Indoor (2)
DYY Supply
DYY Jan (1)
Non IEUA Extractions (1)
Desalted GW (1)
Native Vegetation
Urban Outdoor (3)
Chino GW (1)
Chino Basin
NonIEUA recharge
Agriculture (1)
Local Rivers2
Area: RAND_IEUA-v0.11
Schematic View
Licensed to: Robert Lempert, RAND Corporation, until 09/30/2007

Director's Message
Table of Contents
**Strategic Goals**: Science, Facilities & Technology
Archives and Supplemental Info

## BUILDING CAPACITY FOR COPING WITH WEATHER AND CLIMATE HAZARDS

### Highlight: Surface Transportation Research and Development

Approximately 1.57 million accidents occur each year in poor weather on the nation's roads and an estimated 713,000 injuries and 7,400 deaths per year (based on an 8-year average) occur, creating an annual economic toll of approximately $42B. Weather plays a role in about 28% of the total crashes and 19% of the total fatalities. Weather also reduces capacity and significantly impacts efficiency, triggering congestion, particularly on roads operating near capacity. Approximately 15% of all congestion is due to poor weather and related road conditions. Since 1998 RAL has had a leadership role in the Road Weather Research and Development Program within the USDOT's, Federal Highway Administration, bringing the surface transportation and weather communities together to improve surface transportation safety and mobility. RAL continues to provide national leadership in surface transportation weather by organizing and participating in national and international surface transportation weather workshops, conferences, training programs, and committees.

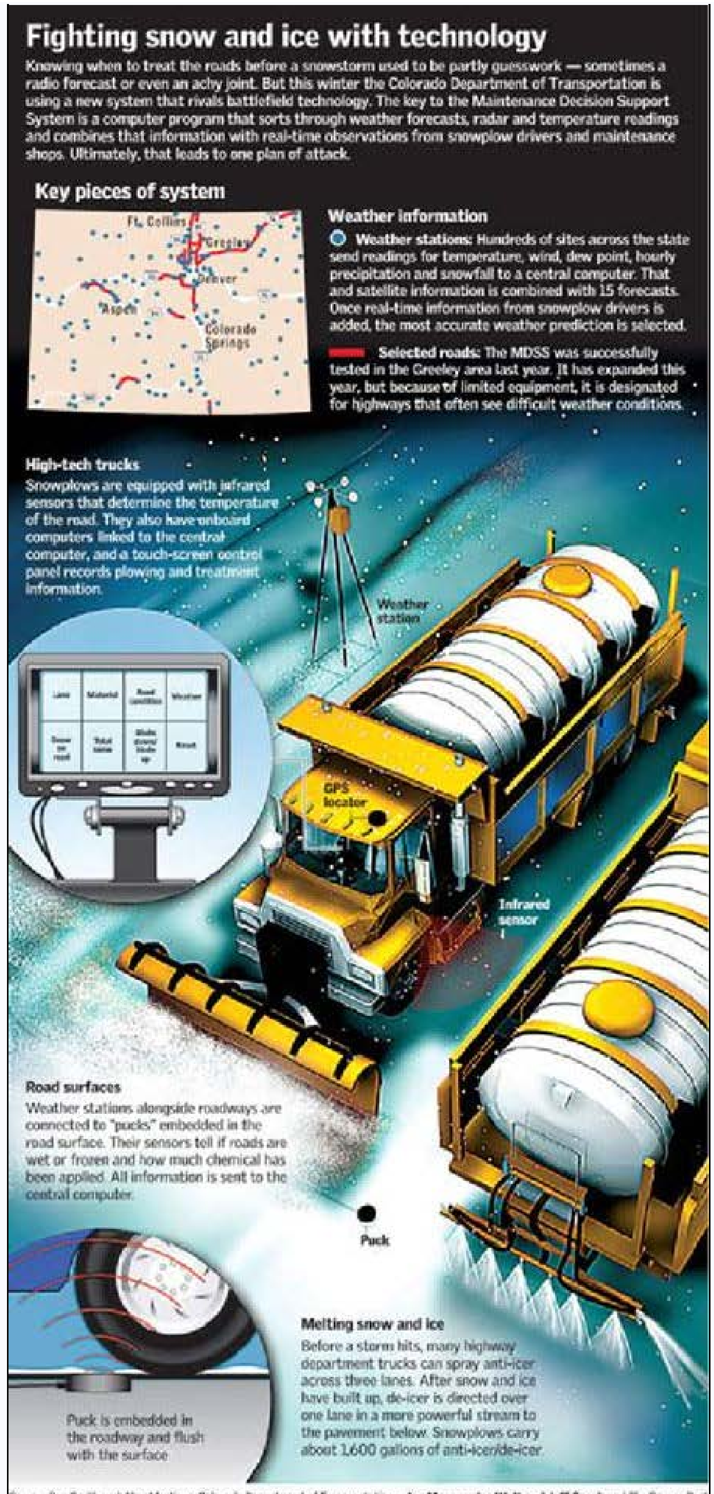
**FY2007 Accomplishments:**

*Maintenance Decision Support System (MDSS):*
Since 1999, RAL has led a team of national laboratories in the development of the prototype winter Maintenance Decision Support System (MDSS), a unique decision support system that provides real-time snow and ice control guidance (e.g., treatment times, chemical choices, rates, and locations) for user-defined roadway segments. In FY07 the modeling, pavement (bridge and roadway) heat balance models, data fusion system, and rules of practice components of the MDSS were enhanced to improve the overall performance of the system. Other highlights included working with Environment Canada to improve and integrate their pavement heat balance model called METRo into the MDSS system; disseminating MDSS Version-4.0 software to over 60 road weather organizations (public and private); and successfully supporting the FHWA's annual MDSS stakeholder meeting, which included more than 80 participants from the surface transportation community including 30 State DOTs.

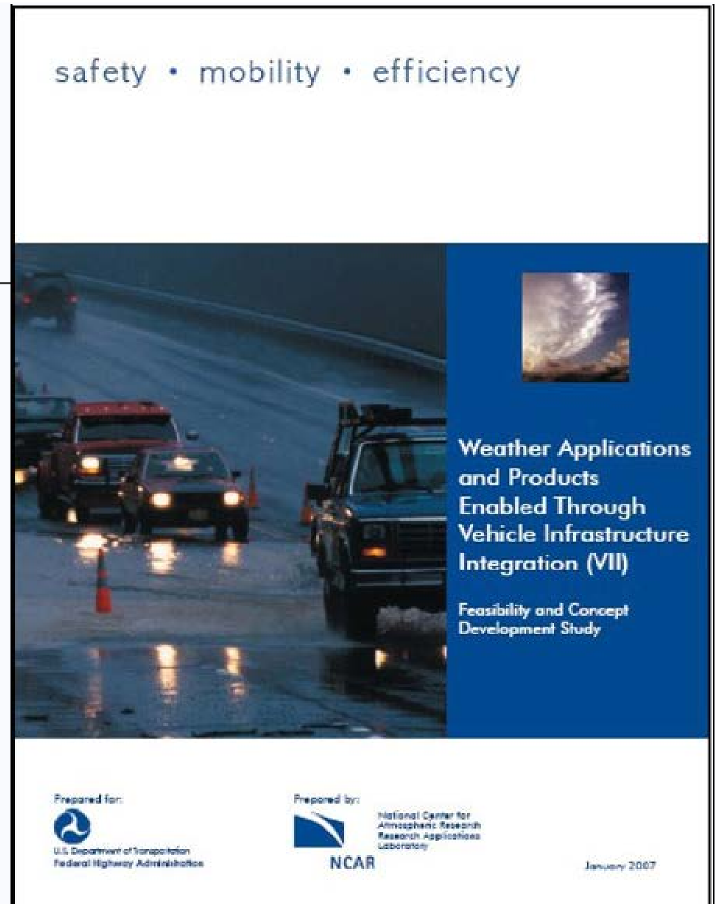
The prototype MDSS was utilized in real-time by the City and County of Denver and the E-470 Public Highway Authority during the particularly severe winter of 2006-2007. A commercial version of the MDSS is being developed and demonstrated as part of a DOT Pooled Fund Research Program. The Pooled Fund MDSS was evaluated by 11 DOTs last winter and another demonstration is planned for the winter of 2007-2008.

*Vehicle Infrastructure Integration (VII)*:
The USDOT has embarked on a relatively new program with the automotive and consumer electronics industries to develop a national capability to support wireless communications for vehicles. The **VII Program** is working toward deployment of advanced vehicle to vehicle and

vehicle to infrastructure communications that could keep vehicles from leaving the road and enhance their safe movement through intersections. RAL is working closely with the FHWA **Road Weather Management Program** to develop concepts and assess the feasibility of utilizing vehicle data to enhance the diagnosis and prediction of weather and road conditions along our nation's roadway network. In 2007, RAL prepared and delivered to the FHWA a major vision document titled Weather Applications and Products Enabled Through Vehicle Infrastructure Integration (VII). This document discussed how probe data from millions of vehicles could be used in the future to support the diagnosis and short term prediction of weather.




*Graphical depiction of MDSS technologies utilized long the Front Range. Courtesy of the Denver Post.*




*RAL developed a feasibility and concept development study on how VII data could be used to improve road weather services.*

**FY2008 Plans:**

*MDSS:* The MDSS will continue to be developed and validated in 2008 using Colorado as a test bed. Prototype MDSS products will be provided to the E-470 Public Road Authority and the City and County of Denver. We anticipate that Denver International Airport may also want to participate in the MDSS demonstration to evaluate the system's capabilities for supporting snow and ice control operations for ramp, runways, and Pena Boulevard. RAL will also work with the Utah DOT to configure and transfer the prototype MDSS to Utah DOT as part of a evaluation project to assess the portability of the prototype MDSS to state DOTs.

*Clarus Initiative:* RAL will continue to support the Aurora Program in the development of new weather and road condition hazard applications for travelers and will provide input and feedback to the FHWA on the development of the Nationwide Surface Transportation Weather Detection and Forecast System Initiative known as the *Clarus Initiative*

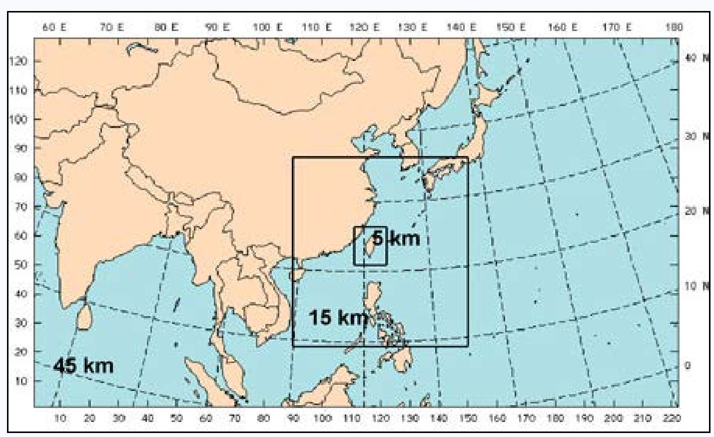
*Vehicle Infrastructure Integration (VII):* In FY2008, RAL will participate in the VII testbed near Detroit, Michigan. RAL will obtain data from test vehicles and begin to analyze their characteristics including quality, density, and geographical and temporal distribution. RAL will also begin the design and development of a Weather Data Translator (WDT) that will be used to parse, ingest, process, quality control, and generate advanced weather and road condition analyses utilizing vehicle probe data. This will be a significant scientific and engineering activity that will eventually facilitate the collection and processing of millions of new surface weather observations.

## Advanced Operational Aviation Weather System in Taiwan

back to top

Since 1998 RAL and MMM have collaborated in the development of an Advanced Operational Aviation Weather System (AOAWS) for the Civil Aeronautics Administration (CAA) of Taiwan. The initial AOAWS project (AOAWS-I) was completed and deployed for operational use in June 2002 and provides the CAA, the airlines, and the flying public with state-of-the-art aviation weather technology to detect and forecast hazardous weather phenomena that affect aviation operations, airspace efficiency, and capacity and safety at Taiwan's major hub airports.

In January 2005, the AOAWS Project entered a second five-year phase. This new phase focuses on the replacement of the MM5 model with the WRF model, advancing the data assimilation system (WRF-VAR) to incorporate new data types (e.g., COSMIC GPS, and other satellite data), upgrading the icing and turbulence products to incorporate the latest advancements developed as part of the FAA Aviation Weather Research Program, and developing and implementing new JAVA based display systems.




Graphic showing the general size of the new Weather Research and Forecasting (WRF) Model domains that became operational in the AOAWS in October 2007. The WRF model replaced MM5 as the Civil Aeronautics Administration's (CAA) aviation weather prediction system. The WRF model is now being run on the Central Weather Bureau's (CWB) IBM supercomputer. The WRF runs in a nested configuration with a model grid spacing of 45, 15, and 5 km.

**FY2007 Accomplishments:**

The AOAWS Program had several major accomplishments this year including the development and introduction of the WRF model as the primary model used by both the CWB and CAA to support general weather prediction in Taiwan and aviation weather forecasting, respectively. The transition from the MM5 to the WRF was no small task as it required the CWB to adopt this new model as its primary mesoscale model, and it required the CAA to agree to upgrade and reconfigure the entire AOAWS to accept the new model data. NCAR successfully completed the transition to the WRF-based system in September 2007 and the system was declared ready for operational use by the CAA in mid-October.

The upgraded AOAWS system includes the WRF model and the WRF-VAR data assimilation system, upgraded MDS, model display, and SMD, and the new JMDS. System enhancements also include refinements to the in-flight icing and turbulence products. The Thunderstorm Identification, Tracking, and Nowcasting (TITAN) was developed and implemented to process data from the CWB radar mosaic and the TTY Doppler weather radar.

#### FY2008 Plans:

RAL, MMM, and our Taiwan technical partner, the Institute for Information Industry, will continue to collaborate on the following research and development activities in 2008:

- Develop and evaluate enhancements to WRF-VAR
- Evaluate new data types and their contribution to WRF performance
- Evaluate the performance of the in-flight icing algorithm using the WRF output
- Evaluate the performance of the jet stream turbulence algorithm using the WRF output
- Continue to refine the Java-based Multi-dimensional Display System (JMDS)
- Begin redesign of the web-based Multi-dimensional Display System (WMDS)
- Continue to provide training of CAA personnel

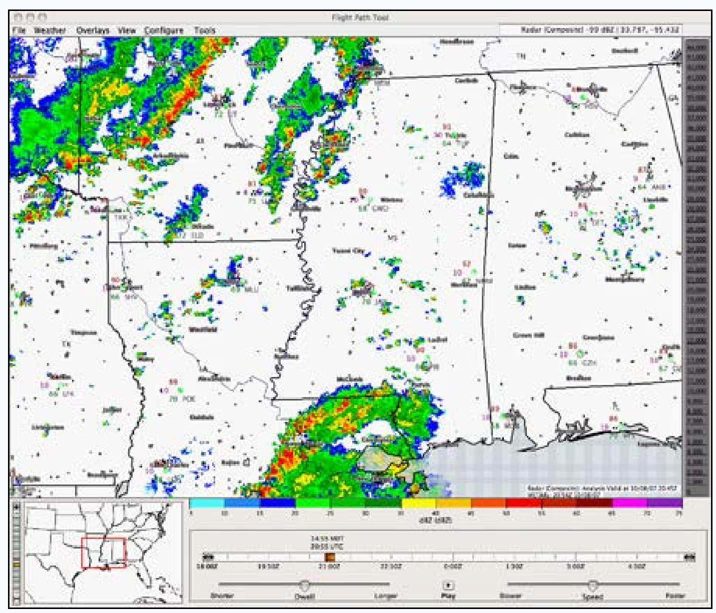
### Aviation Digital Data Service

back to top

The Aviation Digital Data Service (ADDS) is jointly developed by NCAR-RAL, NOAA-Global Systems Division, and the National Weather Service's Aviation Weather Center (AWC) with funding from the FAA Aviation Weather Research Program. ADDS disseminates weather products to the aviation community via the web. The AWC provides 24 hour-a-day support for Operational ADDS, while an experimental version of ADDS resides at NCAR-RAL and provides next-generation products and services.

#### FY07 Accomplishments:

ADDS developers at RAL worked closely with the helicopter emergency medical services (HEMS) user community to tailor the ADDS Flight Path Tool to meet their needs for weather information in a very narrow range of altitudes and short distances. Version 1 of a new HEMS tool was made available on 1 Nov. 2006, and throughout 2007 its usage grew as word spread and a number of testimonials from users indicated that it has improved their situational awareness of weather and the safety of their operations.



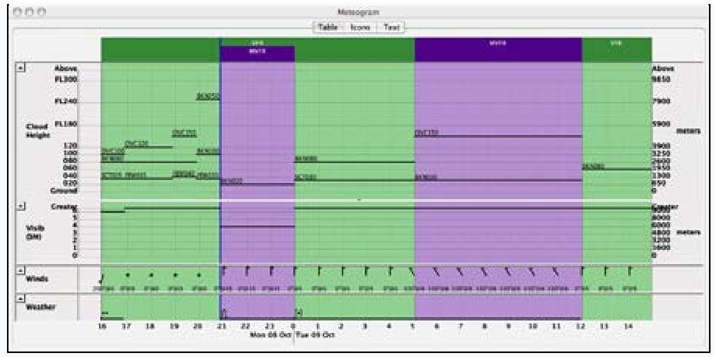
1) Sample screen capture of the new, version2 Flight Path Tool. Composite Level-2 NEXRAD radar data shown for 2045 UTC 08 Oct 2007.

During 2007, NCAR-RAL integrated some of the interfaces and features of the newly created HEMS software application into a second version of the Flight Path Tool. Key modifications include the ESRI ArcIMS map solution, simpler interface to weather products via menus, and new weather products including NEXRAD Level-2 radar data. This new version of the application is currently being tested and prepared for release at the end of the year.

Besides the new Version 2 Flight Path Tool, a new visualization of observed and forecast weather data at airports was created. In a single graphic, the *observed* weather data at airports (in METAR format) is seamlessly merged with terminal forecasts (TAFs) of the same weather conditions into the future. In one quick glance, users can now see past, present, and future weather conditions at an airport and the immediate impact to their aviation flight category.

#### FY08 Accomplishments:

In the next 12-18 months, ADDS will focus on digital delivery of all weather products in industry-standard formats. For example, aviation weather text products including observations, forecasts, and advisories are currently available in XML and CSV formats. In the near



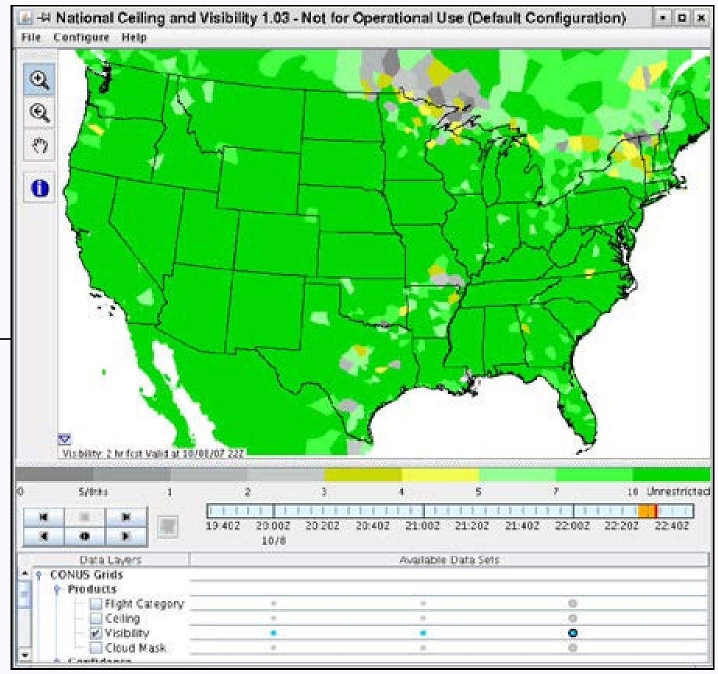
2) Sample "meteogram" time-series showing seamless combination of observed and forecast weather data at Little Rock, AR. Past 6 hours observed data is combined with the "terminal forecast" for future 18 hours.

future, these will be served using a Web Feature Service, a standard created by the Open Geospatial Consortium (OGC), allowing users to integrate these ADDS data into a variety of GIS applications. Likewise, ADDS developers are researching the capabilities of an OGC Web Coverage Service to deliver its gridded weather forecasts of icing, turbulence, and more. In coordination with the FAA's System Wide Information Management Program and the Joint Planning and Development Office, work will continue to make ADDS data available on a machine-to-machine basis. And finally, further enhancements will be made to the HEMS tool: radar and satellite data will be incorporated; user-specific data (e.g., location of hospitals, helipads/bases, etc.); street-level maps will be made available; and a search interface created.

### Ceiling and Visibility Research and Development

back to top

Adverse ceiling and visibility (C&V) conditions create serious flight safety hazards for general aviation, as well as costly reductions in traffic flow efficiency for commercial operations. On a yearly basis, C&V hazards result in 30-40 fixed-wing general aviation accidents, ~65-75 deaths and losses of ~$150-160M. Reduced C&V conditions are second only to convective weather as a cause of U.S. flight delays. RAL research funded by the FAA Aviation Weather Research Program (AWRP) directly addresses both safety and efficiency concerns through the development of improved C&V weather information and decision support systems.




NCV real-time ceiling height analysis as it appears on the Flight Path Tool on ADDS.

#### FY07 Accomplishments:

The National Weather Service (NWS), the Joint Planning and Development Office, and the National Ceiling and Visibility (NCV) Research Team at NCAR have determined that NCV's automated diagnosis and forecast systems are viable technologies for the operational production of data grids that will flow into the NWS forecast process. They are included in NextGen planning as a critical part of the planned "four-dimensional data cube."

A new NCV analysis system was delivered to the Aviation Weather Center (AWC) in Kansas City in summer 2006 and during FY2007 support was provided to the AWC and the FAA for ongoing operational system testing and evaluation. The NCV real-time analysis grids for ceiling, visibility and flight category have been made available as experimental products used by the National Weather Service's Eastern Region aviation forecast modernization process through the year. They are shown to be accurate for local conditions and have good reliability in representing the most probable conditions *between* reporting sites. These results encourage further development and use of NCV gridded ceiling and visibility products.

The operational NCV forecast integration system was re-implemented to update the weights of the various forecast components (including RUC, LAMP MOS, persistence and data mining) on an hourly basis. A playback system based on the operational system was implemented for internal research and development. The forecast integration system now supports both agile selection as well as a weighted majority vote algorithm. Both schemes are actively being tuned and evaluated by the science staff for performance. The NCV forecast system was adapted to incorporate the new GFS LAMP and its more frequent updates and sites leading to improved forecast performance.

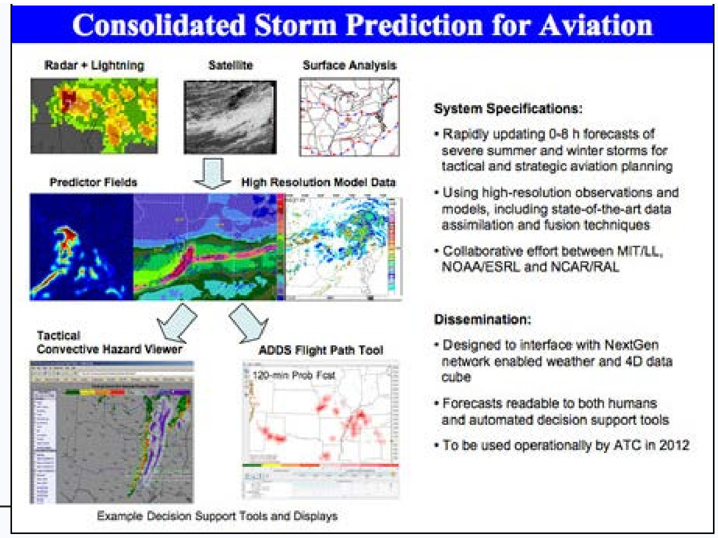
#### FY08 Plans:

Testing and evaluation of the NCV analysis product will continue in FY2008, and we anticipate that the analysis system will be approved for operational use. In addition, the NCV forecast integration system will be evaluated by NOAA/GSD with the goal of moving it to the Experimental ADDS website and transferring it to the Aviation Weather Center.

### Consolidated Storm Prediction for Aviation

back to top

For more than twenty years the FAA has funded research and development efforts aimed at improving short-term forecasting of storm hazards affecting aviation. This work



Example Decision Support Tools and Displays

has led to the creation of more than 15 separate forecasting tools, algorithms, and systems. In FY07 the FAA changed its strategy and created a new research team tasked with development of a single forecast system. This new "Consolidated Storm Prediction for Aviation" (CoSPA) program brings together researchers from NCAR, MIT/Lincoln Laboratory, and NOAA's Global Systems Division to create a 0-8 hour forecast for both summer and winter storms. Forecast products from this system will be designed to satisfy the current needs of Air Traffic Management (ATM) as well as the future demands of the Next Generation Air Transportation System (NextGen) in which much of the strategic air traffic decision making will be made by automated decision support tools.

**FY2007 Accomplishments:**

The first steps in the development of CoSPA have included: creation of an inventory of existing technologies in the operational nowcasting community; evaluation of existing technologies; identification of gaps in existing technologies; development of an appropriate system architecture; and creation of a research and development agenda to address technological gaps.

Highlights in system design and software engineering thus far include:
Establishing methods for data exchange and agreement on a common data format. Coordination with the FAA's System-Wide Information Management (SWIM) team will allow CoSPA to take advantage of the proposed network-centric approach to data sharing between the FAA and other government agencies.
Creating a system architecture with a modular design to foster ease of plug-and-play experimentation with new technologies.
Developing a new Graphical User Interface to provide a menu-driven selection of datasets, preprocessing techniques, and blending methods, as well as produce standard statistical skill scores for graphical display or output to files for further processing.

A scientific R&D agenda has been established and work is underway in the following areas:
Extrapolation – New techniques for improving the skill of extrapolation forecasts at longer lead times are needed. To meet this need, the variational echo tracking technique is being compared with a Lagrangian TITAN-based technique; results to date indicate that both techniques have associated strengths and weaknesses.
Nowcasting (0-2 hr) Storm Initiation –. The ability of current technologies to predict storm initiation is being assessed using the Random Forest statistical technique. This technique will also be used for to analyze different predictor fields' ability to forecast storm growth and decay.
Data Assimilation - Team members have been testing and evaluating new techniques for assimilating radar data into rapidly-updating NWP models. Current work focuses on improved assimilation of the 3D radar reflectivity through latent heat nudging and variational analyses of the 3D wind field.
Blending – Work is underway to use new blending techniques to combine the relative strengths of observation-based and model-based forecasts into a seamless forecast can be easily understood by Air Traffic Managers. A testbed has been created for the evaluation of extrapolation, model and blending forecasts, and intercomparisons are being made. Results indicate that critical components of the blending will be the climatological processing of the extrapolation forecasts, phase correction of the model forecasts (see figure below) and statistical weighting of the two forecasts.
Precipitation Calibration – Scientists are working to better calibrate automated precipitation measurements. Accurate measurements of snowfall rates, as well as accirate detection of the phase of precipitation, are essential for implementing correct de-icing procedures and hold-over times for planes during winter storms.

**FY2008 Plans:**

A major milestone for Summer 2008 will be the first real-time demonstration of the experimental CoSPA system. It will produce 0-6 hour high resolution (3.3 km) forecasts using heuristic-based extrapolation forecasts and output from a high-resolution mesoscale model with real-time radar data assimilation. The products will be rapidly updating so that the latest model and observational data are incorporated. Work will also continue on all of the R&D tasks outlined above.

### Convective Weather Forecasting: Benefits of a "Human over the Loop"

back to top

The Aviation Weather Group of the National Weather Service has funded NCAR during the past three years to install and run the Thunderstorm Nowcasting System (Auto-nowcaster or ANC) at the NWS Dallas/Ft.Worth (DFW) Forecast Office (FO). Two primary objectives of the Forecaster-Over-the-Loop demonstration are to assess 1) the role of the NWS forecaster in providing value-added enhancements to gridded, automated, nowcast products produced by the Auto-Nowcaster, and 2) the usefulness of these products as guidance for the forecaster in producing short-term forecasts, area warning updates and CWSU outlooks for terminal/enroute aviation traffic. The overarching goal is to improve the consistency, reliability, and accuracy of 0-2 hour convective forecast products for automated aviation weather digital products (4-D grids) for the National Aerospace System's Next Generation Air Transportation System (NGATS).

Previous demonstrations of the ANC system for FAA-funded activities have shown that forecaster input into the ANC process, particularly in producing storm initiation nowcasts, added consistency, reliability and accuracy to the 0-1 hr short term, time and location specific thunderstorm nowcasts. The primary objective this year has been the evaluation of performance of the Auto-nowcaster thunderstorm initiation nowcasts with and without forecaster input into the process. Using standard statistical calculations of probability of detection (POD), false alarm rate (FAR) and critical skill index (CSI) over the whole NWS County Warning Area (CWA) domain, it is difficult to separate out the CSI skill associated with the storm initiation nowcasts, as nowcasts of extrapolated storms generally dominate the statistics over the very large domain where many storms are occurring simultaneously. For this reason, a new approach was taken by Rita Roberts, Eric Nelson and Tom Saxen to perform the statistical evaluation of storm initiation nowcasts. The approach was simply to compute the statistics over smaller domain sizes that are more relevant to the scale on which the many different discrete areas of convection are occurring (Figure 1). We have found that this approach provides us a more detailed and informative look at nowcast performance and a better scientific understanding of the factors that increase or decrease the accuracy of the nowcast.

Overlaid onto Fig. 1 are the CSI skill scores of ANC performance with (blue) and without (magenta) forecaster-input during the complete event for five of the subset boxes. The CSI scores in the top two plots (Boxes 1,2 and 4,3) show minor differences in skill with and without forecaster input. Within these boxed regions, very little initiation is occurring and most nowcasts are based on the extrapolation of existing storms. The benefit of forecaster involvement is much clearer in the statistics for the other three subset boxes (Boxes 1,1; 2,2; and 3,2). Forecaster-entered convergence boundaries clearly had an impact in the increased accuracy of the nowcasts. Significant new convection initiated in these boxed regions during the 10 hr period spanning this event and forecaster-entered boundaries aided in the timely nowcasts of new convection triggered by these boundaries. Increases of CSI scores ranged from 0.3 – 0.5, a substantial increase in accuracy.

Expanding upon these results an additional step was taken to combine the statistics from the individual sub-grid boxes over the duration of the event to evaluate the overall performance in storm initiation nowcasting when forecaster-entered boundaries are used in determining storm initiation. Results indicate that the use of forecaster-entered boundaries in the forecast process leads to increased POD of storm initiation and increase in overall accuracy of CSI.

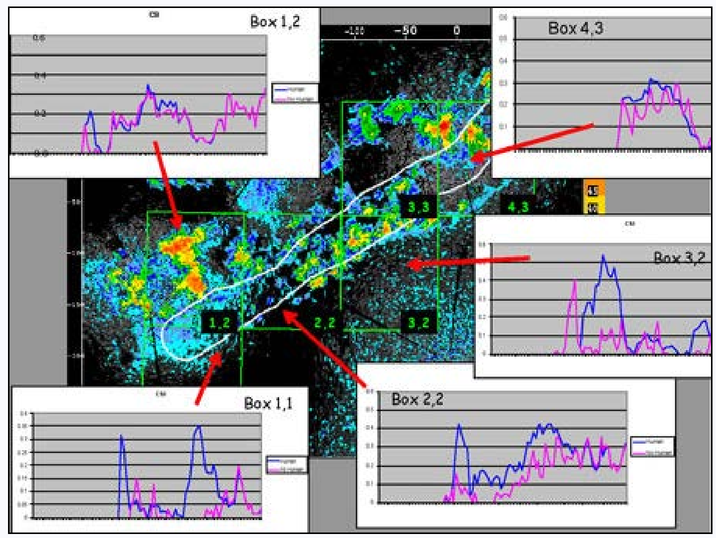


Figure 1. Comparison of CSI performance of Auto-nowcaster thunderstorm nowcasts with (blue curves) and without (magenta curves) forecaster-input into the system computed for the boxed (green) regions shown. The white polygon is the 60 min nowcast of new storm initiation produced by the Auto-nowcaster. See text for more details.

Encouraged by these results, the NWS Meteorological Development Laboratory (MDL) has been collaborating with Rita Roberts,Dave Albo and Dan Megenhardt to transfer the components of the NCAR ANC forecaster interactive tools to MDL for inclusion in a prototype AWIPS system running at MDL. Surface convergence boundaries will be entered by the forecasters on AWIPS and the boundary information will be sent to the ANC machine for inclusion in the ANC processing. This is anticipated to 1) increase the ease of forecasters for entering boundaries because of their familiarity with the AWIPS displays and 2) to facilitate incorporating this task into the everyday routine of the NWS Short Term Forecaster. Transfer of the other software components of the ANC into the MDL prototype AWIPS will occur during FY2008.

## DTRA Sensor Data Fusion

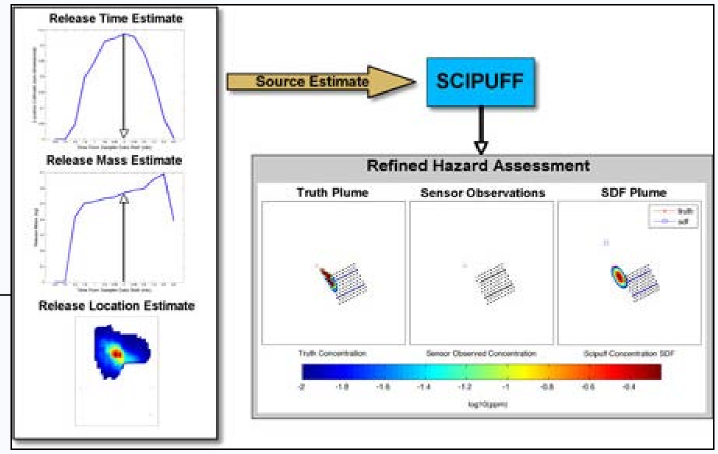
back to top

Since late FY04, RAL has been sponsored by the Department of Defense's Defense Threat Reduction Agency (DTRA) to develop tailored meteorological decision-support applications for the military and domestic emergency response communities. In particular, these applications are used to enhance DoD's Chemical, Biological, Radiological, Nuclear, and Explosive (CBRNE) hazard prediction toolsets such as the Hazard Prediction and Assessment Capability (HPAC) and more recently the Joint Effects Model (JEM). RAL's work has two primary objectives: development of an operational algorithm which can both estimate an unknown CBRNE source and predict a refined downwind hazard from that source, using available CBRNE and meteorological sensor observations; and integration of this algorithm into the HPAC/JEM hazard-prediction toolsets. To support testing and evaluation of this product, RAL is developing a virtual testing and evaluation environment (VTHREAT) which will enable simulation of a realistic CBRNE release scenario, placement of CBRNE and meteorological sensors, and extraction of the resulting synthetic sensor readings. These synthetic observations can then be used by the evolving algorithms to evaluate their ability to recreate the CBRNE event.

### FY07 Accomplishments:

In FY07 RAL developed and demonstrated of a prototype VTHREAT system which provides the capability to emulate a CBRN attack scenario. During the development of the VTHREAT prototype, DTRA requested that RAL use the VTHREAT concept to provide field test design guidance for DTRA's FUSION Field Test 2007 (FFT-07). The question posed to NCAR was "What is the optimal release and collection configuration to ensure a high probability of detection, while also avoiding saturation of the front line detectors AND supporting the distinction of multiple simultaneous releases". Subsequently, VTHREAT was used to generate three typical atmospheric conditions for the field test area, Dugway Proving Ground, Utah. Using synthetic atmospheric datasets, myriad material releases were simulated with three different proposed sensor configurations. The synthetic sensor readings were extracted and analyzed to determine the probability of detection under each of these configurations. These results were then presented to the FFT-07 Science Team Board in July 2007. After reviewing NCAR's recommended sensor configuration, the board approved utilization of this layout for the operational tests in September. The FFT-07 tests were recently completed and the field test has been deemed a success by the DTRA sponsors. The VTHREAT system also includes a gui application which allows users to interactively create synthetic sensor and meteorological data sets. This VTHREAT prototype application was demonstrated in September 2007 at the FFT07 VIP at Dugway Proving Ground, Utah.

FY07 also marked the development of the Variational Sensor Data Fusion (SDF) prototype. Phase I of this effort used the existing L3-Titan SCIPUFF code (and adjoint) to calculate a source estimate and then used that source estimate to run a single forward SCIPUFF simulation. This phase of the prototype was recently completed and demonstrated in September 2007 using synthetic chemical and meteorological sensor data generated with the VTHREAT prototype. (Figure 1)



Variational SDF Prototype Phase I Sample Results.

**FY08 Plans:**

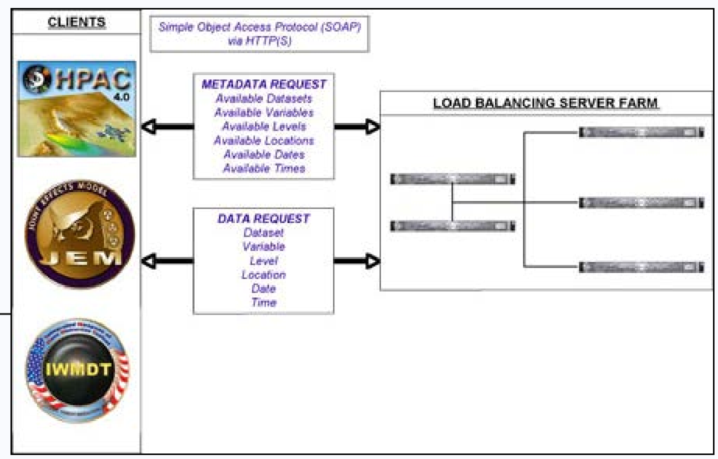
The VTHREAT GUI application will continue to be refined during FY08. Current plans call for the development of additional types of meteorological sensors (towers, rawinsonde, and LIDAR) and the ability to dynamically place grids of chemical sensors. The release of the first official version of the VTHREAT system is scheduled early FY09.

The primary activity of the SDF program during FY08 will be the continued development of the variational sensor data fusion algorithm. Phase II of this algorithm is designed to improve upon the initial source estimate, and associated forward prediction demonstrated in FY07 utilizing a recently developed Eulerian plume model (and adjoint), that iteratively refines the source estimates with variational data assimilation techniques. Phase II development is currently underway and is on schedule for an initial operational demonstration in November 2007. Continued refinement of the Phase II algorithm will be conducted throughout FY08. Current plans call for the development of the capability to include observations taken at multiple times and the ability to identify the source locations from multiple release scenarios.

## DTRA Weather Services Research and Development

back to top

Since late FY04, RAL has been sponsored by the Department of Defense's Defense Threat Reduction Agency (DTRA) to develop tailored meteorological decision support applications for the military and domestic emergency-response communities. In particular, these applications are used to enhance DoD's Chemical, Biological, Radiological, Nuclear, and Explosive (CBRNE) hazard prediction toolsets such as the Hazard Prediction and Assessment Capability (HPAC) and more recently the Joint Effects Model (JEM) (see figure at right).



NexGen MDS and API Conceptual Overview.

**FY07 Accomplishments:**

In FY07, RAL continued to refine the NexGeneration Meteorological Data Server (MDS) and its associated Application Programming Interface (API). New MDS versions were released in February and April 2007 to DTRA facilities in Alexandria, VA and Albuquerque, NM. The next version is scheduled for operational deployment in October 2007.

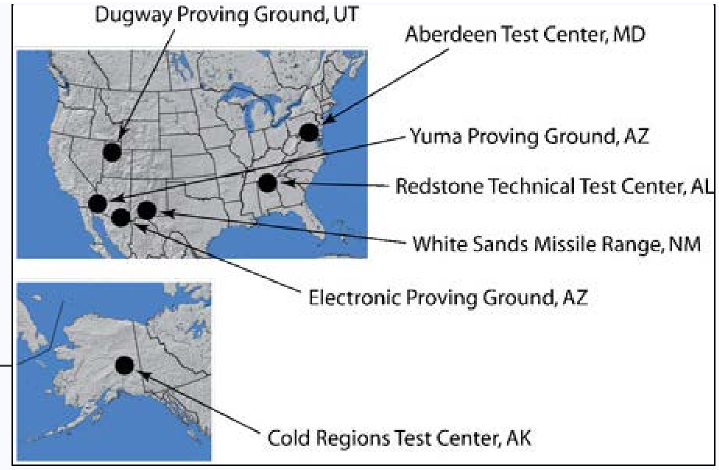
The effort to refine and improve the HPAC weather interface in support of the HPAC 5.0 release also continued with major improvements made in new, more modular component architecture for the software system including published Application Programming Interfaces (APIs); replacement of the legacy MDS Client interface with the new NexGen MDS API; and general GUI Enhancements.

FY2008 Plans:
Developmental support for HPAC 5.0 Service Pack 1, scheduled for delivery January 2008, is underway. Weather interface related improvements are focused on the NexGen MDS GUI. These GUI updates include: notification to user of estimated download file size, if it exceeds a prescribed maximum allowable file size; estimated file size and download status; identification of data source (useful for those using the "AUTO" download option); and estimate of the time it takes to generate NWP analyses.

## Four-Dimensional Weather System: ATEC

back to top

Over the past decade, the U.S. Army Test and Evaluation Command (ATEC) has sponsored the research and development of the Four-Dimensional Weather (4DWX) system, a cutting-edge weather modeling system based on MM5 and the WRF Model. 4DWX provides high-resolution mesoscale modeling capability, short-term thunderstorm prediction, multi-dimensional integrated displays, and fine-



4DWX is accredited for operational use at seven test ranges.

scale climatological analysis tools, enabling the Army to test military hardware under precise conditions across the full spectrum of arctic, tropical, desert, and other natural and controlled environments. 4DWX is accredited for operational use at seven test ranges:

**FY2007 Accomplishments:**

*Real-Time Four-Dimensional Data Assimilation (RTFDDA):* This unique scheme assimilates observations from a variety of data feeds, preserving the data's temporal dimension during assimilation. New analyses and forecasts are made every one to three hours, depending on the range, providing the operational forecaster with very timely information. A recent addition to RTFDDA is the Model Manager, which is a user interface that provides more modular, automated control of non-operational RTFDDA simulations, and also provides the resource management necessary to efficiently use the Test Center's computing resources.

*3-Dimensional Variational Data Assimilation (3DVAR):*
3DVAR techniques at the mesoscale are being evaluated, and a number of non-standard observations that cannot be included in RTFDDA's observation-nudging scheme, such as satellite radiance, GPS, and radar, are being incorporated. 3DVAR is currently being integrated into the RTFDDA system, yielding a model-based solution that will account for all available observations.

*Ensemble Forecasting:*
Late in FY07 RAL successfully fielded at Dugway Proving Ground (DPG) a test version of an operational ensemble of 4DWX forecasts in support of FFT07, the FUsing Sensor Information from Observing Networks (FUSION) Field Trial. The ensemble system (called E-RTFDDA) extends the pseudo-deterministic, single RTFDDA realizations by running a suite of RTFDDA forecasts, all valid at the same place and time. The ensemble comprises 30 members whose differences are induced by varying initial conditions, boundary conditions, model physics, and model cores. The system cycles every 6 h and produces four 36-h forecasts per day. Currently forecasts are uncalibrated, but research into calibration (including first and second moments of ensemble distributions) continues. As a critical step in this work, we are generating a 3-year archive of retrospective forecasts that will provide statistics necessary for an initial attempt at calibration and will allow us to optimize the size of the ensemble.

*Coupled Applications*: The direct NWP output from 4DWX is the essence of the forecast guidance used by staff at the ATEC ranges, but a great amount of added value is achieved by coupling this direct output to secondary models, also known as *coupled applications*. These include:

- Noise Assessment and Prediction System (NAPS)
- Second-order Closure Integrated Puff (SCIPUFF) model
- General Electric Missile and Satellite Simulation (GEMASS) Program
- Open Burn / Open Detonation Model (OBODM)

*Model Verification:* In FY07, RAL continued development of approaches to model verification that go beyond traditional metrics such as root-mean-squared errors calculated at points. Among the newer approaches to verification are those that treat predicted and observed weather as one or more "events," or "objects"—a change in wind direction, or a coherent region of rainfall, for instance. Object-based approaches do not inherently handicap more resolved models and are often more consistent with the mental images that end-users have of forecasts and observations.

*Web Portal:* Development continued in FY07 on a dramatically new look and feel to the 4DWX range Web pages using portal technology, which permits administrative and user customization. The portal's flexibility, accessibility, modularity, and extensibility make it ideal for serving as the new foundation for most 4DWX user interfaces.

*Climate FDDA (C-FDDA:* RAL has begun generating a test archive of mesoscale climatographies for use by two ATEC ranges for long-range scheduling of the optimal time, day, season, and location for materiel testing under specific weather conditions.

**Plans For FY08:**

The first version of MetVault, a central data repository for observations, model output, and sundry other electronic information, will be released. It includes a sophisticated search engine, a suite of services that will enable users to extract, interpolate, combine subsets of stored data, and write out the data in a variety of formats, and a quality control system for observations ingested into the 4DWX database.
Work will also continue to refine and extend the Global Meteorology on Demand (GMOD) tool, which enables non-scientists to launch highly resolved, rapidly executed NWP simulations anywhere on the globe with a simple, Web-based user interface. And RAL will continue to explore methods for assimilating radar data into 4DWX. In FY08 we anticipate significant advances from an approach that

is based on the coupled cycling of RTFDDA and the Variational Doppler Radar Assimilation System (VDRAS).

### Future Combat Systems Modeling and Simulation

back to top

The Future Combat System (FCS) is the U.S. Army's program to modernize American war-fighting capabilities and achieve the ability to rapidly deploy a dominant ground force anywhere in the world within days. Because most weapons testing and military operations rely heavily on accurate weather information, the Army relies on tools such as the 4-Dimensional Weather Real-Time Four Dimensional Data Assimilation (4DWX-RTFDDA) system developed at RAL in collaboration with the Army Test and Evaluation Command (ATEC). This modeling system provides high-resolution 4-D synthetic weather analyses and forecasts by continuously merging all available observations with full physics models. It has become a very valuable tool for providing weather modeling support for FCS Modeling and Simulation (FCS/MS). Since 2004, NCAR RAL has been continuously adapting and refining this modeling system and proving realistic simulated battle-field-scale weather events for the FCS/MS applications.

#### FY2007 Accomplishments:

RAL produced model simulations of events for FCS with 4DWX-RTFDDA final analyses for two events - one at the US Army Dugway Proving Ground (DPG), Utah, involving nocturnal boundary layer flows; and the other at the Army Cold Region Test Center (CRTC), Alaska, involving an extreme cold-weather event. Both weather processes present unique modeling challenges due to complex terrain and the scarcity of measurements. The complete model output for the simulated events includes the meteorological products and celestial-object information (moon phase, solar and lunar illumination).

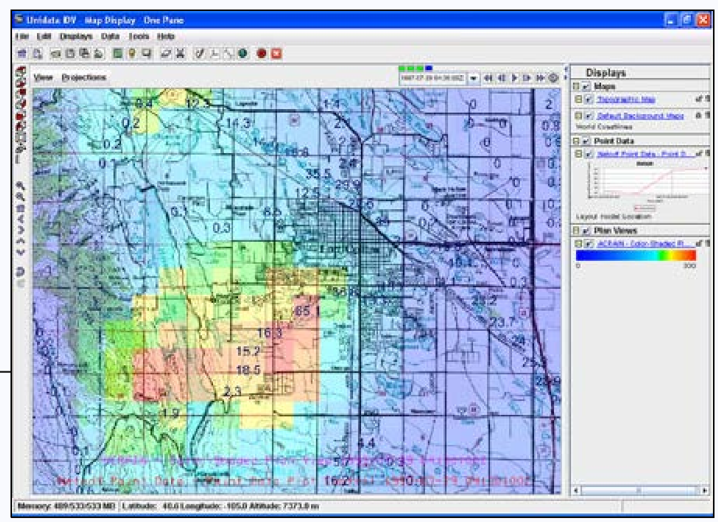
A second accomplishment involved the study of weather impacts on soil "trafficability", a term used to describe the mobility of a broad variety of military ground vehicles over specific local terrain, land use, soil type, composition and moisture. Soil moisture is, of course, heavily dependent on recent and current weather conditions, especially precipitation. The 4DWX-RTFDDA system is being used to generate a summer trafficability scenario at DPG and surrounding region in Utah. A case study demonstrates the great potential of applying 4DWX-RTFDDA modeling technology to provide an estimate of real-time trafficability parameters (e.g. surface soil strength, stickiness, slipperiness, and critical-layer depth) and short-term (0 – 48h) forecasts for battle field planning.

#### FY2008 Plans:

Development of new capabilities to support the FCS/MS missions will be further explored. Specifically, to better simulate trafficability, RAL will work with the Army DPG modelers to couple the 4DWX-RTFDDA model system with Army trafficability models such as the NATO Reference Mobility Model. Meanwhile, RAL will continue to improve the 4DWX-RTFDDA modeling capability, which provides real-time support for the upcoming FCS Distributed Test Events (DTEs). Special effort will be committed to exploring the weather-sensitive variables that are commonly used by military planners, such as Cn2 for laser targeting applications and vertical wind shear over complex terrain for unmanned aerial vehicle (UAV) operations.

### Hydrometeorological Processes

back to top




Hydrological impacts of significant weather and climate events often translate into staggering human, economic and environmental costs. Despite decades of research, significant gaps remain in how weather and climate information are used for reliable hydrological prediction. Additionally, it is now well-recognized that terrestrial hydrologic processes are not only influenced by weather and climate but also exert a significant feedback to the coupled Earth system. The nature of the relationship between terrestrial hydrologic processes and the atmospheric processes that simultaneously drive and respond to them are the focus of RAL's Hydrometeorological Processes efforts.

#### FY2007 Accomplishments:

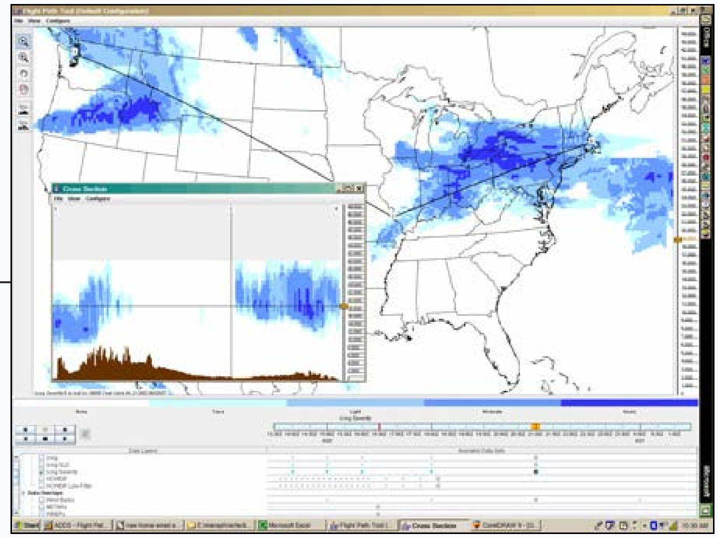
*Romania*: During FY07 RAL continued to provide hydrological modeling support for a World Bank-funded project for the country of Romania. Working in collaboration with scientists from Baron Advanced Meteorological Services (BAMS) we have completed a suite of enhancements to the Noah-distributed hydrological model and implemented and tested the new modeling system in several new river basins in both the U.S. and in Romania. Work also focused on fully parallelizing all components of the Noah-distributed hydrological modeling system for the execution of parallel computations on NCAR supercomputers.

*Colorado Front Range*: A new project aimed at improving predictions of short term (hours to 1 day) flash flooding events in the Colorado Front Range was initiated during FY07. This project deploys, in an unprecedented manner, the newly developed Noah-distributed hydrological modeling system over a large region in north-central Colorado. During FY07, the model domain was defined and attributed and case study simulations were executed which focused on simulating the 1997 Ft. Collins flash flood (Figure 1). Additionally, the Noah-distributed model has been coupled to the Advanced Weather Research and Forecasting model for fully-coupled simulations of high-impact hydrometeorological events. Results from an initial round of sensitivity studies have been completed and were presented at the annual WRF User's workshop in late June.

## In-Flight Icing

back to top

National Transportation Safety Board records indicate that in-flight icing causes more than 25 accidents annually, with over half of these resulting in fatalities and damaged aircraft. The cost of injuries, fatalities and aircraft damage is estimated to be $100M annually. The RAL In-Flight Icing Program addresses this problem by producing improved operationally -available, high-resolution, accurate diagnoses and forecasts of aircraft icing conditions. This work is funded by the FAA's Aviation Weather Research Program.



### FY2007 Accomplishments:

An upgraded version of the Current Icing Product (CIP) depicting icing severity has been thoroughly evaluated and cleared for unrestricted operational use by all aviation decision makers. This designation opens the door for vendors to include it in their product suites for in-cockpit use by pilots. CIP is the first product developed by the FAA's Aviation Weather Research Program to receive this designation.

Progress was made in improving the microphysical parameterizations within the MM5, Rapid Update Cycle (RUC), and Weather Research and Forecast (WRF) models to provide better forecasts of potentially hazardous icing conditions. In particular, a parameterization of snow density varying with crystal size has resulted in significant improvements to our ability to model precipitation on the ground and hydrometeor content aloft.

Continued evaluation of NASA's advanced satellite products to improve the severity product is very encouraging, pinpointing areas of hazardous icing. Additionally, freezing drizzle detection using NEXRAD data looks feasible, and RAL scientists are now engaged in determining how and where to implement the new detection algorithm.

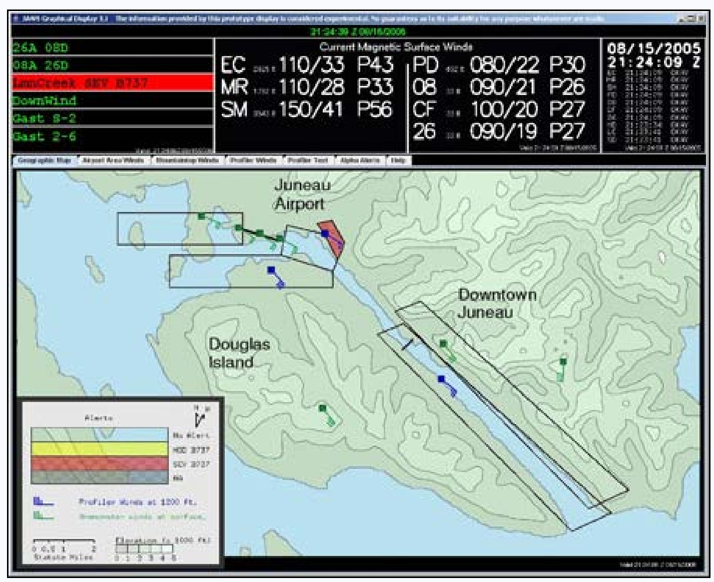
### FY2008 Plans:

Work will continue to move the forecast version of the icing algorithm (FIP) to operational status for the National Weather Service and FAA. Work is underway to make the new WRF Rapid Refresh model the basis for our icing diagnosis and forecasting algorithms. New data sets (e.g., NEXRAD 3D mosaic and advanced satellite products) will be tested for use in the Current Icing Product. Further development of microphysical parameterizations using data sets from the ICE-L field experiment will be conducted, and a confidence field will be created for our icing algorithms to help them become part of automated decision-making systems. Finally, we will begin planning for North American and global versions of our icing algorithms.

back to top

## Juneau Terrain-Induced Turbulence

The Juneau, Alaska, environment is characterized by rugged terrain and adverse weather that combine on occasion to produce moderate to severe terrain-induced turbulence and wind shear for flights into and out of the Juneau International Airport. To address this problem, the FAA tasked RAL in FY97 with the development and implementation of a new wind hazard warning system for the airport. Over the last ten years, RAL engineers and scientists have built a prototype warning system that relies on statistical correlations between wind-related parameters observable by the system (i.e., speed, direction, shear, variance, etc.) and the location and severity of turbulence. Since terrain is fixed and there are distinct strong-wind scenarios, correlations are expected between winds and hazards. These correlations were established using the warning system's input measurements and hazards measured by research aircraft during three intensive field projects. The graphical display was designed for a variety of users including Automated Flight Service Station specialists, airline dispatchers, and pilots. It contains information that depicts current alerts and conditions as well as conditions during the past hour. The prototype warning system is used every day by airlines and pilots flying in and out of Juneau to assess the current turbulence hazards around the airport.




Geographic display of Juneau Aviation Warning System. Hazard warning areas are outlined as boxes.

### FY2007 Accomplishments:

During FY2007, the FAA evaluated options for the final configuration of the terrain induced turbulence warning system in Juneau. RAL supported this effort by providing

information to the FAA about the capabilities and operation of the prototype system. RAL also operated and maintained the prototype warning system in Juneau to allow airlines and pilots to assess the important and unique weather information it provides.

**FY2008 Plans:**

RAL will continue to operate and maintain the warning system to continue service for the Juneau airlines and pilots. The FAA will complete its evaluation and decide on the final warning system configuration in FY2008. RAL will then complete the technology transfer of the prototype system to the FAA in FY2008 and FY2009.

Sheep Mountain Anemometer Site in February 2007.

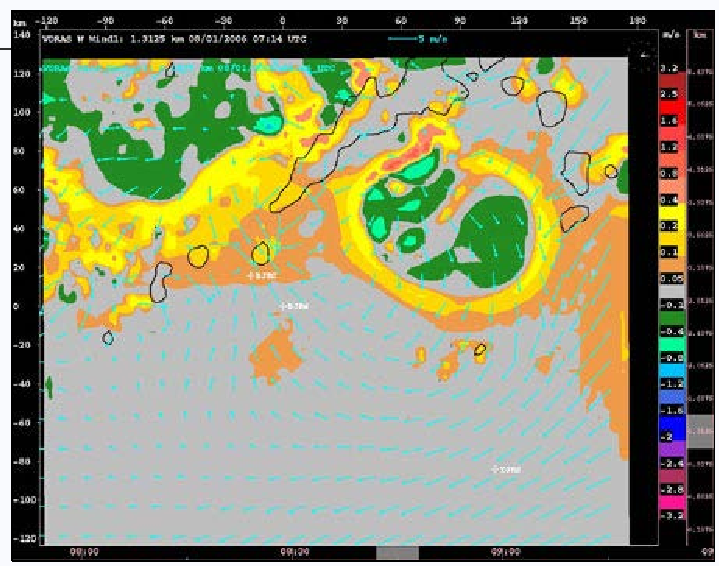
back to top

### Nowcasting Technology Transfer to China and Beijing 2008 Forecast Demonstration

The research and development efforts of RAL's Convective Weather Group are aimed at improving short-term (0 – 6 hour) thunderstorm forecasting and bridging the gap in skill between observation-driven expert systems and numerical weather prediction. One of the programs conducted by the Convective Weather Group is a collaborative effort with the Institute of Urban Meteorology (IUM) of the Beijing Meteorological Bureau (BMB) to transfer the NCAR AutoNowcaster (ANC) to Beijing in support of China's role as host of the 2008 Summer Olympics. As part of this multi-year project, scientists from NCAR and the BMB are studying the local characteristics of thunderstorm initiation and evolution to modify and tune the ANC algorithms for optimal performance in the Beijing area. Efforts are also underway to train the IUM staff on thunderstorm nowcasting techniques and the use of the ANC.

**FY2007 Accomplishments:**

The last component of ANC, the software for satellite applications, has been installed in Beijing and the Chinese satellite data were ingested to ANC. Training of the IUM staff took place on the use of satellite applications and ANC in general. The ANC system that is running at BMB was named BJ-ANC. It includes the Variational Doppler Radar Assimilation System (VDRAS) which retrieves and assimilates boundary-layer winds and thermodynamics from Doppler radar, surface stations, and sounding data. The BJ-ANC has been demonstrated during the summer 2007 along with a number of other nowcasting systems including NCAR's Niwot (a system that blends nowcasting and numerical weather prediction techniques) to prepare for the WMO-sponsored forecasting demonstration during the Beijing 2008 Summer Olympics.




VDRAS vertical velocity field (color) and wind vectors at 0714 UTC, Aug. 1, 2006. The black contours are the observed 30 dBZ reflectivity at 0846 UTC. The vertical velocity field shows a clear updraft maximum near the Beijing C-band radar (marked as BJRC) 1 hour and 32 min before the 30 dBZ convective cell appears.

Several severe storm cases that were documented during the past summers were studied to examine Beijing convective weather characteristic and forecast challenges. It was found that the storms had various initiation mechanisms and terrain forcing played a critical role. VDRAS analyses of these cases revealed convergence and humidity features that existed a few hours before storm initiation in the regions of metropolitan Beijing districts. These features will be further examined and analyzed to investigate their connections to storm initiation forecasting. Fig. 1 shows an example of how the analyzed updraft correlates to the location of storm initiation. The cold pool and gust front characteristics and their contribution to storm development are also studied.

**FY2008 Plans:**

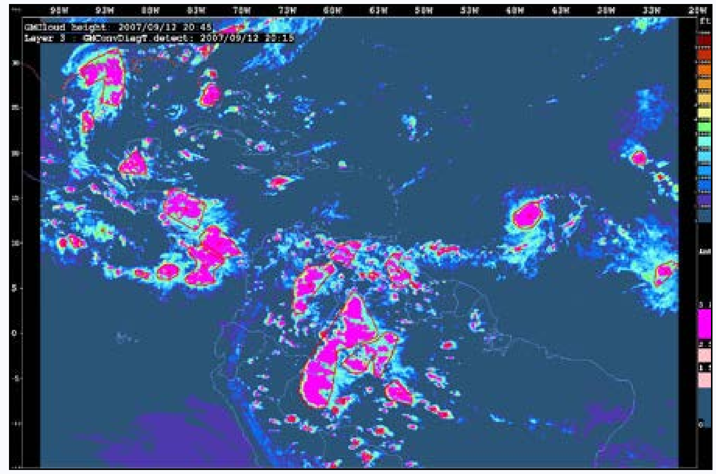
NCAR scientists will participate in the summer 2008 forecasting demonstration project before and during the Olympics in Beijing.

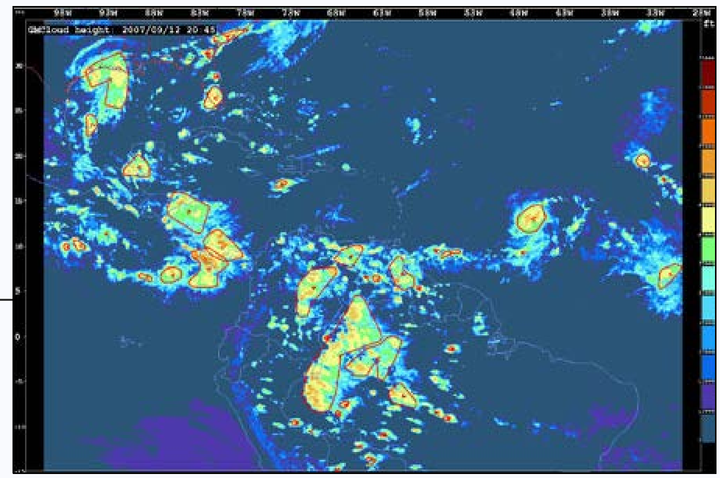
Further training of the BMB forecasters on nowcasting techniques will be conducted. The results from the case studies will be written up as journal papers.

## Oceanic Weather

back to top

Convection is an aviation hazard that can produce turbulence, icing, hail and lightning. Over the continental United States, the aviation community is well-served by the national Weather Surveillance Radar 1988 Doppler (WSR-88D) network that gives accurate and timely detections of the presence of hazardous convection. Over remote oceanic regions, however, the aviation community is hampered by the scarcity of available data that can be used to create products that detect and warn pilots, dispatchers and air traffic controllers of the current and future locations of hazardous convection. Unexpected convective development while en route can lead to costly re-routing and delays. Transmitting this critical information into the flight deck is difficult and further compounds the hazards faced by oceanic flights. The long duration of oceanic flights requires convective forecasts with longer lead times than those required for the continental United States. Under NASA Earth Observing System sponsorship, the Oceanic Convection Program at the RAL is working to overcome these limitations through the use of geostationary and polar-orbiting satellite observations and global numerical model results within an intelligent system that generates 0-2 hour nowcasts of convection location. Collaborators in this research include the National Center for Atmospheric Research, the Naval Research Laboratory-Monterey (NRL), and the Massachusetts Institute of Technology Lincoln Laboratory (MIT LL).





The cloud top height output is shown for 12 September 2007 at 2045 UTC for the Gulf of Mexico domain. Overlaid onto the cloud top height in a) is output from the convective diagnosis oceanic algorithm (shown in magenta) and in both a) and b) the 1-hour nowcasts of convection location are indicated by the red polygons with storm motion vectors.

### FY07 Accomplishments:

This R&D effort is currently focused on the Gulf of Mexico. Figure 1 shows an example of the cloud top height product overlaid with the convection diagnosis oceanic (CDO) product. The CDO has been devised using a scaled combination of three satellite-based algorithms that define where convection is present. The CDO is then tracked in time using the thunderstorm initiation, tracking and nowcasting (TITAN) algorithm that provides the 1-hour and 2-hour nowcasts of storm location, indicated by the red polygons in Figures 1a and 1b. Accomplishments in FY07 include software development of ingestors for polar-orbiting satellite data sets of the QuikSCAT near-surface winds, the sea surface temperature and soundings. The storm tracking algorithm was refined to improve results and an updated version of the NRL cloud classification algorithm was implemented. Investigation has commenced into characterizing the environment of regions where convection initiation has occurred.

Verification of oceanic products has been hindered by the limited number of independent data sources. However, two such data sources do exist and are beginning to be exploited: the TRMM Precipitation Radar and the CloudSat Cloud Profiling Radar. Lincoln Lab is taking the lead in verifying the oceanic convection products using these radar data. In addition, the oceanic convection products are being generated over the continental United States to enable comparison of the oceanic convection products to the WSR-88D reflectivity field.

### FY08 Plans

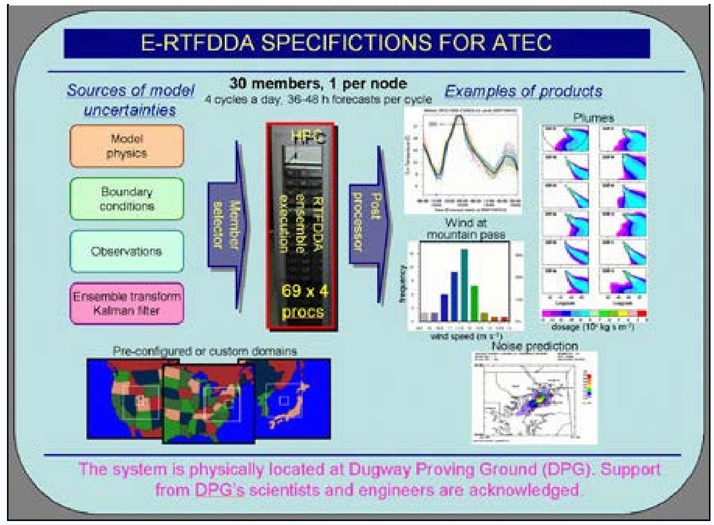
Development of the Oceanic nowcasting system will continue. Characterization of the environment near initiating convection will be used to devise prediction methodologies. Likewise, characterizing the environment near dissipating convection will be undertaken. The total precipitable water global satellite field will be ingested to better define regions where convection can be sustained. The merger of global model fields with observations will be undertaken such that the maximum amount of mesoscale detail will be retained. Expansion into the Pacific domain is planned.

## Real-Time Modeling and Data Assimilation

back to top

### FY2007 Accomplishments:

RAL modelers have continued their effort to implement the "observation-nudging"-based FDDA scheme in the Weather and Research Forecast (WRF) model. A reliable research version of the algorithm has been included in WRF-ARW




A schematic description of E-RTFDDA system

version 2.2, which was released for public use in Dec. 2006, along with utility programs for observation-data preparation and a brief user guide. In FY07, RAL modelers focused on improving the "observation-nudging"-based WRF RTFDDA modeling system for real-time operations at the Army test ranges. A robust data quality-control (QC) algorithm was built using the WRF-VAR framework and RTFDDA real-time cycling model outputs.

A variety of data-assimilation approaches have been developed for WRF. Each data-assimilation approach has its pros and cons with respect to assimilation of different kinds of observations for weather of different scales. Therefore it is potentially advantageous to join the schemes in a reasonable way so that the advantages of the different approaches can be combined. In FY07, a hybrid data-assimilation approach that is based on the RAL "observation-nudging"-FDDA, the PSU "grid-nudging"-FDDA, and the ESSL WRF-3DVAR data assimilation schemes was developed. The idea is to enhance the 4DWX-RTFDDA data-assimilation capability by using "grid-nudging" with intermittent 3D analyses produced by WRF-3DVAR. With this algorithm, the WRF-3DVAR capability that assimilates remotely-sensed observations such as satellite radiance and radar radial winds and reflectivity can be merged with the "observation-nudging" capability for meso- and small-scales that assimilates temperature, moisture and wind measurement from diverse observation platforms. Results from initial tests are encouraging.

The last, but the most noteworthy, accomplishment is the development of a 4DWX-RTFDDA based mesoscale ensemble analysis and forecast system (E-RTFDDA). E-RTFDDA extends the RTFDDA deterministic forecasting capability to probabilistic weather prediction by executing an ensemble of RTFDDA models which sample the uncertainties in the model components. In August 2007, a 30-member E-RTFDDA ensemble analysis and forecast system was run on an Army High Performance Computer Modernization Program (HPCMP) HPC machine at the Army Dugway Proving Ground (DPG) to support the FFT07, a major sensor data fusion field campaign which was also at DPG. The ensemble system is composed of fifteen MM5 and fifteen WRF members which sample the uncertainties in model physics, boundary conditions, measurements, data assimilation and analysis algorithms, and model dynamics. The system is summarized in Fig. 1. The system is considered to be one of the most advanced operational systems of its kind in the world, with its continuous data assimilation and forecast-cycling capability, multiple scales with a 3.3 km grid fine mesh, and inclusion of multiple ensemble perturbation schemes. It runs 4 cycles a day and produces 6-h analyses and 36 h forecasts for each cycle. The ensemble system successfully ran through the field campaign, and continued to run afterward for longer-term system verification. The web-based probabilistic-forecast graphics products are produced and can be viewed at http://dpg-ingest.4dwx.org/images/ens/index.html).

### FY2008 Plans

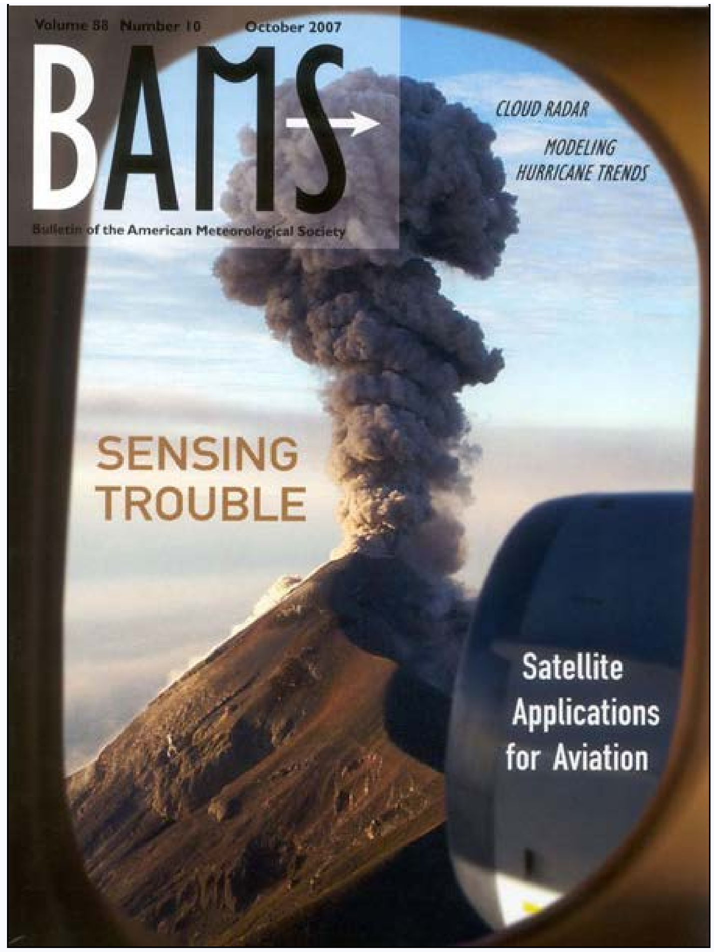
For hybrid data assimilation development, the focus will be on exploration of assimilation of satellite radiance and radar radial winds using the hybrid scheme. Currently, studies have been undertaken with the IHOP-2002 cases to tune up the data assimilation parameters, and the implementation of the hybrid scheme for RTFDDA operations is planned during late FY08. Aside from the "nudging-3DVAR" hybrid development, a "VDRAS" (Variational Doppler Radar Analysis System)-"observation-nudging" hybrid approach will also be studied. This hybrid scheme will make use of VDRAS to work as a bridge for incorporating Doppler radar radial winds and reflectivity measurements into high-resolution WRF-RTFDDA through the "observation-nudging" mechanism.

Research will be undertaken to 1) develop and evaluate existing and new ensemble perturbation schemes, including the ensemble-transform Kalman Filter approach and the ensemble adjustment Kalman Filter approach; 2) develop more experience and conduct statistical verification relative to operational ensemble forecasting; 3) generate re-forecasts for the last three years and develop ensemble calibration algorithms; and 4) start to investigate a 4-D EnKF scheme which makes use of "Kalman-Gain" to define the spatial weighting factors of "observation-nudging" data assimilation.

## Transitioning Advanced Satellite Observations into Practical Applications

back to top

RAL scientists and engineers are continuing work on a number of projects that involve the acquisition and application of meteorological satellite data to enhance understanding of atmospheric processes and applications. Much of this work is being supported by NASA, through the Advanced Satellite Aviation Weather Products (ASAP) initiative and through a system of competitive grants awarded by NASA's Applied Sciences Program. The goal of ASAP is to enhance the transition of new and existing satellite information and products into operational products by collaborating with the FAA's Aviation Weather Research




Program (AWRP) Research Teams (RT), many of which are based at NCAR. This effort is specifically addressing hazards such as in-flight icing, convective weather, turbulence (clear-air and cloud-induced), and the monitoring of weather in the data-sparse areas over oceans. RAL's role in ASAP is to coordinate the contributions from the participating universities and laboratories with the needs and requirements of the FAA's aviation weather Research Teams and to evaluate the accuracy and usefulness of these advanced satellite products. This program is described in an article team members published in the October 2007 issue of the *Bulletin of the American Meteorological Society.*

**FY2007 Accomplishments**

During 2007 the In-Flight Icing RT continued testing satellite-based cloud microphysical products produced by NASA Langley for possible incorporation into operational icing products such as the Current Icing Product (CIP). RAL scientists worked with scientists from the University of Alabama Huntsville (UAH) and the University of Wisconsin's Cooperative Institute for Meteorological Satellite Studies (UW/CIMSS) to test the utility of satellite-based, high-resolution, early cloud imagery for identifying favorable areas for convective development capable of growing into hazardous storms and to identify cloudy and clear-air features that may help identify areas of strong turbulence.

Three new, NASA-funded projects got underway during FY07. Each is aimed at enhancing the use of NASA Earth Science data sets in decision support systems targeting areas of national need. These projects, include studies of oceanic aviation weather hazards (in collaboration with scientists at the Navy Research Laboratory Monterey and MIT/Lincoln Laboratory); aircraft avoidance of convectively-induced turbulence due to thunderstorms (in collaboration with scientists at UAH and UW/CIMSS); and improved monitoring and forecasting of soil moisture and temperature for agriculture (in collaboration with DTN/Meteorlogix).

As a spin-off of this effort to make better use of satellite observations for practical applications, RAL Project Scientist David Johnson has proposed a method for enhancing satellite imagery for enhanced resolution near the edges of the image area. During FY07 UCAR submitted a patent application for this hardware-based enhancement device.

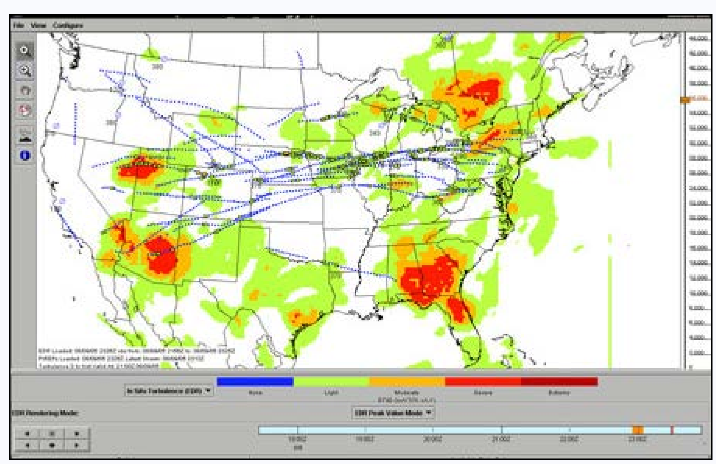
**FY2008 Plans:**

The RAL NASA ASAP effort will continue during 2008 with a gradual transition of the new satellite products into operational use through collaborations with the FAA aviation weather Research Teams.

## Turbulence Research and Development

back to top

Encounters with turbulence pose significant safety, efficiency and workload issues for commercial and general aviation. The number of pilot-reported encounters with turbulence is substantial, with moderate-or-greater turbulence pilot reports averaging about 65,000/year and severe-or-greater reports averaging about 5,500/year. More often than not, pilots will try to avoid or exit turbulent air, so turbulence significantly impacts national airspace (NAS) efficiency and air traffic controller workload. Fortunately, not every significant encounter with turbulence results in an injury; nevertheless, according to NTSB numbers, each year turbulence accounts for approximately 71% of all weather-related accidents and incidents. The cost to U.S. airlines due to injuries (medical attention and liability suits), cabin and aircraft damage, flight delays, and time lost to inspection and maintenance is substantial, with estimates in the $150-$500 million/year range. In order to help reduce the


Experimental ADDS Web-based display showing in situ turbulence reports

number and severity of turbulence encounters and the impact of turbulence on the NAS, RAL scientists are working on improving the detection and forecasting of turbulence and providing operationally useful products directly to users and will supply input for the automated decision support systems planned for the Next Generation Air Transportation System.

overlaid on contours of the Graphical Turbulence Guidance (GTG) turbulence forecast product.

Aviation turbulence R&D at RAL is funded primarily through the FAA's Aviation Weather Research Program and is augmented by NASA's Advanced Satellite Aviation-weather Products (ASAP) program and the Boeing Corporation.

**FY2007 Accomplishments:**

- A new turbulence detection and on-board quality control algorithm was developed. The software has been provided to Southwest and Delta Airlines for deployment by the end of CY07.
- The NEXRAD Turbulence Detection Algorithm (NTDA) was implemented and tested in collaboration with the FAA's Advanced Weather Radar Techniques team, and the software was delivered to the NWS for deployment on all NEXRADs.
- A real-time demonstration of the NTDA was expanded to use data from 83 NEXRADs east of the Rockies. A 3-D graphical product was made available to meteorologists and dispatchers via a web-based Java display, and a customized text-based graphic of in-cloud turbulence ahead was uplinked to select United Airlines aircraft.
- The Graphical Turbulence Guidance-2 (GTG2) algorithm continues to progress toward Aviation Weather Technology Transfer (AWTT) Board approval for operational status, which is expected in early 2008. Experimental product displays are available on the Experimental ADDS web site.
- A prototype GTG-Nowcasting system was developed and implemented in RAL.
- A comprehensive study regarding the use of airborne GPS receivers to measure turbulence was performed and delivered to the Boeing Corporation.

**FY2008 Plans:**

Work will be concentrated in the following areas:
In situ measurements: Verification of the edr measurements against pireps will continue, and ICAO documentation on the algorithm will be completed. Fleet-wide implementation of the winds-based edr algorithm on approximately 280 Southwest Airlines planes will be completed. Further, implementation of the algorithm on 140 Northwest Airlines planes will begin. We are also in discussion with other airlines, both national and international, about implementation on their respective fleets.

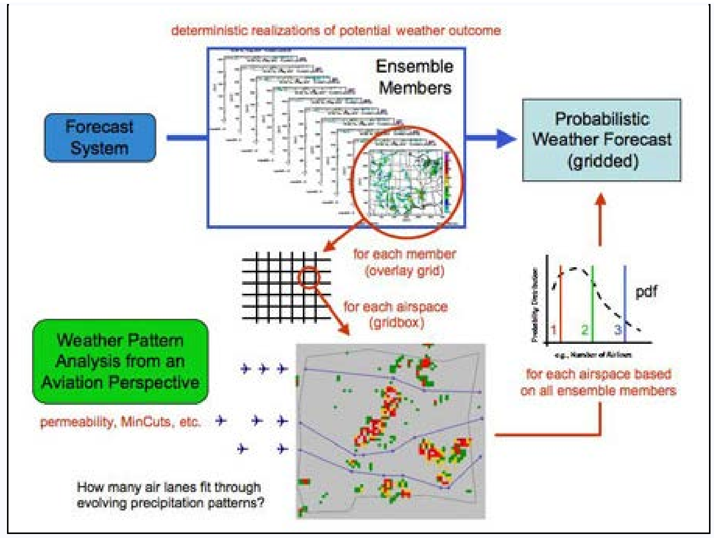
Remote sensing observations: NTDA-1 will be implemented on all NWS NEXRADs in summer 2008. Work on the next generation algorithm, NTDA-2, will commence to accommodate upcoming scheduled NEXRAD upgrades, e.g. phase coding, dual-polarization, super-resolution, new volume coverage patterns, and a possible new spectrum width estimator. This will provide improved coverage, particularly at lower altitudes. NTDA uplink demonstrations are expected to continue. R&D on a CIT diagnosis model will continue, using empirical relationships and conceptual models based on NWP model, satellite, lightning, NTDA EDR, etc., which will eventually become part of GTG-N.

Nowcasting/forecasting: GTG2 should become "operational" and available on the ADDS web site in early CY08. This product produces forecasts of clear-air turbulence sources out to 12 hours, updated hourly. Preliminary testing of the next version, GTG3, will commence next year. This version will provide probabilistic forecasts, will use all available in situ reports, and will include explicit mountain wave turbulence diagnostics. Work will continue on the nowcast product (GTG-N) which combines all observations of turbulence (including NTDA-2, in situ, PIREPs, and satellite-based diagnostics) with GTG3 analyses to produce a probabilistic nowcast, updated at 15 min. intervals.

## Weather Integration with Air Traffic Management

back to top

Weather, especially convective storms, continues to exert a disruptive influence on aviation, both in the terminal area and en-route air traffic flow. Aviation users need 0 – 6 hour forecasts that provide not only details about the likely weather outcome, but also information about storm structure, intensity, and organization, and associated forecast uncertainty. This emphasizes the need for short-range (0 – 2 days), high-resolution (<10 km spatial resolution) ensemble weather forecasting systems. Optimization of air traffic management, especially under future scenarios of anticipated much increased demand, requires automated decision support tools that integrate probabilistic weather information to estimate airspace capacity and provide guidance for managing air traffic flows under consideration of the associated prediction uncertainties. Under NASA sponsorship, RAL is defining and refining new concepts of how probabilistic weather forecasts can be tailored for aviation needs and integrated with automated decision support tools.



Probabilistic scenario forecast concept

**FY07 Accomplishments**

A detailed report has been compiled that reviews short-term weather forecasting techniques, from the perspective of both observation-driven expert nowcasting and numerical weather prediction systems. Emphasis has been placed on numerical ensemble forecasting procedures that will become highly valuable for aviation users. Moreover, a novel approach of how ensemble weather forecasts in the not-too-distant future may be analyzed from an aviation point of view and packaged for integration with automated air traffic management decision support tools has been presented (see figure below). This new approach draws upon recent experience gained with probabilistic convective scenario forecasts. The focus of the report has been on convective storms primarily because of their disruptive influence on air traffic flows. However, the concepts developed there may be applicable to other en-route weather hazards, such as turbulence and icing, as well.

**FY08 Plans**

The new concepts developed during the FY07 will be further refined and feasibility analyses conducted. In particular, use will be made of high-resolution ensemble model simulations to create probabilistic weather forecasts with a specific tailoring from an aviation perspective.

## Winter Weather Research and Development

back to top

Winter weather research and development at RAL has focused on developing a real-time nowcasting system called the Weather Support to Deicing Decision Making (WSDDM) system. Recent additions to the system included the Check Time system, and a high resolution winter weather modeling system using radar data assimilation. “Check Time” is a UCAR patented technology for ground deicing that provides users with an aircraft independent wall clock time that indicates when an applied aircraft deicing fluid is close to failure based on the current minute by minute snowfall rate and temperature. A snow Check Time system was developed in previous years and tested at Denver International Airport and shown to provide value to users. An All-Weather Check Time system was developed last year and adds three new sensors: Vaisala PWD-11 precipitation type sensor, Rosemount Freezing Rain sensor, and a GEONOR snowgauge. The addition of these three sensors allows the system to provide Check Times for all precipitation types (including ice pellets, snow pellets, freezing rain and drizzle).

**FY2007 Accomplishments:**

The key accomplishment for FY07 was the development of a Liquid Water Equivalent (LWE) real-time system consisting of a GEONOR snowgauge, a hotplate snowgauge, a WXT weather, and a precipitation type sensor. The motivation for this development is the need for real-time liquid equivalent snowfall rates for use in holdover time determination. Data were collected at the Marshall test site for this purpose and provided to the FAA for approval. The evaluation and approval process is ongoing. We also successfully demonstrated the ability of the RAL-developed snowmachine to perform deicing fluid testing at temperature close to 0 ºC for a variety of deicing fluids, a temperature range in which testing has proven difficult in the past.

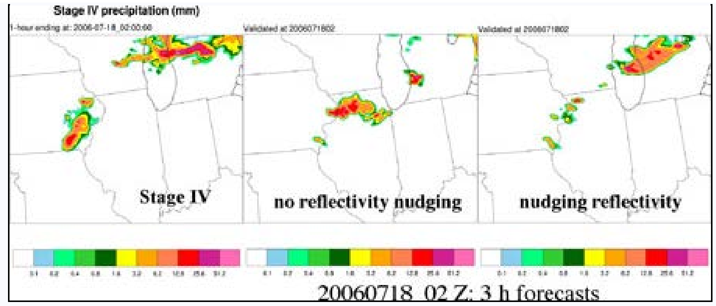
**FY2008 Plans:**

The main focus for FY08 will be the demonstration of the LWE system at four sites: Pittsburgh International, Chicago O’Hare, Denver International, and Minneapolis/St. Paul airports. Data from the LWE system will be provided to airlines, pilots and deicing users via a web site and radio broadcast. The FAA will evaluate the results of the demonstration and provide final approval to use the system operationally. The data from the Marshall site will also be used in this evaluation. Vaisala will develop a commercial version of the system that will be made available to users after FAA approval. A diagram of the LWE system is given below.

## Zero to Six Hour Storm Forecasting

back to top

High-resolution data assimilation and numerical modeling are critical elements in the effort to improve short-term (0-6 h) forecasts of convective storms. Radar data assimilation using advanced techniques allows a model to start up with initial conditions that account for the presence of existing storms and can result in significant improvement in the




Comparison of two 3 hour forecasts, one without reflectivity nudging (middle panel) and the other with reflectivity nudging (right panel), of a storm occurred near Chicago on July 8, 2006. The Stage IV precipitation analysis is shown on the left for verification.

timing and location of forecasting convective storms. At RAL's Convective Weather Group our modeling efforts emphasize the assimilation of radar reflectivity and radial velocity level II data from operational network into high-resolution cloud-resolving models. Two data assimilation systems have been developed and continue to be improved. One is reflectivity nudging using Real-Time Four-Dimensional Data Assimilation (RTFDDA), and the other is a 4D-Var based Doppler radar retrieval system known as VDRAS. These two systems are used both for research and real-time demonstrations.

### FY2007 Accomplishments:

Several cases documented during the FAA-supported summer 2006 forecasting demonstration period in the Indiana/Illinois domain have been rerun to evaluate the impact of reflectivity nudging on forecast improvement of convective events. Fig. 1 compares 3-hour forecasts with and without the reflectivity nudging. Recently, we have started to migrate the reflectivity nudging scheme from a MM5 modeling system to the WRF model, version 2.2. The mosaic reflectivity data ingest module has been adapted to WRF already. The reflectivity and latent heating nudging algorithms are now made compatible with the WRF modeling infrastructure.

In an effort to improve the computational efficiency of VDRAS, the code has been modified to enable a MPI parallelization capability. Tests on SCD's Linux Cluster computer showed that the parallelization was successful. A scheme for radial velocity dealiasing that uses VDRAS analysis as reference wind was developed and showed improvement over using radiosonde observations. Additionally, exploratory analyses reveal that it might be beneficial to couple the RTFDDA and VDRAS data assimilation systems to improve temperature and wind fields around convective storms. This would be accomplished through an iterative process in which the initial RTFDDA analysis is used as background field for the VDRAS wind and thermodynamic retrieval, which then are ingested into the RTFDDA assimilation cycle.

### FY2008 Plans:

Plans call for running the 3km WRF reflectivity nudging in real-time next summer in a domain covering the northeastern United States. Tests will be conducted with the 3km WRF domain initialization using different model analyses, including the RUC 13 km analysis in collaboration with NOAA/GSD scientists. Work will continue on code development and testing of the WRF-based reflectivity nudging. Also, the assimilation of VDRAS wind into the RTFDDA will be further evaluated.

***Strategic Goal 2, Priority 2***


*Postal Address: P.O. Box 3000, Boulder, CO 80307-3000 • Shipping Address: 1850 Table Mesa Drive, Boulder, CO 80305 • Contact*

## NCAR STRATEGIC PRIORITY: BUILDING NEW CONNECTIONS WITH RESEARCHERS IN DEVELOPING NATIONS

### Building Capacity in Developing Countries

RAL has led three recent projects focused on West Africa and the Sahel: 1) improvement of a modest radar network and data-distribution system within Burkina Faso and Mali; 2) development of a partnership among UCAR, the Ghana Meteorological Agency, and the Ghana university community to develop an operational Weather Research and Forecasting (WRF) model for West Africa; and 3) conduct of a recent workshop in Ouagadougou, Burkina Faso from April 2-6, 2007, for which the theme was "Improving Lives by Understanding Weather" (http://www.africa.ucar.edu/sahelconference.html). These activities are summarized below.

**FY2007 Accomplishments:**

Work has begun to develop an operational network of weather radars in West Africa, beginning with Burkina Faso, Mali, and Senegal. In all three countries, existing (and sometimes non-operational) radars are being rehabilitated and upgraded with simple personal-computer-based software systems that allow the radars to be controlled and maintained with only minimal engineering support. In addition, two of the radars are using Unidata software, developed at UCAR, to deliver operational data through a web interface. Finally, Mali and Burkina Faso have signed an MOU pledging to share radar data with each other, using the same Unidata software. Figure 1 shows the coverage of some of the radars. More information about the radar project in West Africa can be found at http://www.rap.ucar.edu/projects/westafrica/radar.html.


Figure 1. West Africa weather-radar coverage (circles). See text for details.

Currently, only a few African countries are running mesoscale models operationally. Most of these models, however, were developed for research, or have not been adapted for African weather. Also, many of the mesoscale models are proprietary, and this makes it difficult to "tune" them to accurately represent local phenomena or customize their output according to local users' needs. Through the African Initiative we are adapting the WRF model to better meet local and regional needs. WRF offers a variety of advantages: it is available free of charge over the web; it can be used for weather and climate research as well as operational forecasting; it can be run at very high resolutions; it possesses numerous physics options; it has a vigorous community of users whose members share ideas and solutions to problems; it is technically supported at NCAR; and formal training is available for new users. Most importantly, it is designed to be customized and adapted, and so provides an ideal platform with which to develop a mesoscale model for Africa. The first step is already done: a WRF-based operational forecasting system, with the highest resolution focused on West Africa (see Fig. 2), has been established. As a second step, operational forecasters in Ghana and surrounding countries are providing input about forecast strengths and weaknesses, and improvements are being made.

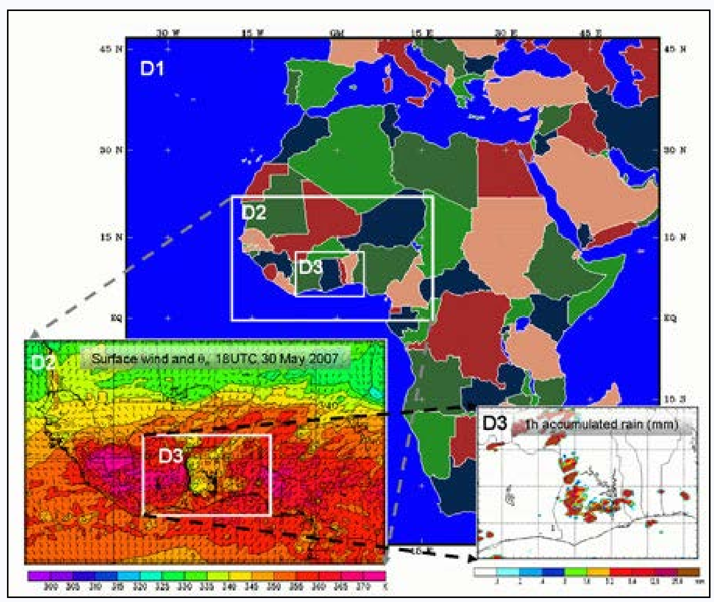



Figure 2. WRF forecast domains for the operational modeling system, with example forecast products on the two inner grids. The grid increments on D1, D2, and D3 are 40.5, 13.5 and 4.5 km, respectively. The forecasts are 48 in duration on D1 and D2, and 36 h on D3.

The "Improving Lives by Understanding Weather" conference, held in Ouagadougou, Burkina Faso on 2-6 April 2007, sponsored by Programme Saaga in Burkina Faso, the Meteorological Services in Mali and Burkina Faso, and the UCAR AI, was attended by over 80 participants from 18 countries. The main purpose of the conference was to explore ways to increase the value and use of meteorological data and models for the economic and societal benefit of countries in the Sahel. A second purpose was to bring together researchers, government ministers, operational forecasters, and university professors from across the Sahel to outline common problems and potential projects. Finally, the conference provided a means for UCAR to begin to fulfill the AI's ideal of "African solutions to African problems," by learning about the context of African meteorological activity. A summary of the conference can be found at http://www.africa.ucar.edu/sahelconference.html.

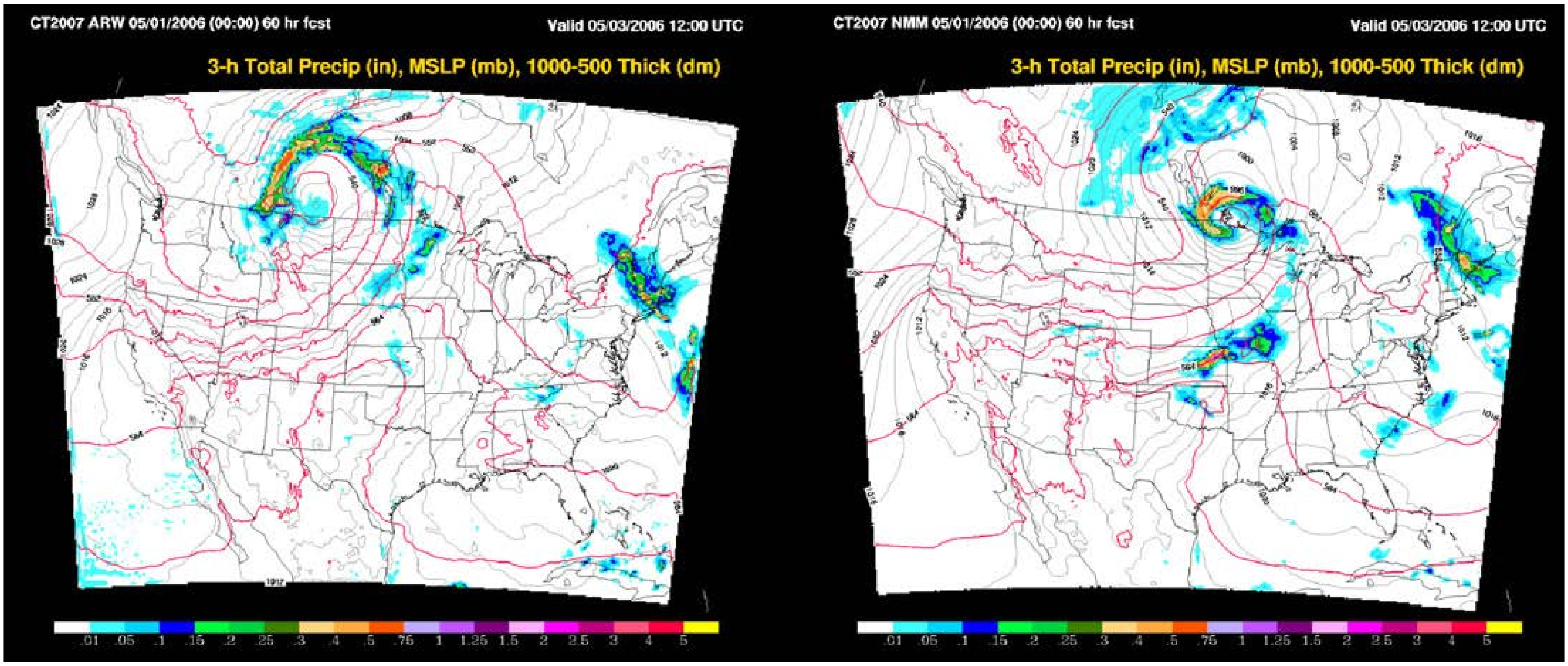
### Long-Term Plans:

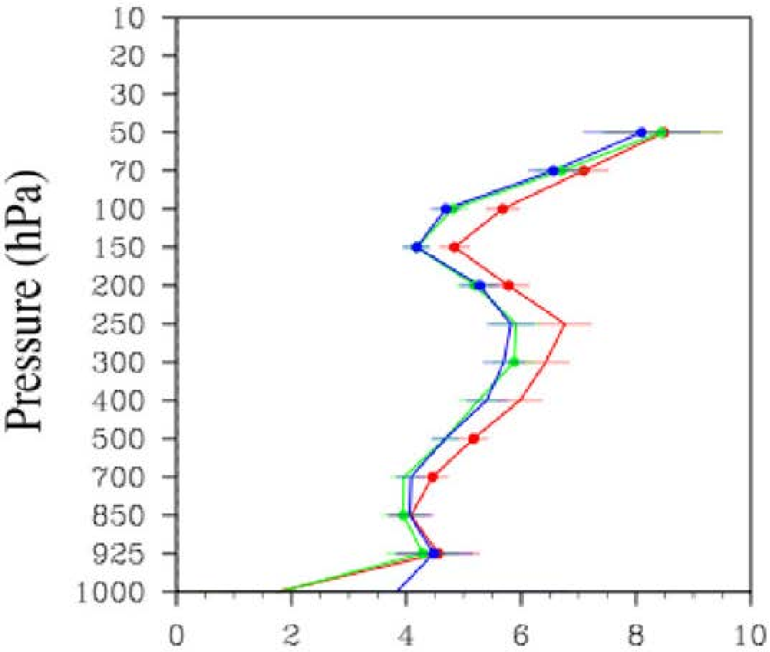
MOUs have been signed between UCAR and Burkina Faso, Ghana, and Senegal which look to a variety of cooperative meteorological and hydrological activities in the future. Task order agreements are currently being negotiated with both Burkina Faso and Senegal to begin small radar upgrade and training programs. The long-range goal in numerical weather prediction is to develop capacity in Africa, such that WRF is running operationally in Africa, is maintained by Africans, and is being adapted by Africans to meet their specific needs.

***Strategic Goal 2, Priority 3***

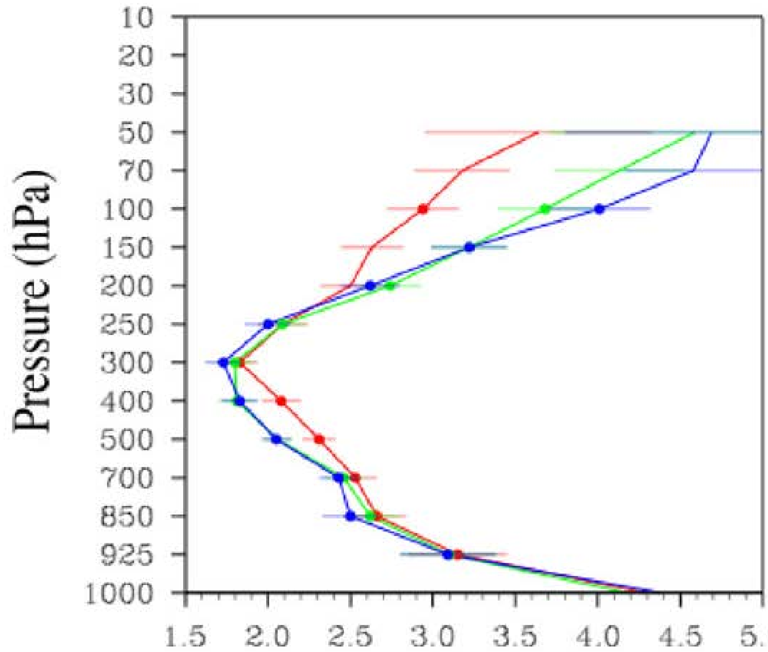


*Postal Address: P.O. Box 3000, Boulder, CO 80307-3000 • Shipping Address: 1850 Table Mesa Drive, Boulder, CO 80305 • Contact*

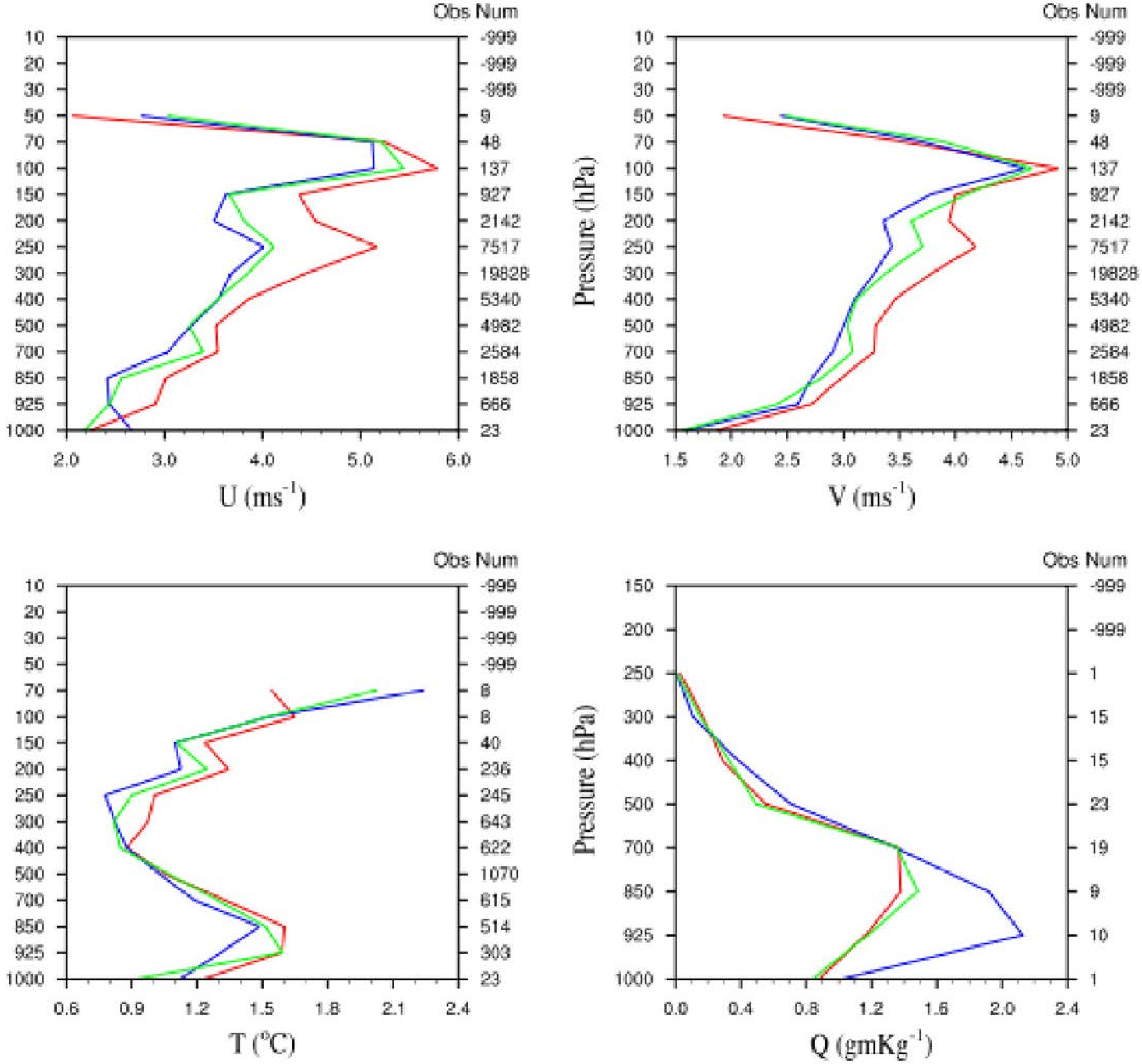

CT2007 ARW 05/01/2006 (00:00) 60 hr fcst
Valid 05/03/2006 12:00 UTC
3-h Total Precip (in), MSLP (mb), 1000-500 Thick (dm)
.01 .05 .1 .15 .2 .25 .3 .4 .5 .75 1 1.25 1.5 2 2.5 3 4 5
CT2007 NMM 05/01/2006 (00:00) 60 hr fcst
Valid 05/03/2006 12:00 UTC
3-h Total Precip (in), MSLP (mb), 1000-500 Thick (dm)
.01 .05 .1 .15 .2 .25 .3 .4 .5 .75 1 1.25 1.5 2 2.5 3 4 5

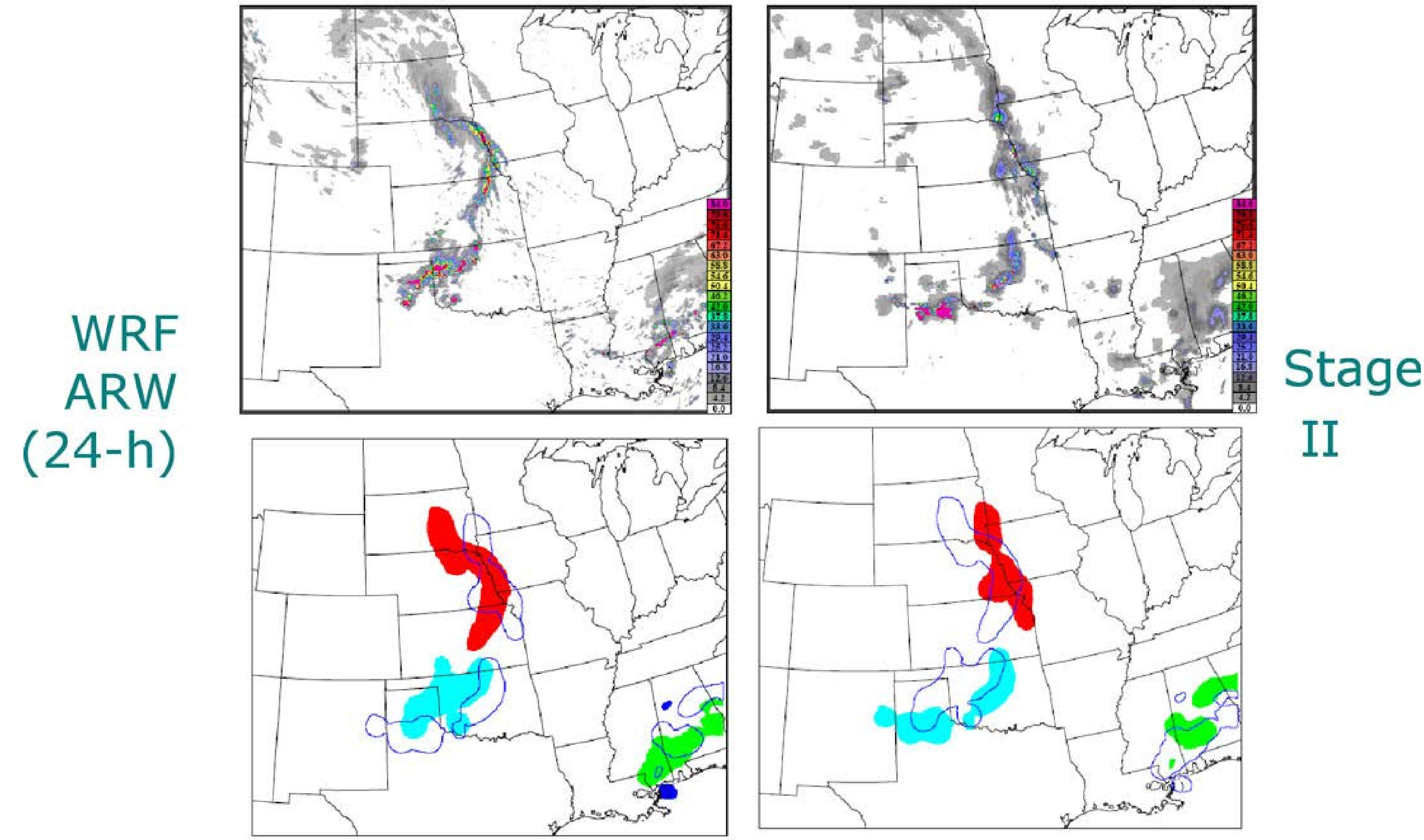


Pressure (hPa)
10
20
30
50
70
100
150
200
250
300
400
500
700
850
925
1000
0
2
4
6
8
10

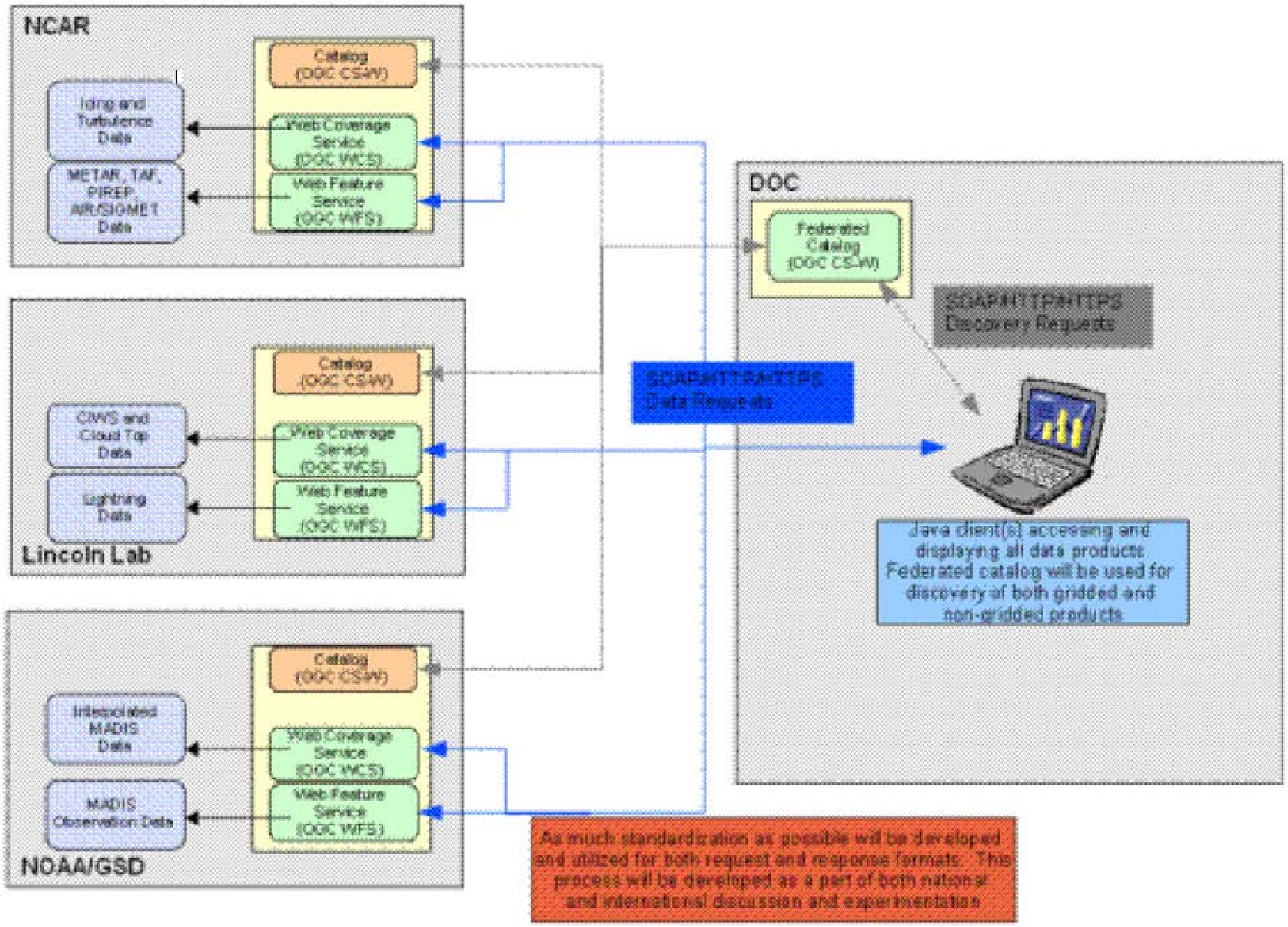



Pressure (hPa)
10
20
30
50
70
100
150
200
250
300
400
500
700
850
925
1000
1.5
2.0
2.5
3.0
3.5
4.0
4.5

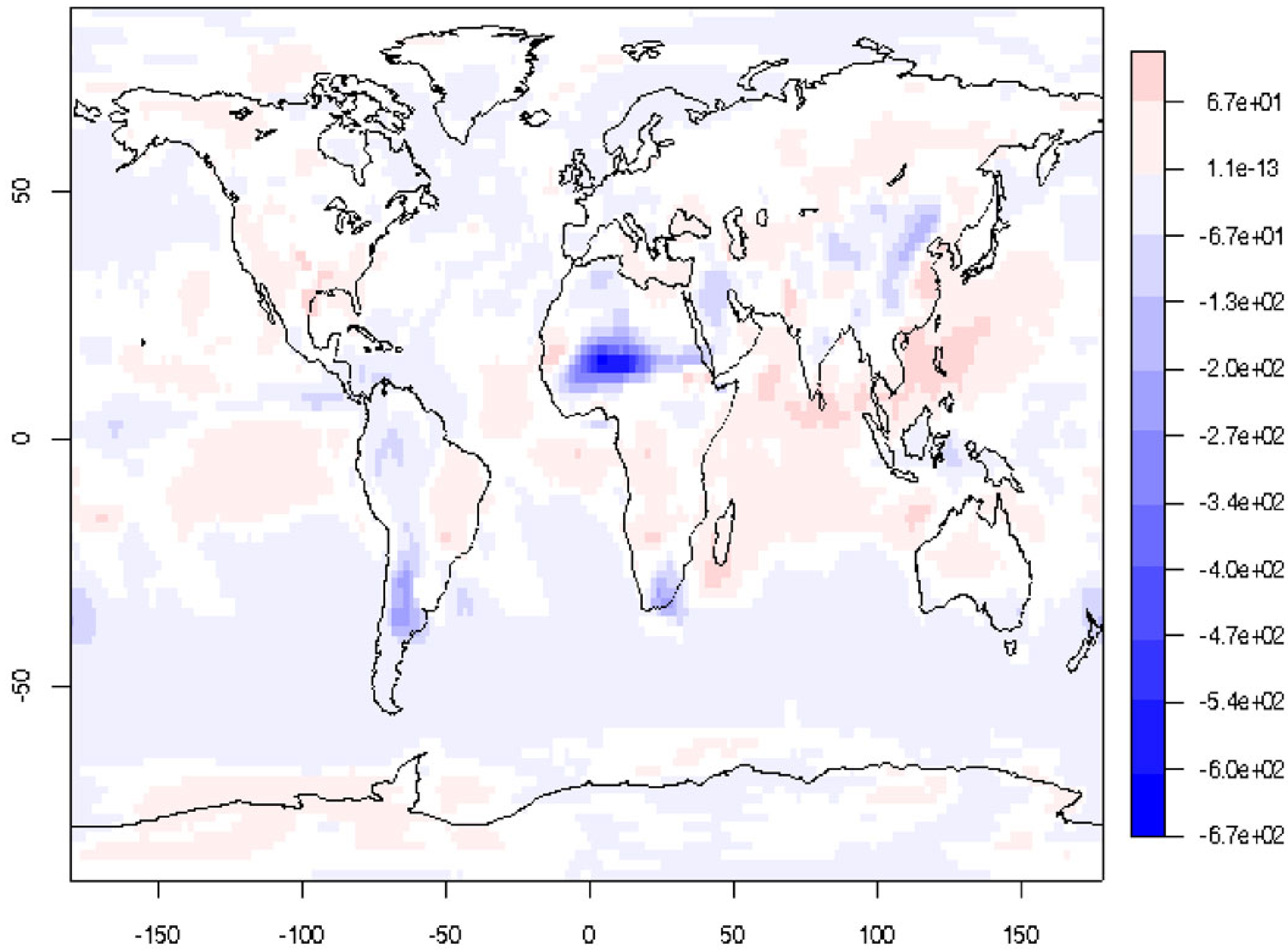

Obs Num
U (ms-1)
V (ms-1)
Pressure (hPa)
T (°C)
Q (gmKg-1)




Radius = 15 grid squares, Threshold = 0.05"

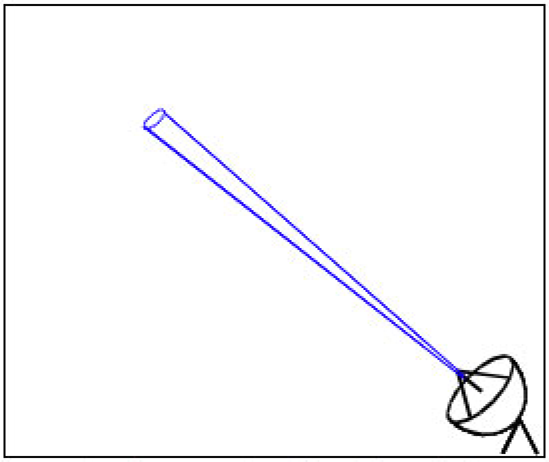
- 

NCAR
Catalog (OGC CS-W)
Icing and Turbulence Data
Web Coverage Service (OGC WCS)
METAR, TAF, PIREP, AIR/SIGMET Data
Web Feature Service (OGC WFS)
Lincoln Lab
Catalog (OGC CS-W)
CIWS and Cloud Top Data
Web Coverage Service (OGC WCS)
Lightning Data
Web Feature Service (OGC WFS)
NOAA/GSD
Catalog (OGC CS-W)
Interpolated MADIS Data
Web Coverage Service (OGC WCS)
MADIS Observation Data
Web Feature Service (OGC WFS)
DOC
Federated Catalog (OGC CS-W)
SOAP/HTTP/HTTPS Discovery Requests
SOAP/HTTP/HTTPS Data Requests
Java client(s) accessing and displaying all data products. Federated catalog will be used for discovery of both gridded and non-gridded products
As much standardization as possible will be developed and utilized for both request and response formats. This process will be developed as a part of both national and international discussion and experimentation

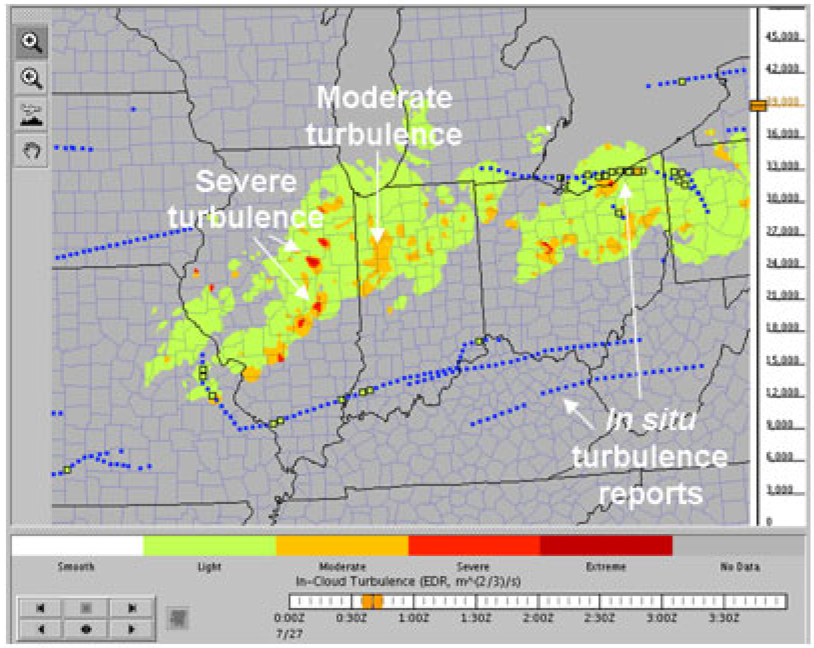


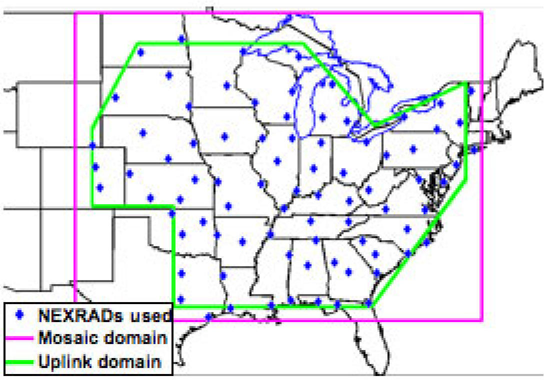
50
0
-50
-150
-100
-50
0
50
100
150
6.7e+01
1.1e-13
-6.7e+01
-1.3e+02
-2.0e+02
-2.7e+02
-3.4e+02
-4.0e+02
-4.7e+02
-5.4e+02
-6.0e+02
-6.7e+02

# NCAR's NEXRAD Turbulence Detection Algorithm



NTDA detects in-cloud turbulence *before* aircraft encounter it.




A summer 2007 demonstration used data from 83 NEXRADs (left) and provided experimental cockpit uplinks to commercial aircraft and a web-based display of 3-D maps of turbulence in clouds and thunderstorms (above).