



CELEBRATING *40* years OF ENVIRONMENTAL RESEARCH

COOPERATIVE INSTITUTE FOR RESEARCH
IN ENVIRONMENTAL SCIENCES

University of Colorado at Boulder

ANNUAL REPORT

2008

**COOPERATIVE INSTITUTE FOR RESEARCH
IN ENVIRONMENTAL SCIENCES**

University of Colorado at Boulder UCB 216
Boulder, CO 80309-0216

Phone: 303-492-1143

Fax: 303-492-1149

email: info@cires.colorado.edu

<http://cires.colorado.edu>

ANNUAL REPORT STAFF

Suzanne van Drunick, Coordinator

Jennifer Gunther, Designer

Katy Human, Editor

COVER PHOTO

Pat and Rosemarie Keough

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Antarctica—Passion and Obsession

Sponsored by CIRES in celebration of 40th Anniversary

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FROM THE DIRECTOR



I am very proud to present the new CIRES annual report for fiscal year 2008. It has been another exciting year with numerous accomplishments, awards, and continued growth in our research staff and budget. The CIRES annual budget surpassed \$50 million, with a 15 percent increase in financial support from the University of Colorado at Boulder, a 9 percent increase from contracts and grants, and a 5 percent increase from the cooperative agreement with NOAA.

CIRES continues to be a world leader in environmental sciences, committed to identifying and pursuing innovative research in Earth system science, and to fostering public awareness of this research. The outcomes and findings of our research are important in forming policies that are crucial for future generations.

CIRES scientists and faculty published 435 peer-reviewed papers during the 2007 calendar year. The honors and awards received by CIRES researchers

and staff are also numerous. Most prominent is the 2007 Nobel Peace Prize, awarded to former Vice President Al Gore and the Intergovernmental Panel on Climate Change (IPCC). Several CIRES scientists contributed substantially to the work of the IPCC that earned this distinguished award. Other significant honors included Fellow appointments to the American Geophysical Union, American Meteorological Society, Acoustical Society of America, Geological Society of America, and the Royal Geographical Society, London.

The CIRES Members' Council held its third annual research symposium on April 2, 2008. This one-day symposium featured presentations from the six CIRES divisions and the Education and Outreach Program. More than 80 scientific posters were presented, which included the research of CIRES' Visiting Fellows. Outstanding Performance Awards and other scientific achievement awards were presented by the Director to researchers and staff.

In partnership with NOAA's Earth System Research Laboratory (ESRL), a new ESRL-CIRES Graduate Student Research Fellowship was created. This competitive award, which includes full tuition, a stipend, and other benefits, will allow graduate students to earn a master's or doctoral degree at the University of Colorado at Boulder and simultaneously conduct research with world-renowned scientists at ESRL.

We welcome three new center directors, including Dr. Waleed Abdalati, Director of the CIRES Center for the Study of Earth from Space, and Dr. William Travis, Director of the Center for Science and Technology Policy Research, who are both new CIRES Fellows. Dr. Prashant Sardeshmukh, from ESRL's Physical Sciences Division and a CIRES Fellow since 2006, is the new Director of CIRES' Climate Diagnostics Center. Further, we welcome three new CIRES Fellows—Dr. Lisa Dilling, Dr. Joost de Gouw, and Dr. Tingjun Zhang—who have been elected by the Council of Fellows for two-year terms.

The annual report is a collaborative effort of a number of people in CIRES—researchers as well as administrative staff—and they all deserve credit for what you will find on the following pages. In particular, I would like to acknowledge the work of Assistant Director Dr. Suzanne van Drunick, who was instrumental in coordinating this effort. Enjoy your reading!

EXECUTIVE SUMMARY AND RESEARCH HIGHLIGHTS

CIRES: Science in
Service to Society



NASA

In 2008, the Cooperative Institute for Research in Environmental Sciences (CIRES) proudly celebrated its 40th anniversary. CIRES, at the University of Colorado at Boulder, is the oldest and largest of the National Oceanic and Atmospheric Administration's (NOAA) Cooperative Institutes.

CIRES is guided by a cooperative agreement (Agreement) between the university and NOAA. The Institute's collaborative research is organized and aligned with NOAA's research by six scientific themes identified in the Agreement. The following summary highlights many of the past year's activities and research accomplishments, and demonstrates how CIRES has grown during the past four decades to become a world leader in Earth system science.

From July 1, 2007 to June 30, 2008 (FY08), CIRES supported 173 Research Scientists, 211 Associate Scientists, 35 Visiting Scientists, five postdoctoral researchers, 32 administrative staff, 127 graduate students, and 54 undergraduate students. In total, CIRES supported 637 scientists, administrative staff, and students, with an overall extramural research budget of \$47,550,000 (7 percent more than FY07). Including university faculty support, CIRES' total budget is more than \$51,000,000, with NOAA funds accounting for about \$24,700,000 (48 percent).

New additions to CIRES members include directors for two of CIRES' Centers, and a faculty search is now underway for a third—a new director of the National Snow and Ice Data Center. Dr. Waleed Abdalati will be the new Director of the Center for the Study of Earth from Space beginning July 1, 2008. Previously, he was the head of NASA's Cryospheric Sciences Branch at the Goddard Space Flight Center, where he led research efforts on high-latitude glaciers and ice sheets using satellite and airborne instruments. He also served as Program Scientist for NASA's Ice Cloud and Land Elevation Satellite. Dr. Abdalati has received numerous NASA awards, including the NASA Exceptional Service Medal in 2004. Dr. William Travis will become the new Director of the Center for Science and Technology Policy Research beginning September 25, 2008. Dr. Travis is tenured in the university's Department of Geography, where he teaches graduate courses in natural hazards, land use, and human ecology. His research focuses on social response to climate change and extreme events, and on coupled social and natural systems, with an emphasis on the American West. Prior to joining CIRES, Dr. Travis directed the university's Institute for Behavioral Science's Natural Hazards Research and Applications Information Center. He received the Orton Family Foundation Fellowship to support work on his recently published book, *New Geographies of the American West: Land Use and Changing Patterns of Place*.

CIRES' Climate Diagnostic Center also has a new director, effective September 1, 2008—Dr. Prashant Sardeshmukh, Senior Research Scientist and CIRES Fellow since 2006. Dr. Sardeshmukh conducts research in NOAA's Earth System Research Laboratory (ESRL) to diagnose, model, and predict large-scale weather and climate variations, on time scales of days to millennia. His current focus is on how rising ocean temperatures affect land temperature changes.

CIRES also welcomes Dr. Lisa Dilling, Assistant Professor of Environmental Studies, to the Center for Science and Technology Policy Research. Dr. Dilling's research interests include the use of scientific knowledge in decision making, climate change science policy, carbon management and governance, human dimensions of the carbon cycle, and scales in decision making and scientific research. Prior to accepting the faculty position at the Policy Center, Dr. Dilling was a CIRES Visiting Fellow, an NCAR Visiting Scientist, and Manager of NOAA's Office of Global Programs' Carbon Cycle Program. Another junior faculty search for the Policy Center will begin in Fall 2008.

The CIRES Council of Fellows elected Dr. Dilling as a new Fellow, and also elected Dr. Joost de Gouw, a Senior Research Scientist in ESRL's Chemical Sciences Division, who studies volatile organic compounds, and Dr. Tingjun Zhang, Senior Research Scientist and permafrost expert at CIRES' National Snow and Ice Data Center.

CIRES is very pleased to continue support of its established programs, which this past year included six Visiting Postdoctoral and Sabbatical Fellows, seven CIRES Graduate Student Research Fellowships, seven Innovative Research Program proposals, and five Distinguished Lecturers. New this year are two programs intended to increase collaboration with ESRL. First is the ESRL-CIRES Graduate Research Fellowship, created to recruit exceptional, prospective, CIRES graduate students and to foster interdisciplinary research and academic excellence.

The competitive four-year award for doctoral students, or two-year award for master's students, includes full tuition, a stipend, partial health insurance, support for one professional meeting per year, and other benefits. ESRL-CIRES Fellowship recipients will complete their coursework in a CIRES-affiliated department or program at the university, while conducting their research at ESRL. Ryan Neely was selected as the first recipient of the ESRL-CIRES Fellowship. Mr. Neely, also a NOAA Hollings Scholar, plans to incorporate lidar development into his graduate research, to study cloud processes and aerosols. The second new program is a lecture series at the David Skaggs Research Center building in Boulder. Presenters include CIRES Fellows and Senior Scientists, who otherwise do not often have the chance to interact with NOAA researchers. Dr. Baylor Fox-Kemper, Assistant Professor in the Department of Atmospheric and Oceanic Sciences and a CIRES Fellow, commenced the series with a presentation entitled "Eddies and Mixed Layers."

CIRES staff organized and sponsored numerous events in FY08. A few highlights include the NOAA Roundtable on Earth System Modeling, the Civilian Applications for Unmanned Aircraft Systems Conference, the United States Arctic Research Commission's 85th Meeting, the Program for Arctic Regional Climate Assessment Meeting, the Forecast Verification Workshop, the Graduate Education Initiative Workshop on Inverse Modeling and Data Assimilation Technology, the International Laser Radar Conference, the CIRES Science Retreat, and a National Snow and Ice Data Center climate briefing for former Vice President Al Gore.

CIRES also celebrated two very special events. First, its 40th Anniversary was commemorated with a reception, hosted by the CIRES Director, which included remarks by Dr. G.P. "Bud" Peterson, university chancellor; Dr. Alexander MacDonald, ESRL Director and Deputy Assistant Administrator, NOAA Research Laboratories and Cooperative Institutes; Dr. Franco Einaudi, Director, Earth Sciences Division, NASA Goddard Space Flight Center and former CIRES Visiting Fellow (1969-1979); Dr. Timothy R.E. Keeney, Deputy Assistant Secretary for Oceans and Atmosphere, Office of Oceanic and Atmospheric Research, NOAA; and Dr. Robert Sievers and Dr. Susan Avery, former CIRES Directors. A spectacular traveling photographic exhibit, *Antarctica—Passion and Obsession*, on loan from Pat and Rosemarie Keough, also helped mark this occasion. The second special event was a farewell reception for Dr. Susan Avery, to wish her all the best in her new position of President and Director of the Woods Hole Oceanographic Institution, and to acknowledge her notable contributions and lasting impact on CIRES.

Looking ahead to future research goals, the CIRES-NOAA FY 2009 and FY 2010 Scientific Workplan was completed. The new Workplan is CIRES' proposed biannual science workplan for the eighth and ninth years (July 1, 2008-June 30, 2010) of its current Agreement. The Workplan describes collaborative research projects, conducted by CIRES, that fall into the six scientific themes identified in the Agreement—advanced modeling and observing systems, climate system variability, geodynamics, planetary metabolism, regional processes, and integrating activities. For each of the 56 proposed research projects described in the Workplan, goals, approaches and milestones are described.

This annual report is an accounting of collaborative research described in the FY 2008 Workplan, which is also organized by NOAA's six scientific themes. Select research highlights from each of the scientific themes are presented below.

Research Highlights and Accomplishments of the CIRES-NOAA Partnership, by Scientific Theme

Advanced Modeling and Observing Systems

CIRES researchers characterize and predict the state of the Earth system on a variety of scales using direct observations and mathematical techniques for projecting outcomes. This theme includes work in diverse disciplines, including atmospheric chemistry, atmospheric and oceanic processes, cryospheric processes, space weather, nonlinear systems applications, data centers, and data management.

- A roving calibration standard for ship flux measurements was completed and deployed on the R/V Knorr during the International Chemistry Experiment in the Arctic Lower Troposphere field program.
- A fast response, state-of-the-art instrument suitable for airborne measurements of atmospheric mercury (Hg) was developed to assist NOAA in providing sound scientific guidance on Hg chemistry, exposure, and control strategies. Gas-phase Hg(0) was measured aboard the Ronald H. Brown during the TexAQS 2006 project, to evaluate potential emissions sources of this compound along the Texas coastline and in industrialized harbor areas. Outside the industrialized source areas, the data show an average Hg(0) concentration of 1.5 ± 1.4 ng/m³, broadly consistent with the

expected background value of 1.7 ng/m^3 . However, within the industrialized Houston Ship Channel and Beaumont–Port Arthur areas, the data show very concentrated, spatially narrow plumes with $\text{Hg}(0)$ concentrations ranging from 15 to 250 ng/m^3 . These observations are not consistent with the latest TCEQ, AIRS, EGRID, and TRI inventory source locations for known Hg emitters in this region. Further research is underway.

- The newly-created Aerosol Scattering to Extinction Ratio (ASTER) instrument is now operating. One of the central motivations for the ASTER development is to measure the scattering and absorption of light by single aerosol particles, because they provide more detailed information and can serve as a complement to existing bulk measurements. The ultimate goal is to have ASTER deployable at ground sites and on ships and aircraft.
- High-Resolution Doppler Lidar, previously used in ship-based studies, was modified for aircraft to measure wind and turbulence profiles.
- A Ground-based Scanning Radiometer for precise measurements of Arctic temperature profiles and total integrated water vapor was deployed in Barrow, Alaska, and successfully operated remotely.
- The North American Rapid Refresh one-hour intermittent assimilation has been running in cycling mode since October 2007. A number of enhancements were added, including the Digital Filter Initialization, which reduces imbalance in the initial state of the forecast so that large-amplitude spurious gravity waves are not initiated at the start of the forecast. The Rapid Refresh code is now approaching a level of reliability that makes porting to NCEP computers practical.
- The Flow-following Finite-Volume Icosahedral Model (FIM) is now making credible seven-day global forecasts. The immediate purpose of this work is to introduce FIM into the Global Ensemble Forecast System of NCEP, hence further diversifying this set of ensemble forecasts. An important emerging forecast application for FIM is tropical-cyclone track prediction. Other possible research applications of FIM include use in long-range chemical transport studies, and as a model component of a global analysis of record.
- The third year of full-scale field operations for the Hydrometeorology Testbed in the American River Basin in California involved eight intensive operating periods. Concentrated arrays of unattended



instruments continuously monitored atmospheric and hydrologic conditions for the entire field season. Experimental, high-resolution (3 km) numerical weather prediction models were run daily, producing probabilistic forecasts of precipitation in the region.

- Automated quality-control techniques for ionospheric data were deployed, including a new version of the Assimilative Mapping of Ionospheric Electrodynamics Model, Simple Inner Magnetosphere Model, and new processing software for Polar Orbiting Environmental Satellite data.
- Improved predictions of traveling solar disturbances associated with coronal holes and coronal mass ejections—which can cause substantial geomagnetic effects resulting in disruption of radio communications and damage to electric power grids and satellites—have been made. Improved measurements were achieved by sounding rocket underflight calibrations of the Solar X-ray Imager and disk-integrated x-ray sensor currently flying on GOES-12 and GOES-13, and by updating the satellite data imaging processing system. The images will soon be available in real time for forecasting needs.
- A new method in chemical forecast modeling was developed, which accurately reproduces the emission ratios imposed as flux conditions within models, and assesses the accuracy of the emission inventories used in real-time forecasts.
- Satellite measurements and chemical-transport model simulations of NO₂ vertical columns over the Ohio River Valley demonstrated substantial reductions in atmospheric NO_x levels since the late 1990s in response to a series of EPA-mandated emission control programs targeting eastern U.S. power plants. The use of satellite retrievals and model calculations of NO₂ vertical columns can also distinguish between the NO_x emissions from western U.S. power plants and urban areas.

Climate System Variability

Climate variability affects all natural systems and human activities. Climate directly influences agriculture, water quality, and human health. Understanding and predicting climate change is of critical interest to the public and to a broad array of decision makers within federal and state government, industry, resources management, and hazard mitigation. CIRES research on this theme addresses changes that occur on time scales from seasons and decades to millennia.

- Tree-ring reconstructions of streamflow were extended to the Rio Grande, and a prototype was created for other regions. In addition, other hydroclimatic variables for the Rio Grande Basin have been reconstructed, including annual precipitation, cool season precipitation, and summer drought severity indices. Web-based tools for data visualization and analysis were also created.
- A major assessment of the contribution of El Niño–Southern Oscillation (ENSO)–related variations to 20th century climate change showed that previously identified multidecadal variations in the Pacific, Indian, and Atlantic oceans all have substantial ENSO components. The long-term warming trends were also found to have appreciable (up to 40 percent) ENSO components. The ENSO-unrelated component of five-year average sea surface temperature variations were attributed to a combination of anthropogenic, naturally-forced, and other factors. Two surprising aspects of these ENSO-unrelated variations were a strong cooling trend in the eastern equatorial Pacific Ocean, and a nearly zonally symmetric multidecadal tropical–extratropical seesaw that has amplified in recent decades.
- The impact of air–sea coupling on the predictability of weekly mean sea surface temperature and atmospheric circulation and diabatic heating in the tropics was investigated using a coupled Linear Inverse Model. Predicted and observed lag–covariances and spectra were generally found to be in excellent agreement. Coupling sea surface temperature to the atmosphere has a notable impact on interannual variability, but only a minor effect on intraseasonal variability. Extratropical subseasonal variations analyzed using the Linear Inverse Model showed that tropical diabatic heating greatly enhances persistent variability throughout the Pacific and over North America, while stratospheric effects are notable primarily over the polar region and Europe.
- New ocean, fire, and fossil fuel models were developed for the CarbonTracker system. The ocean model now has 31 regions (previously 11). The fossil fuel model now takes advantage of country-based data to improve spatial resolution. The fire model is now kept up to date so that actual year fire emissions, instead of climatological fire emissions, are used in the data assimilation.
- A comparison of CO₂ emission estimates for the Brazilian Amazon with aircraft measurements

suggests that there is much more variability in the real biosphere than is represented by the CarbonTracker model. Similarly, a comparison of Amazonian methane emissions with satellite and aircraft observations shows that process-based models also underestimate methane emissions.

- An inventory of biomass burning emissions on a decadal (1900–1990) and a yearly (1997–2005) basis was developed by applying a scaling factor to the historical burnt areas dataset. This approach helps ensure consistency between historical and recent emissions. Most modeling studies of the evolution of tropospheric composition assumed that preindustrial biomass burning emissions were about 10 percent of the current emissions, with a rather similar spatial distribution. However, results from this study show a very different evolution: global emissions due to biomass burning show a slight decrease from the 1900s to the 1960s. After that decade, a significant increase occurred, due to intense deforestation in tropical parts of South America, Africa, and southeast Asia.
- Air samples from multiple remote sites in both hemispheres were collected and analyzed to update the Ozone Depleting Gas Index through 2007. The Index shows that the overall atmospheric abundance of ozone-depleting gases continued to decrease through 2007, at a rate of 1–2 percent per year.
- The feasibility of simultaneously observing soil moisture and snow water equivalent using remote sensors was investigated using polarimetric scanning radiometer (PSR) measurements during the 2003 melt season. Results show that the high-resolution PSR data exhibit emissivity modes that are similar to those observed in the historical datasets, and the empirical relationships between emissivity and the snow water equivalent closely match those found in the past theoretical studies. Comparison of the total water content from the Advanced Microwave Scanning Radiometer for the Earth Observing System and the PSR observations shows that the satellite measurements underestimated the total volume of water storage from airborne observations by a factor of five, on average.

Geodynamics

CIRES geodynamics research aims to characterize the internal processes of the planet, including the properties of the core–mantle boundary, convection within the Earth’s mantle, and the effects of convection on the surface of the planet.

- A significant breakthrough was achieved in magnetic field modeling with the production of magnetic field model MF6, representing the static magnetic field caused by the magnetization of the Earth’s crust. MF6 builds upon the CIRES/NGDC scientific geomagnetic field model produced last year, and is the first satellite-based magnetic model to resolve the direction of oceanic magnetic lineations.
- Using input models for various parameters of the ionosphere and thermosphere, including the horizontal winds, a method has been developed to invert the observed satellite-derived meridional current profiles for the eastward electric field. The resulting electric field estimates have been validated using radar measurements. The method is very robust, even during magnetic storms, and the accuracy far exceeds that of satellite-based direct electric field measurements. The magnetic-field-derived eastward electric field estimates provide a valuable new space-weather product.

Planetary Metabolism

Planetary metabolism is the complex web of biochemical and ecological processes and their interaction with the lithosphere, atmosphere, and hydrosphere. Both natural and anthropogenic disturbances drive the structure and dynamics of natural systems, and a thorough understanding of these complex processes is essential to protect the biosphere from the adverse effects of pollution, destruction of natural landscapes, and inadvertent alteration of climate.

- Emission inventories for isoprene, a volatile organic compound released from vegetation that can play an important role in the photochemical formation of ozone, were evaluated by two different methods, using the available airborne data from four missions. The first method estimated isoprene emissions from the isoprene mixing ratios, using measured boundary-layer heights and calculated levels of hydroxyl radicals. These estimates were then compared with emissions from the inventory extracted along the flight tracks, which used temperature and photoactive radiation. In the second method, isoprene emission inventories were incorporated into the Lagrangian transport model

Flexpart and compared with measured isoprene mixing ratios along flight tracks. Study results suggest that the modeled and measured emissions agree within a factor of two, which was typical for data from the four missions and the different inventories investigated. These data will improve the understanding of the role that the exchange of gases (emitted by vegetation or biomass burning) between the surface and the atmosphere plays in shaping regional climate and air quality.

- Using nocturnal satellite observations, an annual time series (1992–2005) of anthropogenic lighting was completed to distinguish contributions from human settlements, gas flares, biomass burning, and heavily-lit fishing boats. An improved global map of poverty rates was also completed. These products will be used in modeling the density of impervious surface areas, gross domestic product, poverty levels, national gas flaring volumes, and trends in fishing activity.

Regional Processes

The effects of climate variability are often regionally focused, thus influencing very specific populations, economic systems, and ecosystems. Therefore, many research endeavors within CIRES and NOAA have a regional focus, addressing a particular set of geographies, demographics, or weather and climatic regimes.

- Two major studies were completed on aerosol–cloud interactions during the Gulf of Mexico Atmospheric Composition and Climate Study (GoMACCS) field deployment in 2006. The first study addressed aerosol effects on cloud albedo and the initiation of precipitation and showed that cloud optical property response to aerosol perturbations can be strongly over-estimated if entrainment is not considered. The second study was a comparison between modeled and observed cloud/dynamical fields, which proved to be in good agreement. A follow-up study, still in progress, is comparing observed radiation fields with radiation fields calculated based on the cloud fields generated by large eddy simulations. This is a very rigorous test of the ability of a model to simulate aerosol indirect effects, because it requires that the model simulate macroscale and microscale cloud properties. Preliminary results show good agreement between the model and observations, provided the aerosol residing between the clouds is also included in the calculations.
- Innovative measurement systems for open-ocean observations within the marine boundary layer have resulted in datasets that have been analyzed for surface, boundary-layer, and cloud processes over the ocean. Two new synthesis datasets containing observations of air–sea fluxes and cloud/radiative properties from nine years of cruises (1999–2007) in the eastern equatorial Pacific were released. Other new or improved systems include a sea spray parameterization model, refined multi-sensor satellite retrieval algorithms for the near-surface specific humidity and air temperature over the oceans, and improved CO₂ sensor systems designed to obtain an extensive database of CO₂ flux and transfer velocity.
- An instrumentation system to measure aerosol radiative properties at sites that are influenced regionally has been fully tested and will be deployed to Taiwan.
- Emissions of black carbon from commercial shipping, part of the TexAQS/GoMACCS 2006 study dataset, were analyzed and found to be underestimated in current inventories by at least a factor of two. Tugboats, which operate exclusively in ports, emit more black carbon than any other vessels, contributing more to the degraded air quality around ports than previously estimated.
- Initial results of investigations on the impacts of mega-cities on regional and global emissions of volatile organic compounds suggest that vehicles are the dominant source of these compounds.
- New techniques were implemented and evaluated for improved transport and chemical evolution in fully-coupled atmospheric/chemistry models capable of real-time forecasts for ozone and particulate matter.
- Data collected by ozonesondes launched during a second 2006 INTEX Ozonesonde Network Study revealed an annually recurring, distinct, upper-tropospheric ozone maximum above eastern North America, centered over the southeastern United States. The location and strength of the ozone maximum is influenced by the summertime upper tropospheric anticyclone, which traps convectively lofted ozone, ozone precursors, and lightning NO_x.
- Data obtained during the TexAQS 2006 field study were evaluated to characterize emissions of CO₂, NO_x, and SO₂ from a large number of commercial marine vessels; to analyze nocturnal formation and loss of NO₃ and N₂O₅ that affect ozone status; to investigate the role of mixing processes in

the nighttime stable boundary layer; to measure formyl radical production in the photolysis of aldehydes for atmospheric model calculations used in regional air quality and climate–chemistry coupling; and to better understand the role of boundary–layer depth in the formation of local high–ozone events, and the distribution of these pollutants over broader regions.

Integrating Activities

CIRES engages in a wide range of integrating activities in research, education, and outreach that encompass each of the Institute’s research themes and contribute to CIRES’ science mission to society. CIRES’ integrating activities include K–16 interdisciplinary education and outreach, graduate and post–graduate education, scientific assessments, interdisciplinary research, and science and technology policy research.

- A new scientific assessment on the impacts of dust storms on southwest Colorado snowpack gained international attention when investigators reported that alpine lake cores showed dust deposition to these mountains is now 500 percent greater than during periods of megadrought (900 to 1300 AD) and before the introduction of cattle and sheep into the western United States. Research is currently underway to develop a modern record of interannual variability of dust forcing and its effect on melt and runoff.
- As part of CIRES’ role in describing scientific findings for decision makers on topics related to climate, a draft report of Synthesis and Assessment Product 2.4, “Trends in Emissions of Ozone–Depleting Substances, Ozone Layer Recovery, and Implications for Ultraviolet Radiation Exposure,” was prepared and reviewed by the National Research Council, and is now undergoing a public review. The final report will be published next year.
- A group of Front Range water providers, organized by the Western Water Assessment (WWA), was awarded an American Water Works Association Research Foundation grant for a joint climate change and hydrology study.
- The workshop, “Tree–ring reconstruction of Animas River streamflow and its use in water management,” was held in June 2008, as a follow–on activity to the May 2007 workshop, “Tree–ring reconstructions of streamflow and their use in water management.” Participants included representatives from federal agencies, irrigation districts, private water consultancies, colleges, and tribes, who engaged in discussions about potential applications of the new reconstruction and additional data needs.
- WWA’s flagship Intermountain Climate Summary of various climate parameters (precipitation, temperature, snow water equivalent, long–lead temperature and precipitation outlooks, reservoir levels, and streamflow forecasts) was produced eight times this fiscal year. Although the summary is designed for water managers in the Intermountain West, its audience is much broader, evidenced by a citation in *Science*. Other climate products include a web–based experimental seasonal guidance that features an ENSO status update, a look at regional conditions, and the most recent Climate Prediction Center forecasts. WWA also supported two National Integrated Drought Information System workshops, one in Boulder on remote sensing, and the other in Kansas City on the status of Drought Early Warning System.
- WWA staff gave more than 30 presentations on the interaction of climate and water at public events in the Intermountain West, including: the U.S. Forest Service’s annual scientific retreat; a Water Utility Climate Alliance meeting attended by the general managers of Seattle, Portland, San Francisco, Los Angeles, San Diego, Las Vegas, Denver, and New York City; the Water Education Foundation’s biannual meeting on the Colorado River Compact; the South Platte Forum; the Western States Water Council; the Western Governors’ Association Annual Meeting; and the CIRES Science Retreat.
- To coincide with the Fall 2008 presidential campaign, the Center for Science and Technology Policy Research has planned two panel discussions that will address various aspects of the energy/climate challenge, and a keynote address at the university’s Energy Initiative Research Symposium.



THE INSTITUTE YEAR IN REVIEW

CIRES researchers explore all aspects of the Earth system and search for ways to better understand how natural and human-made disturbances affect our dynamic planet. CIRES' focus on innovation and collaboration has made us a world leader in interdisciplinary research and teaching.



Contributions to NOAA's Strategic Vision

Cross-cutting, interdisciplinary research priorities within CIRES complement NOAA's current Five-Year Research Plan priorities, which aim to enhance the understanding and prediction of Earth's environment. The Five-Year Research Plan reflects NOAA's response to some of the nation's most challenging environmental needs, as identified in the 20-Year Research Vision, and supports the four mission goal areas identified in the NOAA Strategic Plan—Ecosystems, Climate, Weather and Water, and Commerce and Transportation. The following are examples of CIRES research that support NOAA's mission goals.

Ecosystem Mission Goal: Protect, restore, and manage the use of coastal and ocean resources through ecosystem-based management.

CIRES contributes to the ecosystem mission goal by developing new databases and hazard assessment techniques designed to improve the assessment of coastal hazards and vulnerability for at-risk U.S. communities. Seamless, accurate, high-resolution digital elevation models are being developed to improve the accuracy of coastal inundation modeling. A pilot study is also underway to assess the social and economic impacts of tsunamis on coastal Oregon.

Other coastal modeling efforts include the development of high-resolution numerical models that combine state-of-the-art observations of surface fluxes, boundary-layer structure, and mesoscale features to evaluate how terrain affects coastal precipitation.



Climate Mission Goal: Understand climate variability and change to enhance society's ability to plan and respond.

CIRES is a world leader in climate science research relevant to NOAA's climate mission goal. Researchers at CIRES continue to substantially contribute to: 1) climate trend analyses using NOAA ground-based instruments, NCAR aircraft-based instruments, and satellite observations; 2) understanding how turbulence influences atmospheric chemistry, composition, radiation, and transport on molecular to global scales, and the effects of turbulence; 3) climate dynamics research to improve understanding of a) tropical Pacific Ocean dynamics related to subseasonal atmospheric variability, b) precipitating cloud systems, and atmospheric circulation, convection, and moisture, and c) heat budgets associated with the El Niño phenomenon; and 4) understanding the production and fate of stratospheric ozone, and the compounds that deplete it.



In support of NOAA's goal to enhance society's ability to respond to climate variability, CIRES' Western Water Assessment developed various climate products, including its flagship monthly Intermountain Climate Summary and web-based experimental seasonal guidance for water-resource decision makers throughout the Intermountain West. CIRES researchers also serve as authors, reviewers, and coordinating editors of ozone-layer depletion, greenhouse warming, and regional air quality assessments designed to help decision makers understand scientific findings.

CIRES' National Snow and Ice Data Center (NSIDC) maintains the World Data Center for Glaciology, one of more than 40 data centers around the world established to collect, archive, and distribute geophysical data. NSIDC's datasets include information on glaciers, avalanches, snow cover, polar ice masses, ice cores, sea ice, and freshwater ice. NSIDC is also digitizing analog cryospheric data under the Climate Database Modernization Program, to make data more accessible online.

Weather and Water Mission Goal: Serve society's needs for weather and water information.

CIRES researchers support NOAA's mission to provide essential information on weather in several ways, including by developing and maintaining a version of the Hurricane Weather Research and Forecasting modeling system, supplied through the Developmental Testbed Center, for use by the weather research modeling community. Improvements are being made in the performance of numerical weather model forecasts through model-process evaluation using data streams from focused observational campaigns, including spaceborne measurements.

CIRES contributes to NOAA's mission to serve society's needs for water information through the Western Water Assessment's annual workshops and web site on tree-ring reconstructions of streamflow for use in water management. The Western Water Assessment also plays a valuable role in the drought task force organized by the Colorado Water Conservation Board for the Governor, and in the production of statewide analyses and forecasts of drought conditions. Efforts by other CIRES water researchers include the design of innovative measurement systems, such as ground-, ship-, and aircraft-based systems to increase our understanding of regional water-cycle processes, and analysis of satellite data to better understand global water cycle processes. Increased knowledge of regional and global water cycle processes also helps to improve weather and climate forecast model performance.

Linking weather and water, CIRES researchers are improving ground-based, airborne, and spaceborne radar rainfall estimates through improved understanding of the number and size of raindrops in precipitating cloud systems.





Commerce and Transportation Mission Goal: Support the nation's commerce with information for safe, efficient, and environmentally sound transportation.

Researchers at CIRES are enhancing aviation transportation safety by improving regional-scale numerical weather forecasts to diagnose key weather parameters, and by designing and evaluating new verification approaches for important aviation parameters, such as icing, turbulence, convection, and oceanic weather.

CIRES contributes to the goal of environmentally sound transportation through its analysis of direct emissions of particulate material from commercial ships, which is of concern not only for potentially deleterious effects on local (ports) and regional (coastal and inland waterways) air quality, but also for direct and indirect warming effects in relatively pristine regions such as the Arctic.

Administration and Funding

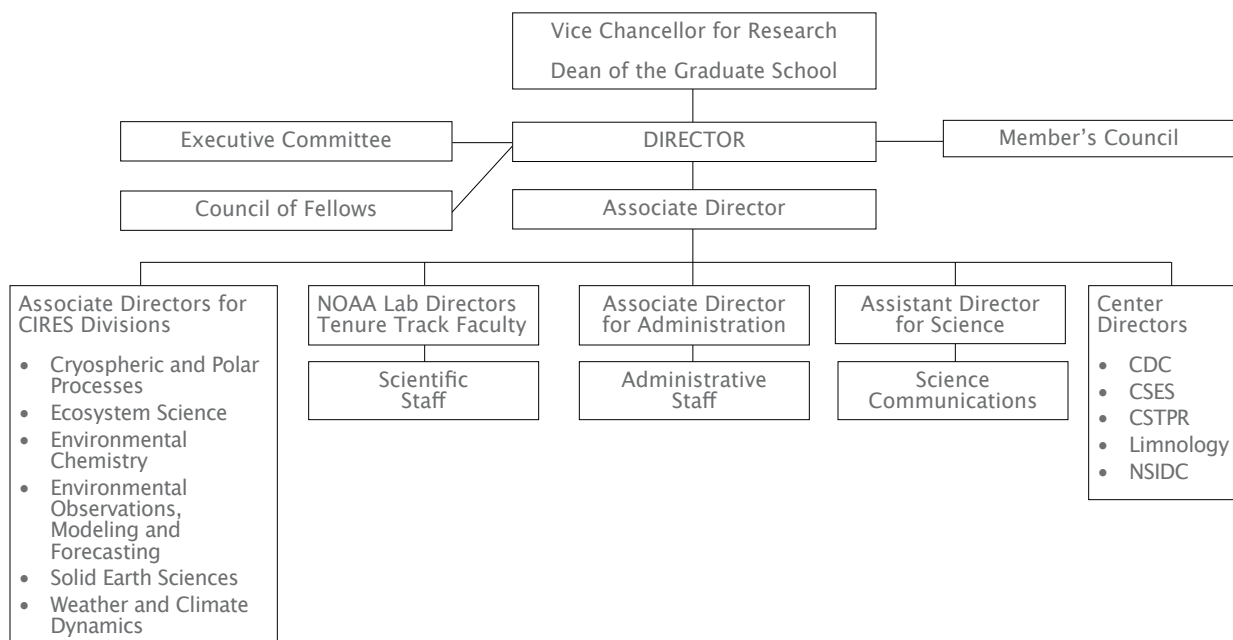
The Cooperative Institute for Research in Environmental Sciences (CIRES) is a cooperative institute established in 1967 between the University of Colorado at Boulder and the National Oceanic and Atmospheric Administration. CIRES maintains an interdisciplinary environment for research on the geosphere, biosphere, atmosphere, hydrosphere, and cryosphere. Institute scientists conduct basic research in support of CIRES', the University of Colorado at Boulder's, and NOAA's goal of advancing public welfare with environmental research, and the Institute strengthens the scientific foundation upon which NOAA's many services depend. CIRES' connections with NOAA and other Cooperative Institutes allow coordinated studies on a scale that could not be addressed by university research units on their own.

CIRES' direction is provided through its Council of Fellows, its executive committee, and various other committees. The Institute fosters interdisciplinary science through five centers that bridge traditional boundaries—the National Snow and Ice Data Center, the Center for Limnology, the Center for Science and Technology Policy Research, the Climate Diagnostics Center, and the Center for the Study of Earth from Space.

Vision and Mission

As a world leader in environmental sciences, CIRES is committed to identifying and pursuing innovative research in Earth system science and fostering public awareness of these processes to ensure a sustainable future environment. CIRES is dedicated to fundamental and interdisciplinary research targeted at all aspects of Earth system science, and to communicating these findings to the global scientific community, to decision makers, and to the public.

CIRES' campus affiliation links NOAA to 13 university departments and programs (see opposite page). Communication is facilitated through the Members' Council, scientific retreats, research symposiums, regular town meetings, and outreach programs. Career progression and excellence are promoted through a career track and an outstanding employee recognition program. A vibrant academic and research environment is fostered through graduate student research fellowship programs, a visiting faculty and postdoctoral program, an innovative research program, and a distinguished lecture series. Advanced research tools are provided through an instrument design group, machine shop, glassblowing, numerical climate models, and access to remote sensing and analytical instrumentation.



THIS IS CIRES

CIRES links NOAA's divisions and centers to the University of Colorado at Boulder's departments and programs.

CIRES Divisions

Cryospheric and Polar Processes

Ecosystem Science

Environmental Chemistry

Environmental Observations,
Modeling and Forecasting

Solid Earth Sciences

Weather and Climate
Dynamics

CIRES Interdisciplinary Centers

National Snow and Ice Data
Center

Center For Science and
Technology Policy Research

Center for the Study of
Earth from Space

Center for Limnology

Climate Diagnostics Center

NOAA Earth System Research Laboratory (ESRL)

Chemical Sciences Division

Global Monitoring Division

Global Systems Division

Physical Sciences Division

NOAA Centers

National Geophysical
Data Center

Space Weather Prediction
Center

University Departments and Programs

Hydrologic Sciences Program

Environmental Studies Program

Geophysics Program

Aerospace Engineering Sciences

Atmospheric and Ocean Sciences

Chemistry and Biochemistry

Civil, Environmental and
Architectural Engineering

Ecology and Evolutionary
Biology

Electrical and Computer
Engineering

Geological Sciences

Geography

Physics

Molecular, Cellular and
Developmental Biology

In recent years, CIRES has maintained modest and steady growth (Figure 1). The largest portion of CIRES' funding (48 percent) is provided by the Agreement with NOAA, and expenditures in this category have increased slightly faster than inflation during the past five years. The continued, collective success of CIRES researchers in obtaining external research awards has also regularly increased at a rate that slightly exceeds the rate of inflation. The university's monetary contribution to CIRES primarily covers faculty salaries, and it varies with year-to-year changes in the CIRES-affiliated university faculty roster.

Agreement expenditures by task for FY08 are shown in Figure 2. Task I expenditures include CIRES administration and internal scientific programs, such as the Visiting Fellows program. Task II provides partial funding for the National Snow and Ice Data Center, the largest of CIRES' five interdisciplinary scientific centers. Task III funds CIRES' collaboration with NOAA's Earth System Research Laboratory, National Geophysical Data Center, and Space Weather Prediction Center. Task IV was created to serve as an efficient administrative mechanism for directing NOAA research grants and awards, which would otherwise be stand-alone grants and awards outside the Agreement, to university researchers in fields allied with CIRES' mission. The Western Water Assessment (WWA) is a CIRES-NOAA program to provide water research and decision support to policy makers in the western United States

The largest share (57 percent) of Task I supports CIRES administration, primarily salaries and benefits for the administrative staff (Figure 3). The Visiting Fellows program receives the second largest share (29 percent) of Task I expenditures, and is supported by other funding as well. Task I also provides partial support of CIRES' Education and Outreach program, other research, and the physical plant facilities.

Task I funding is supplemented by CIRES' portion of the university's indirect cost recovery (ICR), which is distributed annually to academic units as a proportion of indirect costs funded through researchers' grants and awards (Figure 4).

Please see the following pages for financial charts.



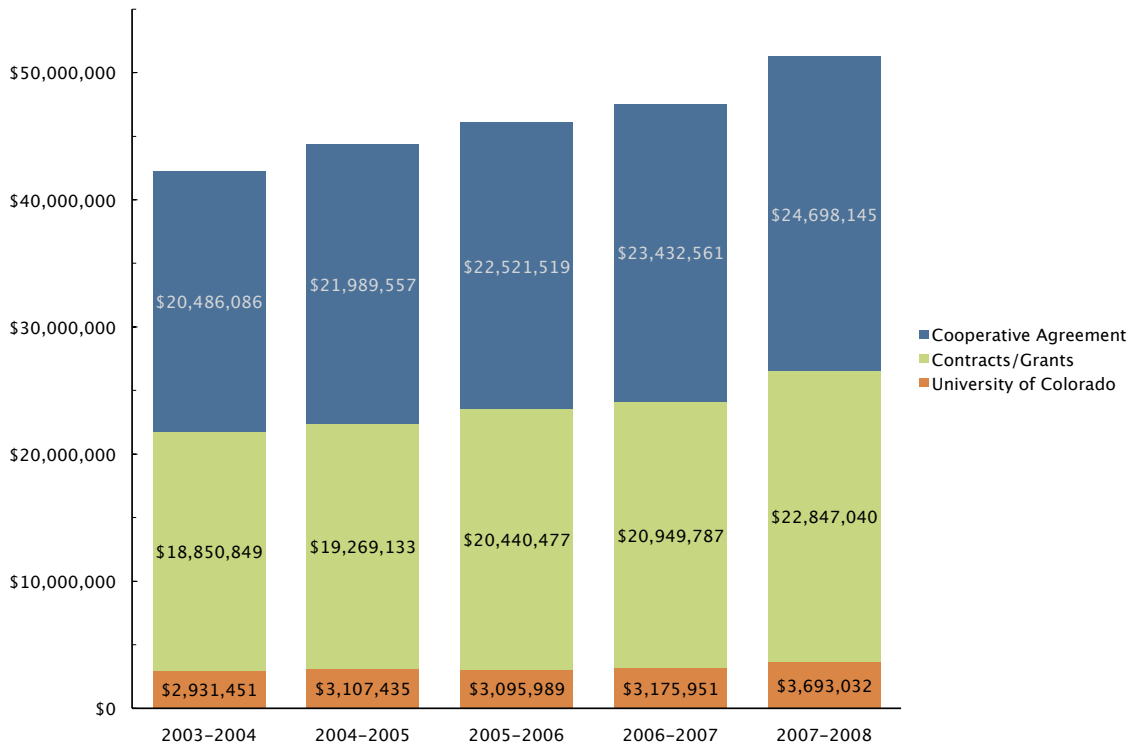


Figure 1. CIRES expenditures, Fiscal Years 2004-2008. CIRES has seen continued growth in university funding, individual federal and non-federal contracts and grants, and NOAA Cooperative Agreement research support.

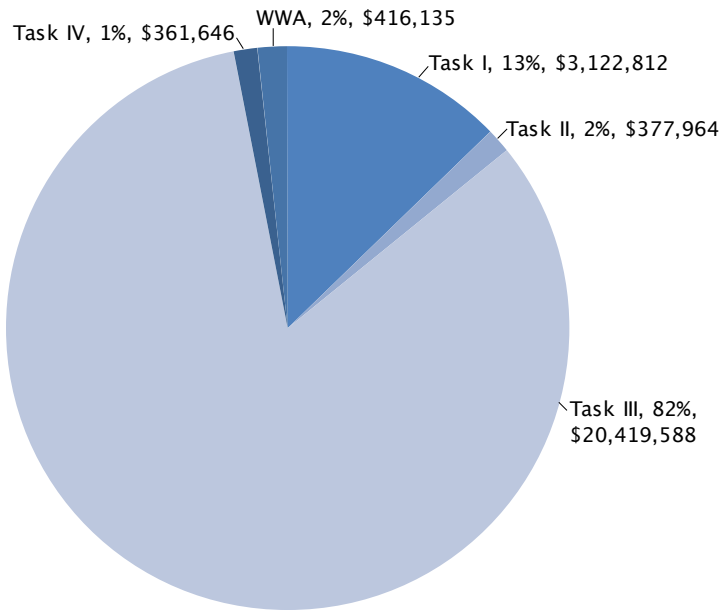


Figure 2. Cooperative Agreement expenditures by task for FY08.

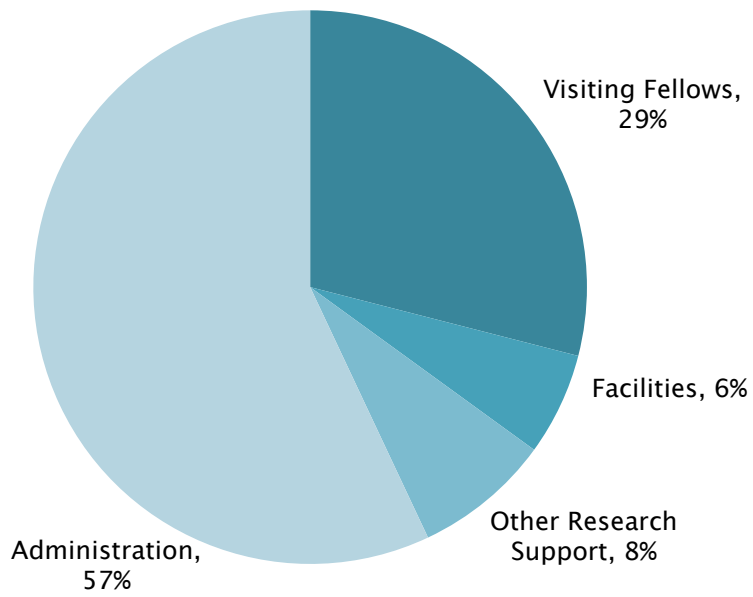


Figure 3. CIREs Task I base fund expenditures for FY08.

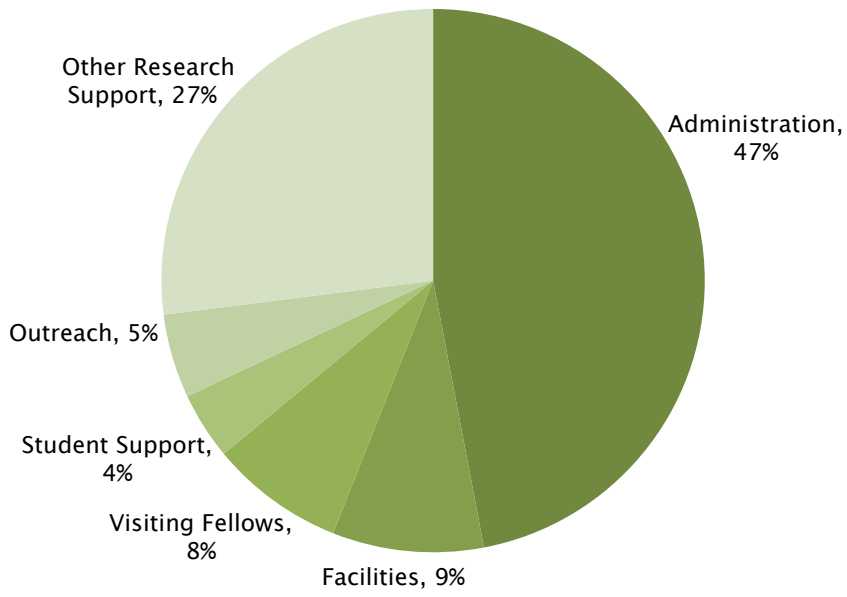


Figure 4. CIREs Task I base fund plus ICR return expenditures for FY08.



Creating a Dynamic Research Environment

CIREs has created a number of programs and initiatives to stimulate interdisciplinary collaborations between CIREs, NOAA, and university departments. The following paragraphs summarize our main programs. Detailed descriptions and specific research outcomes can be found in the other sections of this report.

CIREs' Outstanding Performance Awards Program

The CIREs Awards Committee, comprised of CIREs Members' Council representatives, annually reviews nominations and recommends awards for outstanding professional achievement. Five awards of \$2,000 each were given this year, three in the science and engineering category, and two in the service category. The awards were presented to each individual or research team at the CIREs Members' Council Rendezvous symposium (see below). This year, CIREs recognized Gary Hodges (ESRL/GMD), Allison McComiskey (ESRL/GMD/CSD), and Oleg Godin (ESRL/PSD) for outstanding performance in Science and Engineering. Christine Ennis (ESRL/CSD) and Mark McCaffrey (CIREs Outreach) were recognized for outstanding achievements in Service.

Visiting Fellows Program

CIREs annually conducts a competitive Visiting Fellows program that promotes collaborative research at the forefront of scientific knowledge. One-year fellowships are made to Ph.D. scholars and university faculty planning sabbatical leave to continue their education in research positions that may foster interdisciplinary training and exposure to scientific assessments and policy research. Since 1967, CIREs has awarded approximately 250 Visiting and Sabbatical Fellowships. Recipients have included previous CIREs Director Susan Avery and current Director, Konrad Steffen. Selections are based in part on the likelihood of stimulating academic interactions and the degree to which both parties will benefit from the exchange of new ideas. To further this goal, the competition is open to scientists from all countries, and priority is given to candidates with research experience at institutions outside the Boulder scientific community. Fellowships are offered to scientists with research interests in the following areas:

- Physics, chemistry, and dynamics of the Earth system (atmosphere, biosphere, hydrosphere, lithosphere, cryosphere)
- Global and regional environmental change
- Climate system monitoring, diagnostics, and modeling
- Remote sensing and in-situ measurement techniques for the Earth system
- Interdisciplinary research themes

Graduate Research Fellowship Program

CIREs has long supported a Graduate Student Research Fellowship program to promote student scholarship and research excellence. Fellowships are restricted to Ph.D. students advised by a CIREs Fellow, or any prospective or current Ph.D. student who might be advised by a CIREs Fellow. Awards include support for up to 12 months, tuition, a stipend, and partial health insurance.

In partnership with NOAA's ESRL, CIREs also launched the new ESRL-CIREs Graduate Student Research Fellowship. This program will allow students to pursue a master's or doctoral degree in one of 13 CIREs-affiliated university departments and programs, while simultaneously working with a world-class research team at ESRL. Eligibility is limited to new students who have applied and been accepted to the university. Fellowship recipients will complete their coursework at the university and work with a CIREs faculty advisor and a NOAA-ESRL science advisor in one of several areas of cutting-edge research. Research topics are selected by ESRL Division Directors and CIREs Fellows and vary annually. The first competition included the following topics: aerosols and climate, trace gases and non-CO₂ greenhouse gases, the Arctic atmosphere, regional weather prediction, optical remote sensing, the carbon cycle, and linking weather and climate. Applications are reviewed by a selection committee comprised of ESRL scientists and CIREs Fellows. Awards include two to four years of full support.

Innovative Research Program

The purpose of the CIREs-wide competitive Innovative Research Program is to stimulate a creative research environment within CIREs and to encourage synergy between disciplines and research

colleagues. The program encourages novel, unconventional, and/or fundamental research that may quickly provide concept viability or rule out further consideration. Activities are not tightly restricted and can range from instrument development, lab testing, and field observations to model advancement. Funded projects are inventive, often opportunistic, and do not necessarily have an immediate practical application or guarantee of success. Each year, an interdisciplinary team selects the award recipients, and the results of their research are presented the following year at a poster reception. The 9th annual Innovative Research Program funded seven proposals, including projects to improve hurricane forecasting, explore the use of bacteria in cleaning up and converting toxins found in crude oil and tar, use ¹⁴C as a tracer to follow carbon pathways in aquatic ecosystems, examine noise and variability in its solar constant on simulated atmospheric circulation, and other novel projects.

Education and Outreach

The CIRES Education and Outreach program provides science education opportunities for educators, students and scientists. Our work emphasizes scientific inquiry and connects with current research, promoting understanding of foundational concepts in geosciences education, across the breadth of CIRES research areas. Examples of programs for educators include workshops and presentations related to climate literacy, communications and science, and professional development related to cutting edge research in solar science and other disciplines. Programs designed for students include the National Ocean Sciences Bowl and courses for students underrepresented in science (in partnership with the university's Math, Engineering and Science Achievement program). Graduate student support is offered through NSF's GK-12 Program. Programs

supporting researchers include a "Making Climate Hot" climate communications workshop, the newly funded Center for Ocean Sciences Education Excellence, the Colorado Collaboratory, and partnerships with scientists preparing geoscience research proposals that include educational and project evaluation components. Educational video products are available on Arctic climate change, Tibetan Plateau uplift, and solar variability.

Western Water Assessment

The Western Water Assessment (WWA) is CIRES' signature integrating activity, involving personnel from ESRL's Physical Sciences Division, the Center for Science and Technology Policy Research, the Center for Limnology, the National Climatic Data Center, the Natural Resources Law Center, the Institute for Behavioral Studies, and the Institute of Arctic and Alpine Research. WWA's mission is to identify and characterize regional vulnerabilities to climate variability and change, and to develop information, products and processes to assist water-resource decision makers throughout the Intermountain West. WWA addresses NOAA's mission, strategic goals, and cross-cutting priorities, as well as other congressional NOAA mandates, including the U.S. Global Change Research Act and the Climate Change Strategic Program. WWA is funded by the NOAA's Climate Program Office.

RENDEZVOUS!

The CIRES' Members' Council held its third annual research symposium on April 2, 2008. This one-day symposium featured presentations from CIRES' six divisions and the Education and Outreach program, and an annual "State of CIRES" address by Director Konrad Steffen. More than 80 scientific posters were presented during the event, including CIRES Visiting Fellows research.



Outstanding Performance Awards (see above), years-in-service awards, and other scientific achievement awards were presented. CIRES was pleased to host not only its own members, but also several visitors from the university and NOAA. Organized by the Members' Council, this symposium continued a tradition that began in 2006, bringing together CIRES members, Fellows, and students to highlight the depth and breadth of science, and to foster scientific exchange in a stimulating setting.

Distinguished Lecture Series

CIRES promotes global perspectives by sponsoring notable speakers whose work crosses disciplinary boundaries. The Distinguished Lecture Series features outstanding scientists, science policy makers, and science journalists who take imaginative positions on environmental issues and can establish enduring connections after their departure.



Dorthe Dahl-Jensen, Niels Bohr Institute
"Greenland Ice Cores Tell Tales on the Eemian Period and Beyond"



Gerald North, Department of Oceanography, Texas A&M University
"Climate Change Over the Last Thousand Years and the Next Hundred"



Steve Hickman, U.S. Geological Survey
"Structure and Properties of the San Andreas Fault at Seismogenic Depths: Recent Results from the SAFOD Experiment"

Mark Jacobson, Stanford University
"Air Pollution Effects of and a Renewable-Energy Solution to Global Warming"



Kerry Emanuel, Massachusetts Institute of Technology
"Hurricanes in the Climate System"



Symposia/Conferences and Workshops

Events sponsored, organized, or hosted by CIRES:

- CIRES Weather and Climate Dynamics Division Retreat (07/07)
- NOAA Roundtable—Earth System Modeling (08/07)
- WWA Workshop: Tree-ring reconstructions of streamflow and their use in water management (09/07)
- Civilian Applications for Unmanned Aircraft Systems Conference (10/07)
- Innovative Research Program Poster Reception (10/07)
- NSIDC Climate Briefing for Former Vice President Al Gore (10/07)
- CIRES 2007 Science Retreat, Cheyenne Mountain Resort (10/07)
- CIRES 40th Anniversary Celebration (11/07)
- Atmospheric Science and Climate Literacy Workshop (11/07)
- Earthworks: Field-based Science Studies for Teachers (11/07)
- Scientific Inquiry: Weaving the Nature of Science into Earth Science Education Workshop (11/07)
- Antarctica—Passion and Obsession A traveling photographic exhibit by Pat and Rosemarie Keough (11/07–12/07)
- Carleton Scholars Visit (12/07)
- CIRES Director's Coffee (01/08)
- Farewell for Former CIRES Director Susan Avery (1/08)
- Making Climate Hot: Effectively Communicating Climate Change Workshop (01/08)
- Roundtable Discussion "Counting Carbon: Tracking and Communicating Emitted and Embodied Greenhouse Gases in Products, Services, Corporations and Consumers" (01/08)
- United States Arctic Research Commission 85th Meeting—Boulder, CO (02/08)
- The Western North American Volcanic and Intrusive Rock Database Workshop (02/08)
- Program for Arctic Regional Climate Assessment Meeting (02/08)

Forecast Verification Workshop (02/08)
 NIDIS Remote Sensing for Drought Monitoring Workshop (02/08)
 WWA Workshop: Climate Change Modeling for Front Range Water Providers (02/08)
 National Ocean Sciences Bowl (02/08)
 Western Water Managers Roundtable (03/08)
 CIRES/ATOC Graduate Education Initiative Workshop on Inverse Modeling and Data Assimilation Technology (IMDA) (4/08)
 CIRES Members' Council Rendezvous Science Symposium (04/08)
 CIRES Outreach Movie "Upward and Outward: Scientific Inquiry on the Tibetan Plateau" (04/08 and 06/08)
 International Laser Radar Conference (06/08)
 NASA Precipitation Measurement Mission Rain Drop Size Distribution Working Group Meeting (06/08)
 Global Land Ice Measurements from Space—Monitoring the World's Changing Glaciers (06/08)

Presentations by Other Guest Speakers

Hugh Morrison	Simulating Arctic mixed-phase clouds using a new two-moment microphysics scheme in MM5 and WRF (07/07)
Thian Yew Gan	What has happened to the snow packs of North America from 1979–2004 based on SWE data of SSM/I passive microwave? (07/07)
Jessica Lundquist	Distributed temperatures in the snow zone: Spatial patterns and innovative measurement techniques (07/07)
Mariusz Pagowski	Behaviour of the Weather Research and Forecasting model boundary-layer and surface parameterizations in one-dimensional simulations during the BAMEX field campaign (07/07)
Christopher Anderson	Sensitivity of the 1993 summer hydrological cycle to Gulf of Mexico sea surface temperatures (08/07)
William Lewis	Klamath redux (09/07)
Douglas D. Davis	The Antarctica Plateau: A new look at boundary-layer atmospheric chemistry (09/07)
Brian Mapes	Predictability on an aqua planet, as deduced from global explicit-convection simulations (09/07)
Norman "Wes" Junker	An overview of research activities at NCEP's Hydrologic Prediction Center (09/07)
Toshi Shinoda	Variability of intraseasonal Kelvin waves in the equatorial Pacific Ocean (10/07)
Al Gasiewski	Airborne imaging of soil moisture (10/07)
Chris Funk	Statistical reformulations of AMIP precipitation fields (10/07)
Kirk R. Johnson	Multidecadal Arctic sea ice variability: Large scale changes and local impacts (10/07)
Marilyn Raphael	Southern Hemisphere atmospheric circulation sensitivity to Antarctic sea ice concentration (10/07)
Ian Howat	The Greenland Cryosphere Analysis Portal (G-CAP): A web-based system for monitoring ice sheet change (10/07)
Rad Byerly	"Health care" as a science policy issue (10/07)
Benjamin Hale	Can we remediate wrongs? (10/07)
Paul Ohm	The internet privacy debate: the problem with balancing security and privacy (11/07)
John Abatzoglou	Spring and fall: The neglected seasons (11/07)
Jim Maslanik	A younger, thinner Arctic ice cover: Increased potential for rapid, extensive sea-ice loss (11/07)
Nadine Salzmann	Use of RCM results for modeling cryospheric processes in complex mountain topography: Examples from the Swiss Alps and the Colorado Rocky Mountains (11/07)
Ted Nordhaus and Michael Shellenberger	Break through lecture (11/07)
David Cherney	American West's longest large mammal migration: Clarifying and securing the common interest (11/07)
Axel Thomas	Relief parameterization and climate interpolation: A case study from China (12/07)
René von Schomberg	EU science and technology policy: Addressing societal and ethical aspects (12/07)

Genevieve Maricle	Shaping science: Turning science studies into science action (12/07)
Betsy Weatherhead	Unmanned Aircraft Systems: Their new role in environmental monitoring (12/07)
Wieslaw Maslowski	On rates of Arctic sea ice decline (01/08)
Thomas Chase	To what degree are climate models useful in guiding policy decisions? (2/08)
Karen Fisher-Vanden	Technology, development, and the environment (02/08)
Elizabeth McNie	Linking knowledge with action (02/08)
Balaji Rajagopalan	The once and future pulse of Indian monsoonal climate (02/08)
Jana Milford	Clean air rules: Challenges in air pollution control strategy design (02/08)
Mark Serreze	The emergence of Arctic amplification, cryospheric and polar processes division seminar (02/08)
Malcolm K. Hughes	Modeling the role of snow and ice in controlling tree-ring growth (02/08)
Chunzai Wang	Global warming, climate variability and Atlantic hurricanes (02/08)
Edward J. Walsh	Storm surge measurement with an airborne scanning radar altimeter (02/08)
Carolina Vera	Climate variability and change in South America from WCRP/CMIP3 models (02/08)
Kathleen Tierney	The good the bad and the ugly: Post-Katrina trends in hazards policy and research (03/08)
Joe Ryan	Abandoned mine cleanups, the Clean Water Act, and environmental good samaritans (03/08)
Paul Polak	Out of poverty (03/08)
Robert S. Stone	Photometric studies of Arctic aerosols: Past, present and future (03/08)
Stu Townsley	Incorporating weather and climate information into Corps Sacramento District reservoir operations (03/08)
Mark McCaffrey	Toward a climate literate society (04/08)
Rebecca Morss	Interactions among flood predictions, decisions, and outcomes (04/08)
Eva Lövbrand	The Democracy paradox in studies of science and society (04/08)
Paul Komor	New energy education programs at CU: What does it mean to teach "energy"? (04/08)
Reiner Grundmann	Path dependency in the cases of ozone layer protection and climate change (04/08)
Elizabeth McNie	Exploring the Agora: Co-producing useful climate science for policy (04/08)
Andrea Ray	Lessons learned from the 2000s Western drought: Evolving linkages between research and services (04/08)
Mark Williams	Dead trees and dead fish in mountains: Predicting and understanding ecosystem changes in seasonally snow-covered areas to climate change at local to continental scales (04/08)
Mimi Hughes	Blocking in areas of complex topography and its influence on rainfall distribution (04/08)
Lynn Johnson	GIS in water resources engineering (04/08)
Carl Koval	The CU-Boulder Energy Initiative: Developing a campus-wide response to energy demand and climate change (05/08)
Jun Du	An overview of NCEP Short-Range Ensemble Forecasting System (05/08)
Arne Winguth	Long-term projections of climate and marine carbon cycle using a comprehensive coarse-resolution earth system model (05/08)
William Travis	Sustainability questioned: Appraising the viability of land use systems (06/08)
Chan Pak Wai	Numerical simulation of turbulence intensity in an area of complex terrain (06/08)
Sarah Wise	Teaching evolution in Colorado (06/08)
Lisa Dilling	Governing the carbon balance: Land use, decision making, and opportunities for usable science (06/08)
Lance Bosart	Troublesome precipitation events: A challenge for models and humans alike (06/08)
Chris Forest	Predictions and uncertainties of 21 st century global climate change (06/08)
Ryan Torn	Ensemble data assimilation applied to Hurricanes Katrina and Rita (06/08)
Chidong Zhang	Climatic effect of aerosol on tropical rainfall: Evidence from satellite observations (06/08)

CIRES PEOPLE AND PROJECTS

NOAA scientists

Randall Dole
David Fahey
Chris Fairall
Fred Fehsenfeld
Graham Feingold
Michael Hardesty
William Neff
Susan Solomon

CU–Boulder teaching faculty

Susan Avery
Ben Balsley
Roger Barry
Roger Bilham
John Casano
Tom Chase
Xinzhao Chu
Shelley Copley
Lisa Dilling
Lang Farmer
Noah Fierer
Baylor Fox–Kemper
Vijay Gupta
Jose Jimenez
Craig Jones
William Lewis, Jr.

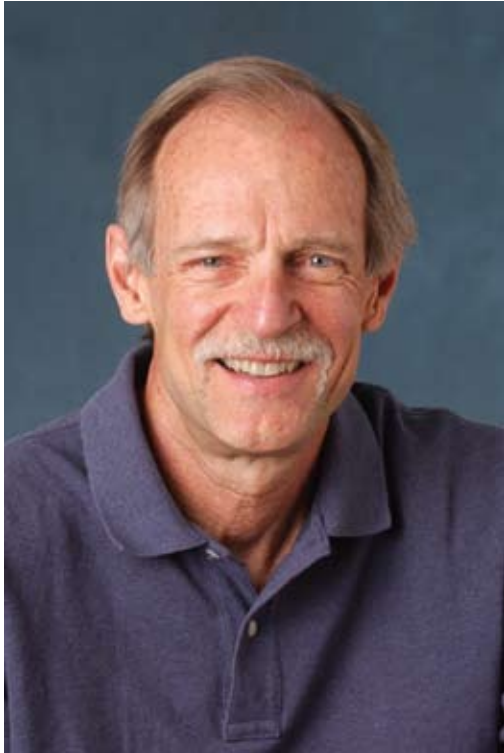
Peter Molnar
Russell Monson
Steven Nerem
David Noone
Roger Pielke, Jr.
Balaji Rajagopalan
Anne Sheehan
Robert Sievers
Konrad Steffen
Margaret Tolbert
Greg Tucker
Veronica Vaida
John Wahr
Carol Wessman

CIRES scientists

Richard Armstrong
Joost de Gouw
Timothy Fuller–Rowell
Mark Serreze
Prashant Sardeshmukh
Tingjun Zhang

CIRES starts with people. Researchers here all seek to better understand the planet, and they do so from different perspectives that reflect diverse areas of expertise. Fellows, students, and outreach professionals work together, forming a network that supports the Institute's centers and expands across the globe. The following pages describe the research of CIRES Faculty Fellows—those who are either university teaching faculty or CIRES scientists.

Faculty Fellows Research



Richard Armstrong

Assessing Changes in the World's Glaciers: The GLIMS Glacier Project

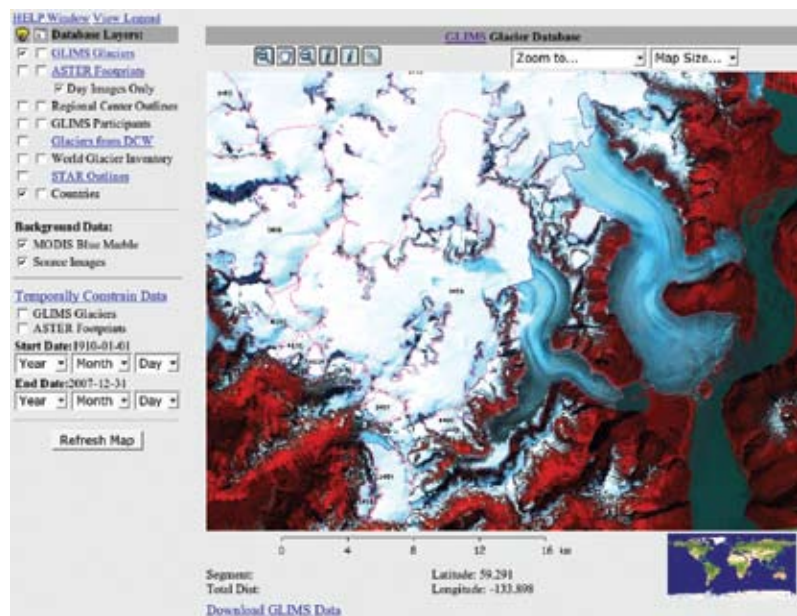
Funding: NASA Earth Science

The Global Land Ice Measurements from Space (GLIMS) project is a fundamental baseline study that systematically quantifies the areal extent of past and present glaciers to allow accurate assessment of the rate and magnitude of glacier changes occurring worldwide.

The international GLIMS project is creating an inventory of the majority of the world's estimated 160,000 glaciers, and mapping their extent and rate of change. GLIMS is an international project, coordinated by the National Snow and Ice Data Center (NSIDC), with participation from more than 60 institutions in 28 countries worldwide. Each institution (called a Regional Center, or RC) oversees the creation and analysis of data for a particular region appropriate to their expertise. These data are submitted to the GLIMS database at NSIDC, accessible at <http://nsidc.org/glims>. This work is being undertaken in direct collaboration with the World Glacier Monitoring Service (WGMS), Zurich, Switzerland, and is a logical extension of the WGMS World Glacier Inventory.

The NSIDC GLIMS project has created a geospatial and temporal database of glacier outlines and various scalar attributes. These data are derived from high-resolution optical satellite imagery, primarily the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) instrument aboard the NASA EOS Terra satellite and the LandSat Enhanced Thematic Mapper Plus. Historic data (maps and photographs) are used to document changes from earlier periods. The database currently contains outlines for more than 65,000 glaciers. The database also includes metadata for more than 150,000 ASTER images (2000–2007) acquired over glacierized terrain. ASTER footprints can be spatially viewed, temporally constrained, and queried to help GLIMS collaborators quickly find suitable cloud-free ASTER imagery. We have also implemented a Google Earth interface to our database of ASTER.

The GLIMS MapServer web site (<http://glims.colorado.edu/glacierdata/>) allows users to view and query thematic layers, including glacier outlines, ASTER footprints, selected high-resolution source imagery, MODIS Blue Marble imagery, GLIMS Regional Center locations, the World Glacier Inventory and glaciers from the Digital Chart of the World. Query results for glacier outlines can be downloaded into a number of GIS-compatible formats, including KML (for viewing in Google Earth), ESRI Shapefiles, MapInfo tables, Generic Mapping Tools, and Geographic Mark-up Language. Glacier outlines can be selected visually using the interactive map, or by using the text search interface to specify values (e.g., glacier name, area, etc.). The data are stored in a spatially enabled database (PostGIS), which has sophisticated functions for spatial data analysis and query.



A screenshot of the GLIMS MapServer shows database layers and options for temporally constraining data.



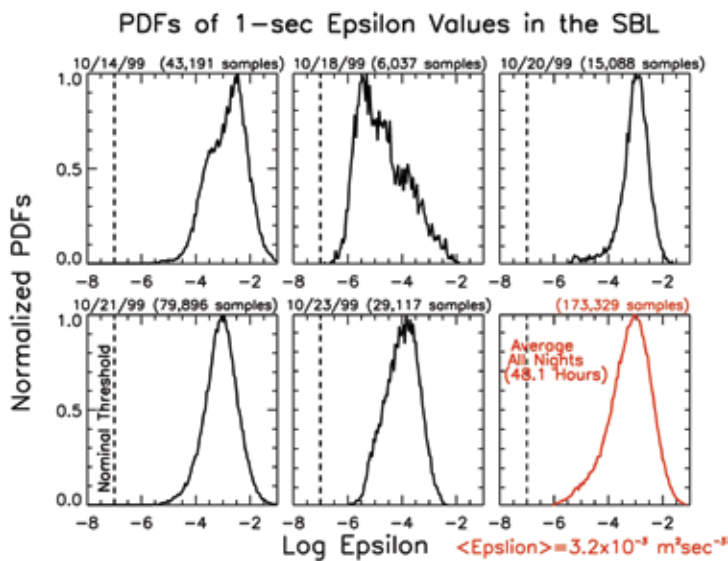
Ben Balsley

The Dynamics of the Residual Layer Determined from High-Resolution In-Situ Observations during CASES-99

We are examining the turbulent characteristics of the nighttime lower atmosphere using results derived from high-resolution *in-situ* studies of the residual layer (RL), obtained during the CASES lower atmospheric campaign in eastern Kansas in October of 1999. These studies typically use data gathered by the CIRES-developed Tethered Lifting System (TLS), which consists of a state-of-the-art kite or an aerodynamic balloon with high-resolution instruments suspended well below from the tether.

We have carefully documented the range of turbulent intensities in both the stable boundary layer (SBL) and the RL. The SBL is the lowest portion of the nighttime atmosphere and is tightly coupled to the Earth's surface, while the RL occupies the region between the top of the SBL and the steep temperature gradient that defines the bottom of the free atmosphere. The SBL is beginning to be understood, but the RL is a poorly studied region, owing to its inaccessibility. Understanding the RL, however, is important for understanding turbulent transport of ground-generated pollutants into the free atmosphere.

Recent studies show a surprising fact: both the SBL and the RL appear to be everywhere and always turbulent, although the turbulence levels can be quite weak. The ubiquity of small-scale turbulence in these regions runs contrary to conventional wisdom and could



significantly modify scientific understanding of turbulent transport through the region. Furthermore, its presence may explain the lack of success in modeling the region. Current results show that the turbulence levels in both the SBL and RL can range in intensity by more than three orders of magnitude.

The figure above shows a set of five probability distribution functions (PDFs) of turbulence intensities on five different nights. The data comprise 1-second intensity values of all of the available data on each of the nights over the entire height range. The red curve in the final panel represents all of the nights, and contains more than 48 hours of 1-s data values.

The vertical black dashed line on each plot shows the TLS threshold detection value, i.e., the minimum measurable value. It is important to point out that all of the measured PDF values in all panels fall well above this detection limit. Thus, it is clear that every one-second measurement during this 40-hour dataset exhibited a significant and measurable turbulence level. It follows that turbulence in the nighttime SBL is ubiquitous. Similar conclusions can be made for the RL (not shown), although RL turbulence levels are 30 to 40 percent weaker, on average.



Roger Barry

with A. Mahoney and F. Fetterer

Twentieth Century Sea Ice in the Eurasian Arctic from Russian Data Sources

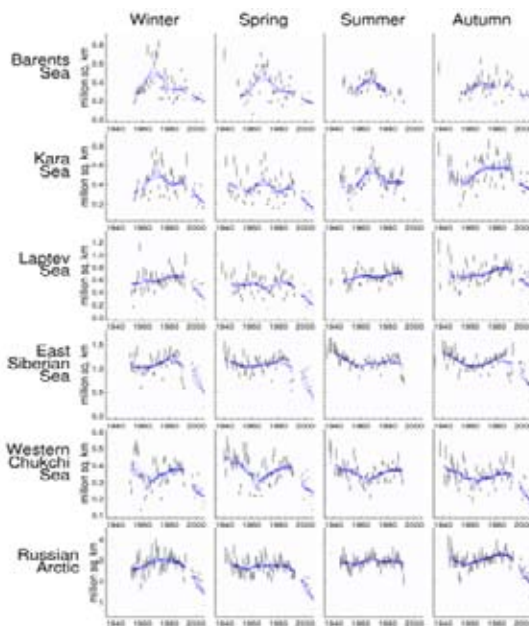
Funding: NASA Cryospheric Sciences

The primary objective of this work was to fill gaps in the Arctic sea ice data record by extending the data before 1950 and after 1992. A secondary objective was to provide summary statistics, and to assess the evidence for climate change in the Russian Arctic during the period 1930s–2005. The 1930–40s saw significant high-latitude warming, and it is important to document accompanying changes in ice conditions, to compare with those occurring since 1990.

Sea ice charts for 1933–49 based on aerial reconnaissance, and recent data for 1993–2006, have been digitized at the Arctic and Antarctic Research Institute, St. Petersburg, Russia. These data are available from NSIDC as Sea Ice Charts of the Russian Arctic in Gridded Format, 1933–2006 (<http://nsidc.org/data/g02176.html>).

From ice chart data, we have located the ice edge, where possible, and calculated seasonal ice extent anomalies for the marginal seas of the eastern Arctic. These results (at left) indicate that although there was also a retreat in autumn (annual minimum) sea ice extent in the early part of the 20th century, there was no apparent retreat in springtime (annual maximum). In recent years however, there has been a year-round retreat of eastern Arctic sea ice extent.

We examined historical meteorological station data for 231 stations above 67°N and within 100 m of sea level that provided data continuously for a minimum period of 30 years. These included 167 stations in the Russian Arctic and 44 stations in the North American Arctic. We also analyzed atmospheric indices (such as the Arctic Oscillation) to seek correlations between Arctic climate and the observed variability in sea ice.



Mean seasonal multiyear sea ice extent in each of the Russian marginal seas. The bars show the estimated 95% error margins for each data point. The blue regions show the combined results of smoothing across different intervals with randomly sampled errors.

We can divide the ice chart record into three periods: A) Sea ice retreat from the beginning of the record until the mid-1950s; B) Generally increasing or stable summer and autumn sea ice extent from the mid-1950s to the mid-1980s; and C) A second period of retreat from the mid-1980s to the present. The air temperature record suggests that the Russian Arctic was warming during period A while the rest of the Arctic was cooling. This, together with the inverse relationship between surface air temperature and sea ice extent, suggests that the sea ice retreat during period A was not likely to have been an Arctic-wide phenomena, unlike the current period of retreat.



Roger Bilham

with graduate student Walter Szeliga, Becky Bendick at the University of Montana, Faisal Khan and Asif Khan at NCEG University of Peshawar, Din Mohammed at the University of Baluchistan in Quetta, Sarosh Lodi at NED University of Karachi, and Ismael Bhat and Bikram Singh, University of Kashmir)

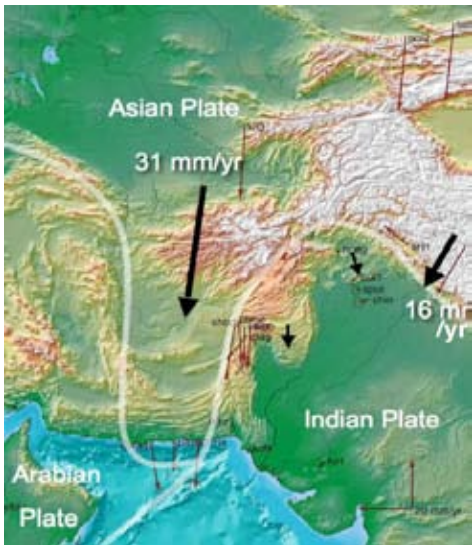
Geodynamics of the Western Edge of the Indian Plate

Funding: NSF

Emblematic of the collision of the Indian plate with Asia is the dramatic growth of the Himalaya during massive, but infrequent, earthquakes. Less well studied are the consequences of the enormous shear stresses caused by the piston-like northward insertion of the Indian plate into the Asian plate. Along northwestern and south central Pakistan, these stresses are responsible for numerous historical earthquakes that have destroyed ancient cities now represented by archaeological ruins, not only close to the prominent plate boundary Chaman Fault, but also throughout Sindh province and the western Punjab. Of great concern is the vulnerability of present populations should these historical earthquakes recur. Pakistan's largest city Karachi (8 million people) lies close to the plate boundary and is, in addition, exposed to potential tsunami hazard. The project has as its goal the characterization of seismic hazard through the measurement of deformation in Pakistan.

Following the catastrophic 2005 Kashmir Mw=7.6 earthquake, we expanded our GPS measurements in the Himalaya and Potwar Plateau to embrace the provinces of Baluchistan and Sindh. In a remarkably successful collaborative program with five university groups in Pakistan and one in India, we have now measured 62 GPS points, and operate six continuous GPS stations, with data from three of them now accessible in real time.

Accomplishments: GPS-derived velocities in the past few years provide the first direct measurements of the deformation processes that drive Pakistan earthquakes. The tectonics of Pakistan are most easily viewed by considering the rigid Indian plate to be fixed (at left). In this view Asia appears as a promontory (outlined in white) pushing south at around 31 mm/year, and western Tibet is converging with northern Pakistan southwestward at about half this velocity. Huge lobes of sediments flow southward over the Indian plate supported by a cushion of easily deformed salt. The location of key GPS points are shown with arrows indicating their velocities relative to India. The rigid craton appears to extend as far west as Karachi and to points just south of the Salt Range. We find that the Potwar Plateau is moving southeast at roughly 2mm/yr and, from the absence of creep on its margins revealed by InSAR, must do so in earthquakes. In contrast, the entire Makran coast of Baluchistan, part of which experienced a tsunamigenic earthquake in 1945, moves at speeds that suggest the earthquake mobilized fluids that were entrained in the sediments, reducing frictional locking. It appears that a future earthquake on the Makran coast may now be delayed by many hundreds of years. The absence of significant horizontal motion of Sindh province relative to the Indian craton also suggests either that we have yet to identify the driving physics of earthquakes in Bhuj, or that the renewal time for earthquakes there must be measured in thousands of years.



John Cassano

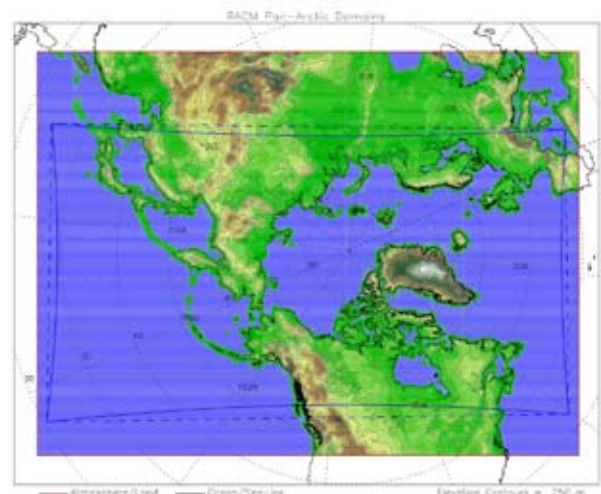
Polar Climate and Meteorology

Funding: NSF, DOE

The Cassano Polar Climate and Meteorology research group at the University of Colorado at Boulder is involved in numerical modeling of polar climate, and observational studies in polar regions. Two ongoing projects in the Cassano research group are the development of a high-resolution Arctic climate system model, and the use of unmanned aircraft systems, UAS, to study atmospheric processes in the Antarctic.

Current generation global climate system models lack the horizontal and vertical resolution to adequately resolve key processes in the Arctic climate system. Improved resolution is possible in a regional model, and we use model physics tailored to the unique aspects of the polar climate system, which ensures that all key processes in the climate system are adequately represented in the model. We use a pan-Arctic model domain that includes all of the sea-ice-covered regions of the Northern Hemisphere as well as all terrestrial watersheds that drain to the Arctic Ocean (figure below, top). One question we plan to address with our Arctic climate system model is Why have global climate models failed to simulate the recently observed rapid decline in Arctic sea ice cover? We hypothesize that processes acting at scales below the resolution of global models are, in part, responsible for this failure of the global models.

Our observational work in the polar regions is motivated by the need to have data to evaluate our model simulations and to allow for continued improvement of those models. A recently funded project will use Aerosonde UAS to make detailed observations of air-sea interactions in the Terra Nova Bay polynya (figure at bottom). Formation and maintenance of this polynya is linked to strong katabatic winds draining from the East Antarctic plateau into Terra Nova Bay. These strong winds promote strong heat and moisture fluxes over the open water of the polynya, leading to pronounced modification of both the ocean and atmosphere. Our UAS measurements will be the first *in-situ* observations of the air-sea interaction over this polynya during the late winter/early spring time period. Data from this field campaign will provide insight into the formation of Antarctic bottom water, details of the atmospheric forcing for this polynya, and validation data for high-resolution numerical simulations.



Simulation domain for the Arctic climate system model under development in the Cassano research group.



Visible satellite image of Terra Nova Bay polynya, October 2007.

Tom Chase

Observational and Modeling Analysis of Land Cover Changes and Climate

We have shown that recent land cover change over the Indian subcontinent during pre-monsoon season (March, April, and May, or MAM) affects the early Indian summer monsoon. Lee et al. (IJOC, *in press*) found that MAM Normalized Difference Vegetation Index anomalies increased in the Indian subcontinent, and the increases are significantly correlated with increases in irrigated area, not with preceding rainfall. July rainfall significantly decreased in central and southern India, and the decrease is statistically related to the increase in the preceding MAM NDVI anomalies. Decreased July surface temperatures in the Indian subcontinent (an expected result of increased evapotranspiration due to irrigation and increased vegetation) lead to a reduced land-sea thermal contrast. Because land-sea thermal contrast is one of the factors driving the monsoon, irrigation weakened the monsoon circulation.



We also found (Lee et al. *in press*), using statistical forecast models of the East Asian summer monsoon, that using land cover conditions in addition to ocean heat sources can more than double the predictive skill of East Asian summer monsoon forecasting models (relative to models using ocean factors alone). This work showed the importance of seasonal land cover in monsoon prediction, and the role of the biosphere in the climate system as a whole.

Model analysis: Recent modeling studies also highlight the effect of changes in the land surface and climate. For example, Lawrence and Chase (2007) showed that replacing the standard land surface parameters in the NCAR CCSM3.0 with parameters that were consistent with MODIS satellite observations, for example, resulted in an increase in bare soil fraction of 10 percent and increases of 10 percent for leaf area index (LAI). The new land surface parameters have strong, repeatable impacts on the climate simulated in CCSM 3.0, with large improvements in surface albedo. In many cases, the improvements in surface albedo directly resulted in improved simulation of precipitation and near-surface air temperature. However the increased LAI resulted in lower overall evapotranspiration with reduced precipitation in CCSM 3.0. This was an unexpected result, and it suggests that while the new parameters significantly affected and improved the climate simulated in CLM 3.0 and CCSM 3.0, the new surface parameters have limited success in rectifying surface hydrology biases that result from the parameterizations within the CLM 3.0. These findings further emphasize the complicated role of the land surface, as a whole, in climate.

Further investigation (Lawrence and Chase, *in press*) indicated that CLM 3.0 simulates mean global evapotranspiration with low contributions from transpiration (15 percent) and high contributions from soil and canopy evaporation (47 percent and 38 percent), which is inconsistent with results from other land surface models Dirmeyer et al. (2005) and physical reasoning. Altering the surface hydrology parameterization to be consistent with SIB

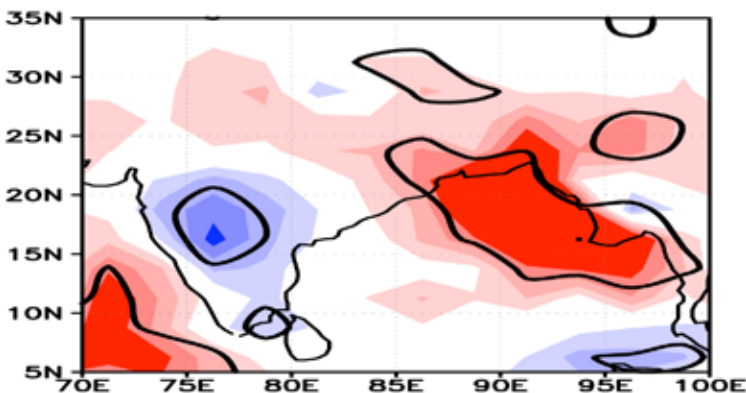
resulted in more realistic partitioning of evapotranspiration, but also had global scale impacts on CCSM model climatology showing that changes in surface hydrology, whether by model physics or human activity, have broad consequences.

References not included in the Publications sections:

Lawrence, P.J. and T.N. Chase (2008), Climate impacts on the Community Climate System Model (CCSM 3.0) of making the surface hydrology of the Community Land Model (CLM 3.0) consistent with the Simple Biosphere (SIB 2.0), *J. Geophys. Res.-Atmos.*, *in press*.

Lee, E., T. N. Chase, and B. Rajagopalan (2008), Highly improved predictive skill in the forecasting of the northern East Asian summer monsoon, *Water Resources Research*, *in press*.

Lee, E., T.N. Chase, B. Rajagopalan, R.J. Barry, T. Biggs, and P.J. Lawrence (2008), Effect of spring land cover change on early Indian summer monsoon variability, *Int. J. Clim.*, *in press*.



Trends in Indian summer monsoon precipitation in the last two decades showing a decrease over much of India, which has been related to changes in land cover by massive irrigation.

Xinzhao Chu

Lidar Innovation and Development, and Polar Atmospheric Sciences

Funding: NSF and ESA

After winning three awards in the last two years—NSF’s Major Research Instrumentation award, Faculty Early Career Development award, and one from the Consortium of Resonance and Rayleigh Lidars—Xinzhao Chu led her research group to focus on three areas: 1) the innovation and development of the MRI mobile Fe–resonance/Rayleigh/Mie Doppler lidar, 2) the development of new technologies for the lidar Consortium Technology Center, and 3) studies of the polar stratosphere, mesosphere, and lower thermosphere using lidar data collected at the South Pole and Rothera, Antarctica. Several significant scientific findings are described below.

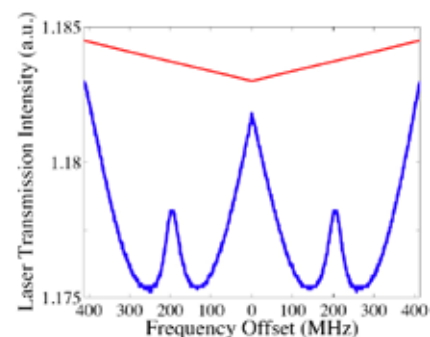
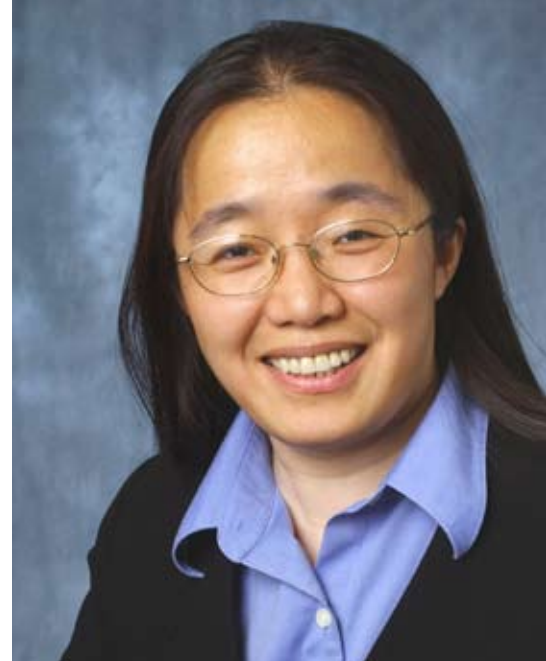
First, Dr. Chu’s research group achieved the first Fe Doppler–free saturation–absorption spectroscopy in the lidar field with the MRI lidar (figure at right, top). The key components are the see-through Fe discharge cell and the 372–nm cw external cavity diode laser. Such Fe spectroscopy provides an absolute frequency reference for the entire MRI lidar to achieve bias–free lidar frequency locking with accuracy better than 1 MHz.

Second, lidar data analyses by graduate student Chihoko Yamashita and Dr. Chu show significant differences between Rothera and the South Pole. 1) The brightness of polar mesospheric clouds is negatively correlated with the strength of stratospheric gravity waves at Rothera, but there is no correlation at the South Pole. 2) Stratospheric gravity potential energy density exhibits a clear seasonal variation at Rothera with the winter average being six times larger than that of summer. The seasonal variation at the South Pole is significantly smaller with nearly constant value through the year (figure at right, bottom). 3) Rothera mesospheric Fe density peaks in late April and early May, which is ~1–month phase shift relative to the South Pole (figure below, left). These results raise an important question: What mechanisms are controlling the polar stratosphere, mesosphere, and lower thermosphere region?

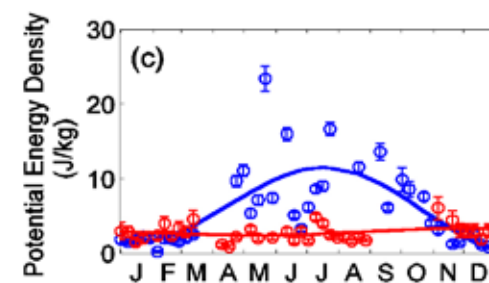
Third, the lidar Consortium Technology Center has been firmly established. Graduate student John Smith developed a LabVIEW–based laser frequency stabilization system with a phase–sensitive detection servo loop, which is applicable to many existing and new resonance fluorescence Doppler lidars.

In addition, the MRI lidar has been fully designed and is expected to be fully operational within 18 months for new scientific endeavors.

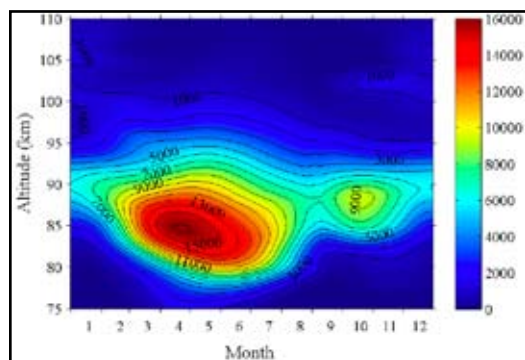
Under the support of CIRES’ Innovative Research Program, Dr. Wentao Huang is developing and testing a Na Double–Edge Magneto–Optic Filter for extending Na wind and temperature lidar measurements to the lower atmosphere. Dr. Chu and Dr. Huang are collaborating with colleagues in Athens, Greece on a feasibility study of space–borne mesosphere lidar under the support of European Space Agency. Graduate student Johannes Wiig is conducting an instability study in the mesosphere and lower thermosphere region using lidar data from Arecibo and Maui.



First Fe Doppler–free saturation–absorption spectroscopy at 372–nm line achieved with the MRI Fe Doppler lidar.



Seasonal variations of gravity wave potential energy density at the South Pole (red) and Rothera (blue), Antarctica.



Seasonal variations of mesospheric Fe density, measured by Fe Boltzmann lidar at Rothera (67.5°S, 68.0°W), Antarctica.



Shelley Copley

Analysis of the Poor Catalytic Performance of Pentachlorophenol Hydroxylase

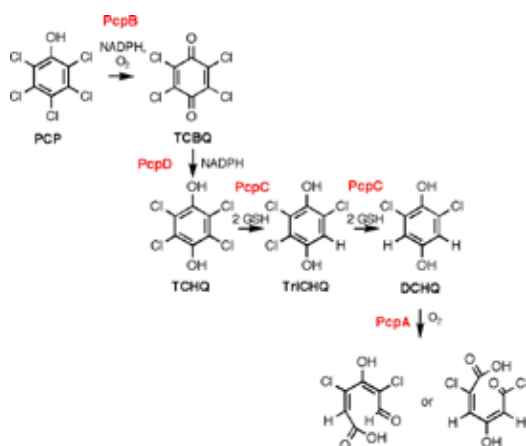
Funding: DOD Army Research Office

Pentachlorophenol (PCP) is a highly toxic pesticide that was first introduced into the environment in 1936. Despite its toxicity, PCP can be completely degraded by *Sphingobium chlorophenolicum*, several strains of which have been isolated from PCP-contaminated soil. Although the ability of *S. chlorophenolicum* to mineralize PCP is remarkable, the inefficiency of the metabolic pathway has limited the potential for its use in bioremediation.

S. chlorophenolicum appears to have assembled a new pathway for degradation of PCP by recruiting previously existing enzymes from at least two other metabolic pathways (at left). None of these enzymes functions very well. The poor activity of PCP hydroxylase (PcpB) limits flux through the pathway. TCBQ reductase (PcpD) is also a very inefficient catalyst. TCHQ dehalogenase (PcpC) is profoundly inhibited by its aromatic substrate. Furthermore, expression of TCHQ dehalogenase is constitutive, and therefore not regulated in tandem with the other enzymes in the pathway. DCHQ dioxygenase (PcpA) undergoes rapid substrate-dependent inactivation during catalytic turnover.

We have examined the reasons for the poor catalytic performance of PCP hydroxylase. The enzyme turns over substrate at a very slow rate (0.02 s^{-1} , compared to $50\text{--}100 \text{ s}^{-1}$ for most enzymes in this family). The rate of the chemical reaction is respectable, but slow release of the product limits the rate of the reaction. Furthermore, there is substantial uncoupling between formation of C4a-hydroperoxyflavin, the species that is supposed to transfer a hydroxyl group to the substrate, and actual hydroxylation of substrate. About 70 percent of the C4a-hydroperoxyflavin decomposes to oxidized flavin and H_2O_2 rather than hydroxylating the substrate. This generates a harmful oxidant in the cytoplasm and wastes NADPH, a valuable source of cellular reducing equivalents. Furthermore, the product formed from PCP, tetrachlorobenzoquinone, is a highly reactive electrophile that forms adducts with the active-site flavin and cysteine residues in the protein, leading to inactivation of the enzyme.

In sum, the poor ability of the enzyme to control the reactivity of its substrates and products leads to havoc at the active site. These results should enable us to understand what aspects of enzyme performance need to be manipulated to evolve a better enzyme.



Pathway for degradation of PCP in *S. chlorophenolicum* ATCC 39723. PcpB, PCP hydroxylase; PcpD, TCBQ reductase; PcpC, TCHQ dehalogenase; PcpA, DCHQ dioxygenase (PcpA); GSH, glutathione.

Joost de Gouw

with Carsten Warneke, Dan Welsh-Bon, and NOAA colleagues

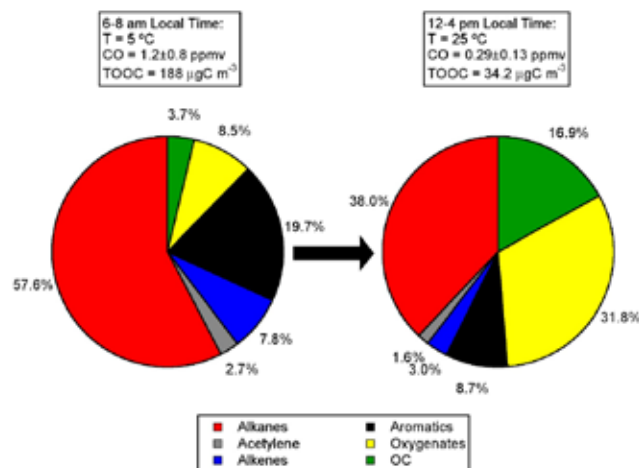
Organic Aerosol in the Atmosphere— Important for Air Quality and Climate, but Where do they Come From?

Funding: NOAA, NSF

Aerosols, microscopically small particles suspended in air, are an important factor in the Earth's atmosphere, influencing both air quality and climate. Aerosols are small enough to penetrate deep into the lungs and have been linked to short- and long-term health effects. Also, aerosols impact the Earth's climate both directly, through the scattering and absorption of radiation, and indirectly, through their role as cloud-condensation nuclei. Both the direct and indirect effects of aerosols are currently among the more uncertain radiative forcing factors in the climate system.

A large fraction (~50 percent) of atmospheric aerosol consists of organic material. The sources of this organic aerosol (OA) are uncertain, however, and are the subject of vigorous debate in the scientific community. Direct emissions of aerosol (primary organic aerosol or POA) are distinguished from secondary production in the atmosphere from gas-phase precursors (secondary organic aerosol or SOA). Both POA and the precursors of SOA can be biogenic or anthropogenic in origin. Obviously, to mitigate the adverse effects of OA on air quality and climate, it is very important to understand their emissions and production mechanisms quantitatively.

During an airborne study in the northeastern United States in 2004 and a surface study in Mexico City in 2006, we quantified the evolution of OA and its precursors in urban air as it is processed. Using the NOAA WP-3D aircraft, we observed the increase in the mass loading of OA in the plume from New York City as it moved out over the Atlantic Ocean. At the surface site in Mexico City, we observed the even earlier stages of SOA formation by comparing the composition of OA and its precursors between the nighttime, when the composition was dominated by direct emissions, and the daytime, when the contribution of SOA was large (figure at right). The graphs show that in the morning, the composition is dominated by gas-phase hydrocarbons, whereas in the afternoon, the combined contribution from OA and oxygenated volatile organic compounds had grown to almost 50 percent. The results from both the northeastern United States and Mexico City studies confirmed the conclusions from previous work, that (1) direct emissions of OA are a minor source on regional scales, (2) the highest OA mass loadings are typically observed in aged urban air, and (3) the increase in OA is much higher than what can be explained by removal of gas-phase compounds that are known to produce SOA efficiently in the laboratory, such as the aromatics. Future work will be aimed at providing an explanation for this discrepancy.



Average chemical composition of organic aerosol (OA), its gas-phase precursors and carbon monoxide (CO) at two different times of the day in Mexico City. All measurements are converted to units of $\mu\text{C m}^{-3}$; OA is given as organic carbon (OC), and the sum of OA and gas-phase species is referred to as total observed organic carbon (TOOC).



Lisa Dilling

With Bill Easterling, Penn State University, and Betsy Failey, Research Assistant

Scales of Decision Making and the Carbon Cycle

Funding: NOAA Climate Program Office

Carbon “sinks,” or processes that store carbon away from the atmosphere, are an important option in mitigation strategies for climate change. Currently, carbon sinks on land act to store a significant portion of the carbon emissions released by human activities. In North America, the proportion is approximately 30 percent. Land-management practices can affect the amount of carbon stored in agricultural, grass, and forested lands. Land-use decision making is therefore an important driver of the carbon cycle. However, little is known about how land managers make decisions that impact carbon storage, and what influences those decisions.

We hypothesize that the terrestrial portion of the carbon cycle is most likely to be managed through land use policies by local and state institutions operating within a framework of federal agencies. We are studying the institutions whose practices and policies influence the biospheric portion of the carbon cycle in two U.S. states—Colorado and Pennsylvania—to understand how decisions made in institutions at different scales currently act to affect carbon sequestration.

Preliminary results in Colorado indicate that policies at a variety of scales influence land-use decision making, although there is still individual flexibility at any particular scale. Federal policies, such as agricultural incentive programs and assistance with conservation measures, are often mentioned by private landowners, but state and local programs can also be influential. For federal, state, and private land managers, carbon is not yet a dominant factor in their decision making; it is not yet really on the radar screen for most. Federal land managers are aware of climate change and seem to be debating how to factor climate change into their land-use decision process, which depends heavily on the National Environmental Policy Act. For these managers, information on climate change and the carbon cycle must be specific to the level of the land area that they are managing, which does not usually match the scale at which such information is available. Results have not yet been fully analyzed, but it is clear that policies and the public process at several scales influence decision making, and that any potential future carbon policy or incentives will be weighed against existing economic values, existing regulations, and a host of priorities for land managers in Colorado.





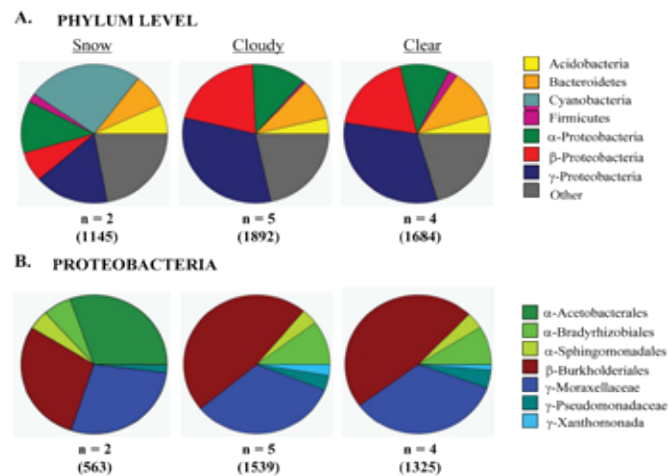
Noah Fierer

Airborne Microorganisms

Funding: A.W. Mellon Foundation, NSF

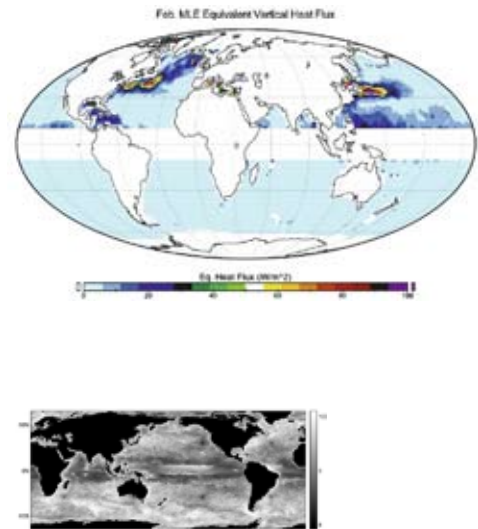
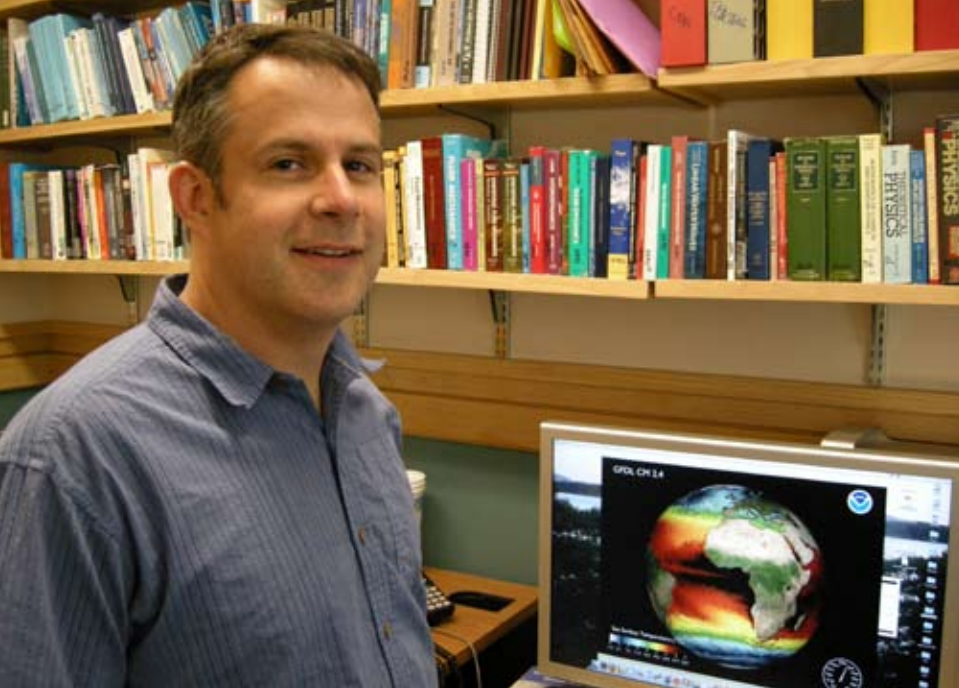
Bacteria and fungi are ubiquitous in the atmosphere and represent a large proportion of total airborne particulates. Atmospheric transport is a key mode of microbial dispersal, and the transmission of airborne plant and animal pathogens can significantly affect ecosystems, human health, and agriculture. Despite the importance of airborne microorganisms, there have been very few studies describing the full extent of microbial diversity in the atmosphere. In addition, recent evidence suggests that airborne microorganisms may be able to alter precipitation events by facilitating atmospheric ice nucleation and cloud condensation. There have been few studies examining the validity of this hypothesis. To address these key knowledge gaps, we used a cultivation-independent molecular approach to identify the bacteria and fungi present in air samples collected from a single site at the Storm Peak Laboratory in northern Colorado (shown above, 3,200 m elevation). We documented shifts in the types of bacteria and fungi found in air during 12 days, assessing the temporal variability in airborne microbes and the climatic factors driving this variability and correlating the microbial information with detailed information on atmospheric conditions and aerosol chemistry.

The air samples were dominated by potentially allergenic fungi and a diverse array of bacteria, including specific types of bacteria that are commonly found in air samples collected from across the globe. Boundary-layer air harbored microbial communities distinct from those found in tropospheric air, and snow samples had distinct microbial communities compared to aerosol samples. We identified a number of unique ice-nucleating bacteria that appear to be capable of inducing ice nucleation at relatively warm temperatures. Back-trajectory modeling of the air masses suggest that the airborne microbial communities may serve as ‘tracers,’ allowing us to track changes in air masses as they move over different land-use types. We are currently expanding on this work to further understand how airborne microorganisms vary across space and time, so we can better predict how airborne microorganisms respond to and potentially influence atmospheric conditions.



The taxonomic composition of the bacterial communities in the atmosphere and snow, sampled from the Storm Peak laboratory during 12 days in April.





Baylor Fox-Kemper

with Raffaele Ferrari at the Massachusetts Institute of Technology and Dimitris Menemenlis at NASA Jet Propulsion Laboratory

Improving Subgridscale Physics in Ocean Climate Models

Funding: NSF/NOAA Climate Process Team

The ocean is vast and diverse. The very largest scales (>1,000 km) of the ocean work with the cryosphere, atmosphere, and biosphere to harnesses incoming solar radiation in balance with outgoing thermal radiation, forming a habitable climate. However, the behavior of the largest ocean scales depends on smaller scale features. For example, the Gulf Stream (100 km) plays a crucial part in transporting heat from the equator to the northern midlatitudes. Smaller features (e.g., mesoscale eddies (10–100 km) and deep convection (1–10 km)) allow the Gulf Stream to function as it does. Even smaller features affect the way the atmosphere, ice, and ocean communicate through the ocean surface (e.g., submesoscale eddies (100 m–10 km), Langmuir circulations (10–100 m), and finescale turbulence (1 cm–10 m)).

The immensely complex equations that govern how these diverse phenomena interact cannot be solved by hand, so numerical computation is necessary. Even the world's fastest computers cannot simulate the global ocean (needed to model global climate) with a fine enough model grid to capture these small features directly. Thus, something must be done to handle, or parameterize, the effects of these unresolved phenomena on the larger resolved scales. The small scale phenomena interact so strongly with the global scale that without these parameterizations an ocean model cannot be used to simulate climate without artificial, unphysical “flux corrections.”

Traditionally, submesoscale eddies (<10km) that inhabit the oceanic surface mixed layer were thought too small to dramatically affect climate. Thus, no attempt to include their effects in climate models had ever been attempted. Yet, an exhaustive series of simulations resolving these eddies revealed that their small size permits a vertical transport of properties that far exceeds that of larger eddies. The submesoscale vertical heat transport even rivals the surface forcing of the ocean by radiation and heat exchange by the atmosphere. Thus these eddies have a global climate impact. A theory was developed—and confirmed against numerical experiments—that allows the vertical fluxes of these eddies to be incorporated into climate scale models. This parameterization reduces climate model biases, and it is now incorporated into three ocean models that will be used in the upcoming IPCC fifth assessment.

Engineers routinely use large eddy simulations (LES) resolving only the largest turbulent features. Yet, their proven subgridscale parameterizations don't work for oceans because mesoscale ocean eddies are unlike small-scale turbulence. They are flat, quasi-two-dimensional features that feel the Earth's rotation and ocean density. A theory for doing mesoscale ocean LES (MOLES) was developed, along with a new parameterization that addresses the unique features of ocean eddies while preserving numerical stability. Computers are just becoming fast enough to employ this new technique on a global scale. The vertical heat flux due to submesoscale eddies (here inferred from satellite data) rivals atmosphere–ocean heat exchange and incoming radiation. The viscosity of a new parameterization for MOLES depends on the resolved eddy energy (\log_{10} scale).

Vijay Gupta

Developing and Testing Multi-Scale Dynamical Foundations of Statistical Scaling in Floods and Riparian Evapotranspiration in Mesoscale River Basins

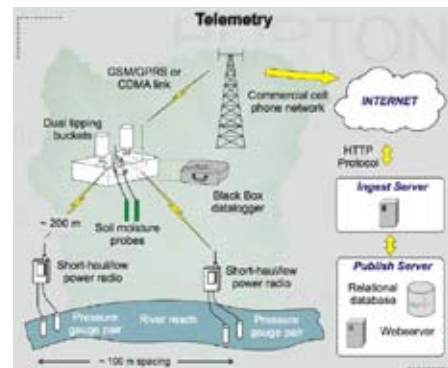
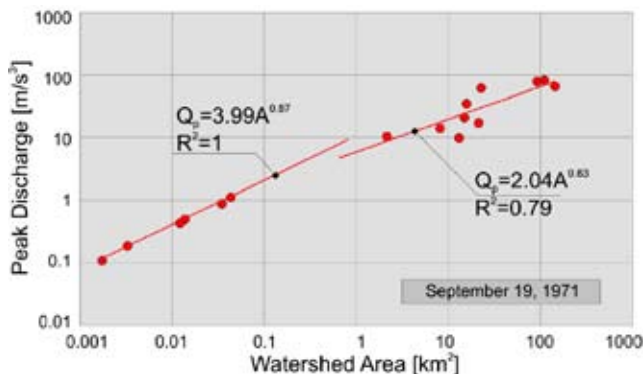
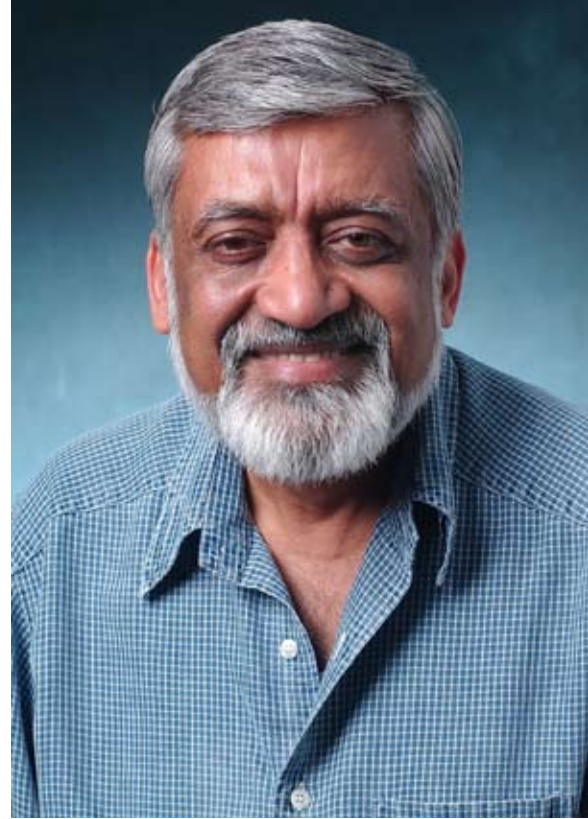
Funding: NSF and DOE ARM climate research facility

Hydro-Kansas (HK) is a multi-investigator, multi-disciplinary, multi-institutional, multi-scale project to understand and predict floods in mesoscale watersheds. Research on floods in engineering hydrology has a very long history, but the physical mechanisms producing floods have remained disconnected from regional (spatial) flood statistics. HK is developing a new geophysical theoretical and observational approach for combining the two disjointed aspects of floods through predicting flood scaling statistics, or power laws (figure below, left), in terms of physical processes on multiple spatial and temporal scales. The central observational facility for the HK project is the 1,100 km² Whitewater Basin, 50 km east of Wichita, KS.

The HK project has been developing in multiple phases for many years. The last phase (2005–07) completed a pilot project, which installed 12 stream flow gauges at the end of complete Horton–Strahler streams, and 14 rainfall-gauging sites in the Whitewater Basin. Rain gauges are being used in tandem with NEXRAD at Wichita for estimating space–time rainfall intensity fields. A network for automated rainfall data acquisition and transmission to a central facility at the University of Iowa was completed (figure below, right). Gupta, Troutman, and Dawdy published an overview book chapter in 2007 on 20 years of progress on the scaling theory of floods.

HK greatly extended its scope by bringing the statistical scaling framework to understand and predict riparian evapotranspiration in river basins. The traditional approaches to evapotranspiration (e.g., eddy-correlation, over large homogeneous areas) are not applicable in riparian areas. A team of new researchers joined the HK researchers conducting flood research, and submitted a proposal to NSF in 2007, which was funded for three years in 2008.

Dr. Gupta is the lead principal investigator of the Hydro-Kansas Research Project, involving: Mr. David Dawdy, hydrology consultant, San Francisco, CA; Prof. Witek Krajewski, IIHR, University of Iowa; Prof. Anton Kruger, IIHR, University of Iowa; Dr. Ricardo Mantilla, IIHR, University of Iowa; Dr. Brent Troutman, USGS, Lakewood, CO; Dr. Peter Furey, North-West Res. Assoc./Colorado Division; and graduate students at the University of Iowa.

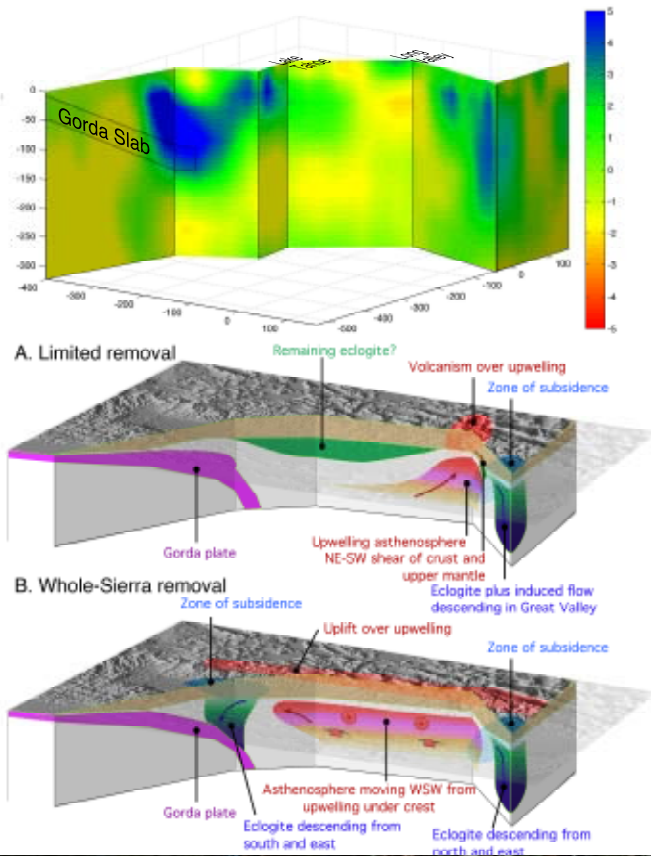


Left, observed scaling in floods for a rainfall–runoff event in the 150 km² Walnut Gulch Basin, AZ. Right, schematic representation of the data collection/distribution framework implemented in the Whitewater Basin, KS.

Craig Jones

Tectonics of Foundering Lithosphere, Sierra Nevada, California

Funding: NSF EarthScope Program and Continental Dynamics Program



In contrast with ocean tectonics, continental tectonics are diffuse and occur in places and with styles not easily anticipated from plate kinematics. One potential cause is the antibuoyant mantle lithosphere under continents, and the potential that it could detach and sink into the mantle. The Sierra Nevada of California might overlie lithosphere that foundered in the past 10 million years. Dr. Jones and colleagues at two other universities are analyzing data from a new seismological experiment to understand the dynamics of this process.

In this, our third year, we removed our network of more than 50 field stations from the northern Sierra Nevada. Heidi Reeg, a graduate student working on this project, has constructed a tomographic image of the Sierran upper mantle and crust, described below. The seismological group met to review results and outline papers in the summer of 2008, and all the scientists will meet in November 2008.

The removal of mantle lithosphere has long been proposed as a means of driving enigmatic deformation in continents, but hypotheses for the impacts of such an event were largely based on theory. Previous geophysical data allowed for two possibilities in the Sierra: that uplift of the range was caused by convective removal of a dense layer at the base of the crust (case B at left), or that only some of the dense layer was removed from part of the range, leaving explanation for most of the elevation of the Sierra to another cause (case A). The first case implies that these convective processes are first-order in building mountains; the second, that they are second order. Inversion of the arrival times of P-waves from earthquakes around the Pacific and northern Atlantic were used to image variations in seismic wavespeed under the Sierra and much of surrounding California. Comparing the two pre-experiment cartoons with the actual variations in seismic wavespeed suggests that elements of both ideas are present. To the right (south), low speed material (oranges) appears under the southern Sierra to the northeast of the high wavespeed “drip” under the San Joaquin Valley, consistent with case A. Far to the north, high wavespeed material associated with a subducting slab is also tied to shallow high wavespeed material under the Sierra, suggesting some convective removal of material from the Sierra being entrained with the downgoing slab, as in Case B. (The bulk of the slab does not show up in this section owing to coverage from available seismometers). Our combined results suggest that convective removal is occurring along the entire range but has progressed to different degrees along the range, with more removal in the south (where the highest elevations are present) and less removal in the north.

Seismometer installation in Yosemite backcountry being removed. Andy Frassetto checks.



Anabaenopsis in nuisance bloom conditions.



William Lewis, Jr.

A Most Unusual Lake

Little Gaynor Lake is north of Boulder on the boundary between a subdivision and Boulder County Open Space lands. In 2007, the CIRES Center for Limnology received a request from Boulder County Open Space to diagnose the cause of extreme odor from the lake, and purple water color (figure below, left). Limnology Center staff measured high concentrations of hydrogen sulfide in the lake, and attributed the purple water color to a photosynthetic bacterium (*Chromatium*) that conducts photosynthesis by use of sulfide, rather than oxygen, as an electron donor.

Local citizens have been anxious to eliminate Little Gaynor Lake's odor and purple color, both of which occur sporadically toward the end of the summer and with the disappearance of ice in the spring of some years. There is no evidence yet, however, that the lake is under any unnatural influence, which raises the question of whether Boulder County Open Space should support modification of the lake's natural but unwanted water-quality conditions.

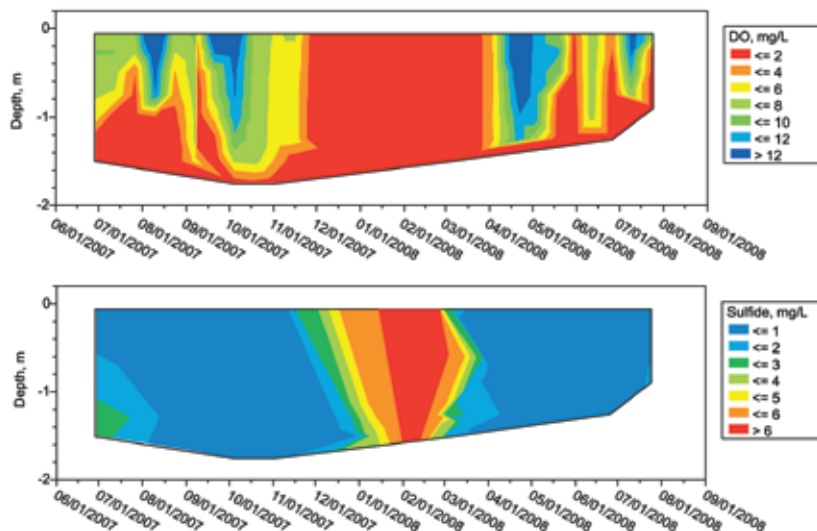
Little Gaynor Lake is unusual hydrologically, which goes a long way toward explaining its unusual behavior. It is a closed basin lake (endorheic lake), lacking a surface inflow or outflow. A small amount of groundwater appears to pass through the lake, but the weak hydraulic flushing causes the lake to accumulate sulfate. The lake is shallow but stratifies thermally during the summer. Surface waters of the lake during summer are dominated almost entirely by the cyanobacterial species *Anabaenopsis elenkenii* (figures above and below, right). During stratification, the lake rapidly loses oxygen (middle figure). Under these conditions, bacterial decomposers use sulfate as an electron acceptor for respiration, thus producing sulfide. Mixing of the lake, which occurs during intervals of cool or windy weather in late summer or spring ice out, brings the sulfide to the surface and allows the growth of the purple photosynthetic bacteria.

Seasonal pattern of oxygen and sulfide in Little Gaynor Lake.

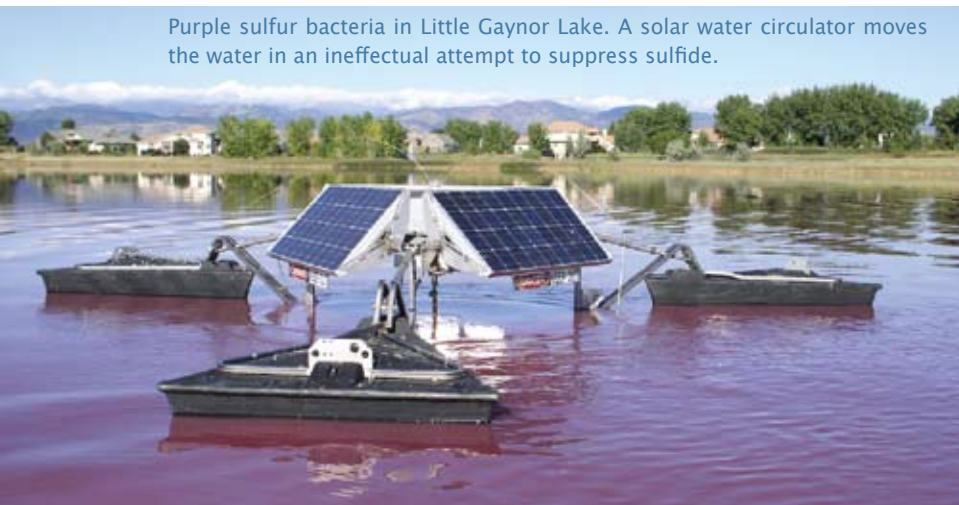
Gaynor Lake may be more than curiosity. The lake builds up large amounts of dissolved organic carbon (DOC, 100 mg/L) that originates primarily from rapid photosynthesis by *Anabaenopsis*. When light conditions are unfavorable during mixing or in winter, *Anabaenopsis*, unlike most types of algae, is capable of using DOC to support respiratory metabolism. *Anabaenopsis* alternately uses autotrophic and heterotrophic modes of metabolism, thus continuing growth even when light is weak or unavailable.

There is presently much interest in biofuel production. The focus has been on grasses and other terrestrial plants for biomass production, but there has long been some interest in unicellular algae. Perhaps *Anabaenopsis* has special biomass production potential because of its abilities to use two modes of metabolism, and to live in saline waters not useful for agriculture. The Limnology Center is currently studying these possibilities.

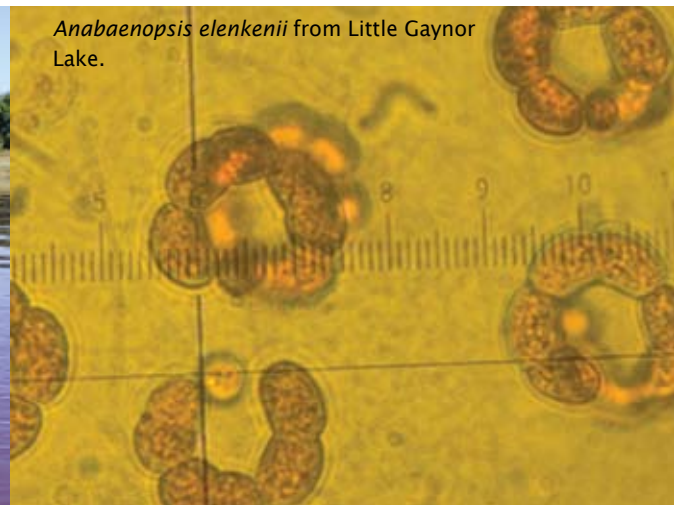
Dissolved Oxygen and Sulfide



Purple sulfur bacteria in Little Gaynor Lake. A solar water circulator moves the water in an ineffectual attempt to suppress sulfide.



Anabaenopsis elenkenii from Little Gaynor Lake.



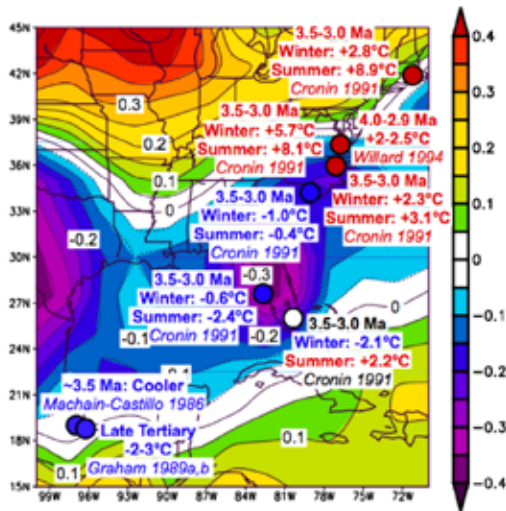


Peter Molnar

Demise of a Permanent El Niño-like Tropical Pacific Sea Surface Temperature Distribution and Climate Transition to Recurring Ice Ages

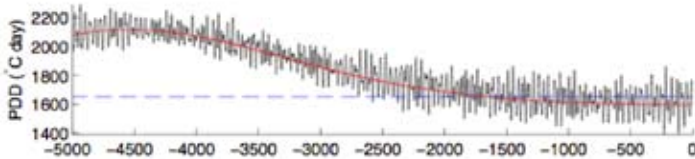
Peter Molnar devoted part of his research effort in 2007 to understanding what processes led to an Ice Age climate starting 3–4 Ma. Underlying this is the idea that before ice sheets advanced over Canada and Fennoscandia, and then retreated, the world was in a permanent El Niño state. Two studies examined which El Niño best represents that state, and how a permanent El Niño prevented ice ages.

Several studies have shown that the eastern equatorial Pacific Ocean was warm, almost as warm as the western equatorial Pacific at 3–4 Ma. Molnar and Cane (2007) examined climates around the globe in pre-Ice Age time and compared them with modern climates, and they found that in many regions, differences between Pre-Ice Age and present-day climates resemble El Niño teleconnections (figure at left, top). For some regions, and especially in the western hemisphere, teleconnections from nearly all El Niño events replicate (qualitatively) pre-Ice Age differences from present-day climates. Rain fell more over the western United States before 3–4 Ma; temperatures in the southeastern United States were lower than today; the Amazon Basin also seems to have been drier. For some regions, however, most El Niño events are associated with patterns that differ from the pre-Ice Age/present-day differences. For instance, Australia seems to have been moister before 3–4 Ma, but during most El Niño events, it becomes drier. The 1997–98 El Niño event and the Pacific Decadal Oscillation (PDO), however, show the opposite pattern; teleconnections from them show a slightly moister climate during that El Niño and during the positive phase of the PDO. The results in total suggest that the 1997–98 El Niño event, and not the canonical El Niño, provides the best prototype for the pre-Ice Age climate.



Map of composite annual temperature anomalies in °C from the southeastern United States and the region surrounding the Gulf of Mexico for nine El Niño years, 1957–58, 1965–66, 1968–69, 1972–73, 1982–83, 1986–87, 1991–92, 1997–98, and 2002–03, referenced against the mean monthly anomalies between 1968 and 1996.

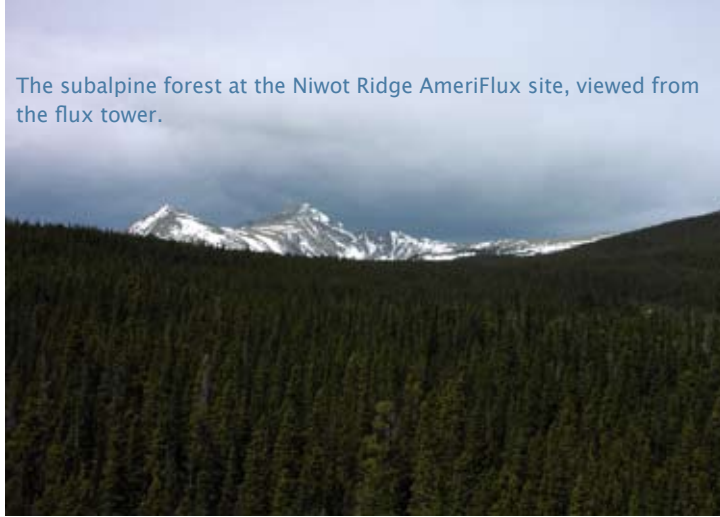
El Niño writes its signature on Canada largely in winter. Canada is warmer than normal in El Niño winters. Ice sheets, however, pay little attention to winter climates. Ice sheets advance when snow does not melt in summer, and they retreat when it does. So, how could an El Niño-like climate affect ice sheet growth and retreat? The simplest manner would be to lengthen summer. Huybers and Molnar (2007) exploited positive degree days (PDDs) during El Niño events to find a scaling between eastern Pacific SSTs and PDDs, and then showed that the warm eastern Pacific in pre-Ice Age time sufficed to prevent ice sheets from growing (figure at left, below).



Glacial implications of tropical cooling. Calculated average positive degree days for northern North America obtained by applying temperature perturbations expected to result from tropical anomalies (red) and also including orbital variations (black). For reference, the lowest number of positive degree days obtained by 2.7Ma is indicated (dashed).

The first study provides a simple explanation for a feature obvious to anyone walking through glacial terrain. The second places quantitative bounds on the conditions under which a climate change, past or future, might increase or decrease the erosion rate. The third focuses attention on an aspect often overlooked in erosion: the process of converting bedrock into sediment, which rivers then can transport. All three take steps toward understanding how erosion occurs, which is necessary if we are to evaluate how, and how much, erosion rates depend on the change from warm equable climates, before 3–4 million years ago, to cooler and more variable climates since that time.

The subalpine forest at the Niwot Ridge AmeriFlux site, viewed from the flux tower.



Russell Monson

Carbon Sequestration in a Front Range Forest

Funding: DOE, NSF

For the past 10 years, we have been monitoring the exchange of carbon dioxide from the top of a 27-meter tower at the Niwot Ridge AmeriFlux site, near the C-1 NOAA site. Our aims are to understand the principal controls over, and magnitude of, the exchange of carbon dioxide from the trees and soils of the ecosystem, as well as their response to interannual climate variation. Our site is one of more than 200 worldwide that function in an integrated network known as Fluxnet, which aims to provide fundamental insight and data to modelers using regional and global carbon budgets, particularly in response to future climate change. We have focused on the question of how this mountain forest ecosystem responds to an acceleration of the onset of spring. In this forest, the transition from winter to spring has occurred two to three weeks earlier, on average, during the past five decades, compared to earlier decades. This acceleration is a systematic component of climate change in the Colorado Front Range, and is expected to continue in the face of future warming trends.

During the past year, we modified the SIPNET ecosystem model to use evapotranspiration measurements from the flux tower and predict patterns of water use by the forest in predicted future climate conditions. We are now working with scientists at the National Center for Atmospheric Research in Boulder to generate projected daily weather patterns in the Colorado Front Range region for the year 2100. We will use these projections to examine the influence of declining snowpacks and modified summer rain regimes on CO₂ uptake by the subalpine forest ecosystem, which characterizes much of the western United States. Furthermore, we have initiated an effort to assimilate flux data from 20 forested sites around the world and use the SIPNET model to predict the impact of future climate change on carbon dioxide uptake by a broad range of global forest ecosystems.



Niwot Ridge AmeriFlux Site in the subalpine forest of the Rocky Mountains, Colorado with lodgepole pine, subalpine fir, Engelmann spruce, 3,050 m elevation.



R. Steven Nerem

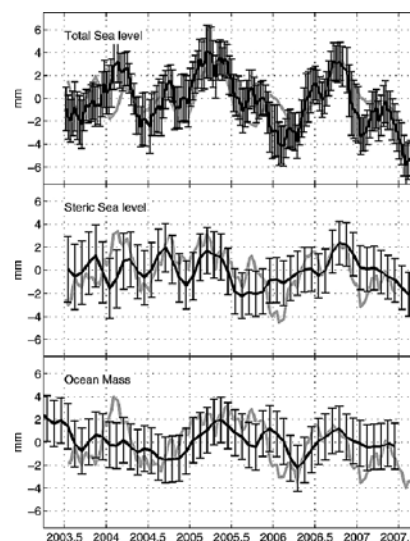
Satellite Observations of Present-Day Sea-Level Change

Observations of long-term sea-level change can provide important corroboration of climate variations predicted by models, and can help us prepare for the socioeconomic impacts of sea-level change. The TOPEX/Poseidon and Jason-1 satellites have observed an average rate of sea-level rise of 3.5 mm/year since 1993. The Jason-2 satellite was launched June 20, 2008 (below) and will continue the sea-level time series initiated by these earlier satellites. Current research efforts focus on determining the causes of sea-level change, relating the satellite record of sea-level change to the longer-term record from tide gauges, and predicting the magnitude and regional patterns of future changes.

From satellites, much has been learned in recent years regarding the contributions to the observed record of sea-level change. Of the observed 3.5 mm/year global averaged sea-level rise, approximately one-third is now thought to be due to the warming of the oceans (thermal expansion), one-third due to the melting of ice in mountain glaciers (~1 mm/year), and the rest due to other exchanges of freshwater with the continents, including ice melt from Greenland and Antarctica. The total rise is significantly greater than has been observed during the last 75 years from tide gauges (~1.8 mm/year).

During the last five years, a new technique has been developed that allows the direct measurement of the water distribution from space. The GRACE (Gravity Recovery and Climate Experiment) satellite mission has precisely measured temporal variations in the Earth's gravitational field since 2002. GRACE has demonstrated the ability to directly measure the change in mass associated with the melting of ice in mountain glaciers and ice sheets, which, in addition to other runoff, adds water mass to the oceans. On seasonal and interannual time scales, GRACE ocean mass estimates have been shown to compare quite well with estimates from satellite altimetry corrected for thermal expansion using shipboard measurements (figure at right).

Satellite altimeter and gravity measurements had a significant role in the formulation of the last IPCC climate assessment in 2007. Satellite altimetry has conclusively shown that sea-level rise has been higher during the last 15 years, compared to the last century. However, this could still represent decadal variability in the Earth system, and any further conclusions will have to await a longer time series of measurements. The record from the GRACE mission, while too short to detect climate signals, has demonstrated the ability to measure changes in the mass of the oceans and the mass of the polar ice sheets. Thus, as this time series becomes longer, it is expected that satellite gravity missions will play an equally important role to satellite altimetry in diagnosing the magnitude of sea-level change and its causes.



Global mean sea-level variability and its components, after removing seasonal variations and a trend. Total sea level (upper panel), the steric component, or thermal expansion, of sea level (middle panel), and ocean mass variability (bottom panel). Black lines show the observed estimates from the satellite altimeter, Argo floats, and GRACE, respectively. Gray lines show the inferred estimates, computed by adding or subtracting the other two observation estimates. Error bars represent random errors on the observed estimates. (Willis, Chambers, and Nerem 2008).



David Noone

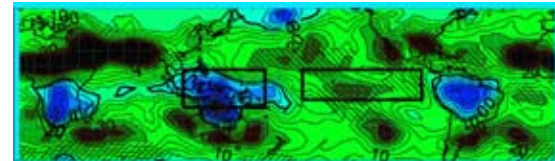
Evaluating Factors Controlling Low Humidity Air in the Troposphere in Collaboration with the NASA Jet Propulsion Laboratory

Changes in the atmospheric hydrologic cycle that accompany climate change are profound. Not only do changes in the precipitation patterns influence terrestrial and marine biosphere systems, but the changes in atmospheric water vapor abundance provide both the largest positive radiative feedback and the source of greatest uncertainty in climate projections. Possible expansion of the subtropics, which tends to make some temperate areas more arid, provides a link between the hydrologic regimes and the large-scale atmospheric circulations, yet the specific mechanisms that control the humidity of the subtropics remains uncertain. Two opposing hypotheses emerge to explain the low humidity of the subtropics: 1) dehydration associated with cloud microphysical processes, and 2) dehydration associated with mixing of dry polar air back toward the equator. Because the isotopic composition of water vapor differs, depending on which one of these mechanisms dominate, the importance of each of these mechanisms can be measured by knowing the isotopic composition of water vapor.

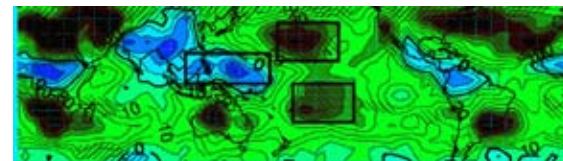
Observations of the HDO to H₂O isotope ratio (expressed as δD) of water vapor between 800 and 500 hPa from the Tropospheric Emission Spectrometer on board NASA's Aura spacecraft have been developed by our research group in CIRES and collaborators at NASA's Jet Propulsion Laboratory. We compared the isotopic composition of days with high relative humidity to the isotopic composition on days with the lowest relative humidity (figure at right). Where the isotopic composition is more negative with high relative humidity (e.g., western Pacific, tropical continents), we can conclude that the humidity is controlled by cloud processes. On the other hand, the subtropical ocean regions show that isotopes are enriched when the humidity is high, and this indicates the low-humidity air in these regions is due to mixing of air from higher latitudes. As such, we find that the dryness of the subtropical oceans is inherently controlled by the large-scale atmospheric circulation, and specifically the exchange of air between the subtropics and higher latitudes. This finding suggests that the explanation one finds in elementary textbooks for why the subtropics is dry is imprecise, and that that changes in the hydrology with future climate change will follow changes in the large-scale circulation of the atmosphere.



a) DJF Q4-Q1 difference in δD (permil)



b) JJA Q4-Q1 difference in δD (permil)



The difference in isotopic composition between days with high relative humidity (quartile 4, or Q4) and the days with low relative humidity (Q1). Negative differences result when water vapor is reprocessed by clouds in the form of evaporation of falling liquid precipitation and is prevalent in the western Pacific and over continents during the monsoon seasons. The largest negative differences are seen over the Amazon, Northern Australia and the Congo in December, January and February (a) and over India and Southeast Asia in June, July and August (b). Positive differences indicate that the lowest humidity values are associated with most depleted vapor, which results from the long history of dehydration associated with air masses from higher latitudes.

Roger Pielke, Jr.

The Climate Mitigation Challenge

Funding: NSF

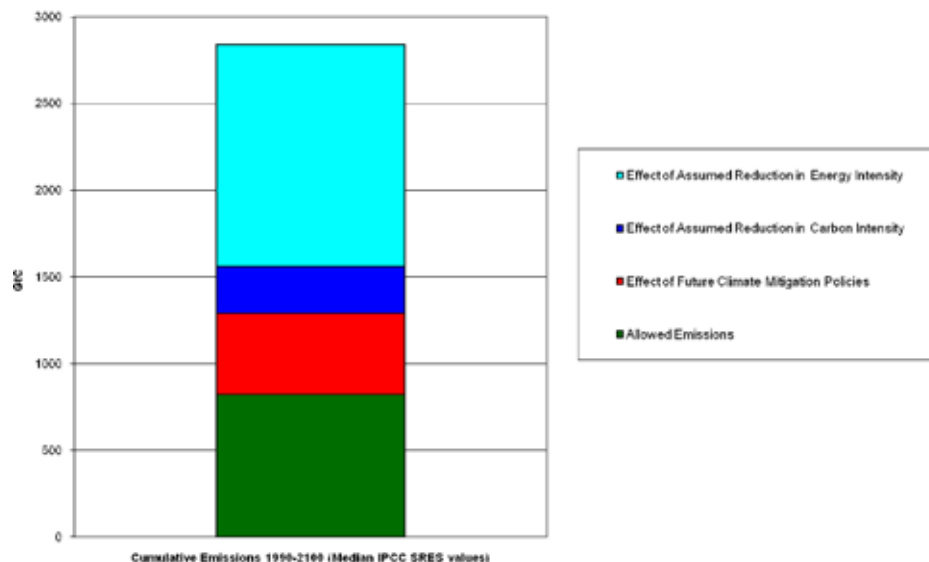
The challenge of stabilizing the concentration of CO₂ in the atmosphere may be much more difficult than currently realized. In a commentary published April 3, 2008 in *Nature*, Roger Pielke, Jr., Tom Wigley (National Center for Atmospheric Research), and Chris Green (McGill University) argue that the magnitude of the technology challenge associated with stabilizing the amount of CO₂ in the atmosphere may have been significantly underestimated by the Intergovernmental Panel on Climate Change (IPCC).

The reason for this underestimate lies in the assumptions of decarbonization common to all scenarios of future emissions growth used by the IPCC. These assumptions may be far too optimistic, and if so, will hide from view the magnitude of the technology challenge associated with stabilizing the amount of CO₂ in the atmosphere. In this commentary, the authors reveal these assumptions, and discuss their significance for policy making.

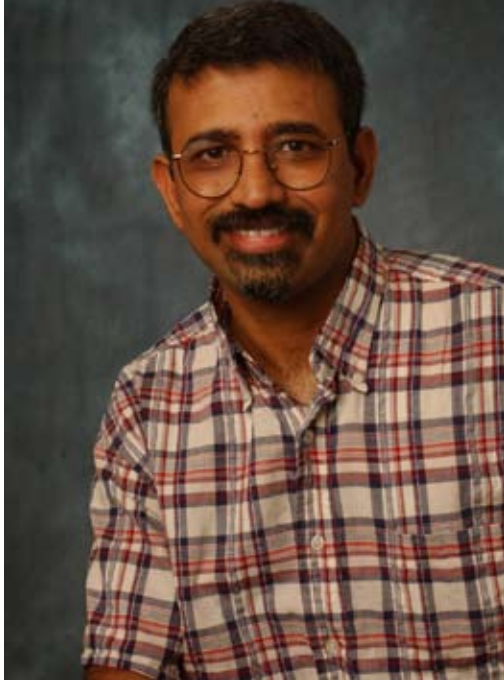
Indeed, the authors present evidence that the first decade of the 21st century has seen greater emissions of CO₂ than projected by IPCC, due to rapid economic development, particularly in Asia. In recent years, the world as a whole has begun to re-carbonize, breaking a long-term trend in which CO₂ per unit energy was assumed instead to continue to decline indefinitely.



IPCC Assumptions About The Effect of Technological Change on Future CO₂ Emissions



The IPCC Fourth Assessment Report median scenario value, the magnitude of emissions reductions 1990–2100 assumed to occur through automatic decarbonization of the global economy via autonomous reductions in energy and carbon intensities. A relatively much smaller amount of emissions reductions must then be achieved via climate policies to achieve stabilization of concentrations at, in this case, about 500 ppm carbon dioxide.



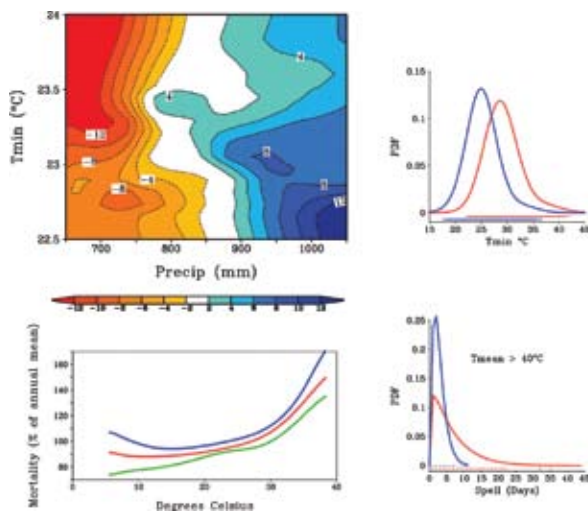
Balaji Rajagopalan

The Once and Future Pulse of Indian Summer Monsoon

Funding: NOAA and NASA

The subsistence of India's burgeoning population and the health of its emergent economy are intricately tied to the pulse of its monsoonal climate. Variability in agricultural output (about 22 percent of the Gross Domestic Product) is largely driven by year-to-year fluctuations in strength of the summer monsoon rains (June to September), accounting for the historical binding of Indian economic and social fabric to climate. We are thus compelled with more than academic interest to determine how human emissions of greenhouse gases may affect the future pulse of Indian monsoon rains. Temperature is rarely considered when assessing the historical vulnerability of India to climate, owing to the fact that India's subtropical geography has ensured great stability of its yearly temperatures—interannual swings are mostly less than 1°C. As such, rain rather than temperature has exposed underlying risks to Indian societal and agricultural concerns to date, but temperature increases can be detrimental to agriculture and human health sectors. In this research we investigate the future variability of the Indian monsoon climate—both precipitation and temperature—under a warmer climate, and its impact on society, using climate simulations from the IPCC suite of models.

Analyzing the monsoon rainfall from the IPCC suite of global climate models for the 21st century, we find that there is a potential for a slight increase in the rainfall (an ensemble average of about 10 percent) from the current mean rainfall of about 850 mm. This is associated with a reduction in the number of rainy days and an increase in the intensity of rainfall over many parts of India. Analysis of circulation fields suggests that the increase in rainfall is due to an increase and convergence of additional moisture over India due to increases in temperature and evaporation (IPCC Fourth Assessment Report). This is consistent with results from sensitivity experiments using individual climate models that also suggest enhanced thermodynamical changes acting to favor an abundance of monsoon rainfall.



Top left, rice yield change (in %) as a function of monsoon rainfall and average T_{\min} over India. Top right, PDF of T_{\min} from PRECIS simulation for the baseline (blue) and future (red). Bottom left, human mortality in New Delhi as a function of mean temperature (green, from cardiovascular causes; red, from respiratory causes; and blue, from other causes). Bottom right, PDF of mean temperature spells (in days) exceeding 40°C.

With regard to temperature, however, history may prove to be a poor yardstick for measuring potential impacts of anticipated future change on India. Our results show Indian temperatures during the late 21st century will very likely exceed the highest values experienced in the 130-year instrumental record of Indian data. This assessment comes with higher confidence than for rainfall, because of the large spatial scale driving the thermal response of climate to greenhouse gas forcing. Furthermore, a substantial increase in both day and night temperatures is indicated from the simulations.

We found that the societal impacts of the temperature increase can be potentially detrimental to socio-economic health. A non-linear relationship between all-India rice yields, rainfall, and minimum temperature was observed from the historical data. Specifically, lower yields under low rainfall are much more exaggerated under higher temperature. Thus, low rainfall years in future are likely to result in severe yield reduction. There is almost a +5°C shift in the minimum temperature in the future simulations, which is significant. There is also a significant increase in the spells with temperature greater than 40°C. This has a huge impact on human mortality as the mortality rate dramatically increases with a temperature of 40°C. With poor infrastructure and lack of air conditioning, this will place a heightened burden on the public health system.

Krishna Kumar, K., et al. (2008), The Once and Future Pulse of the Indian Monsoonal Climate, Proceedings of the National Academy of Science (PNAS), (in review).

IPCC (2007), Climate Change 2007—The Physical Science Basis Contribution of Working Group I to the Fourth Assessment Report of the IPCC (ISBN 978 0521 88009-1 Hardback; 978 0521 70596-7 Paperback)

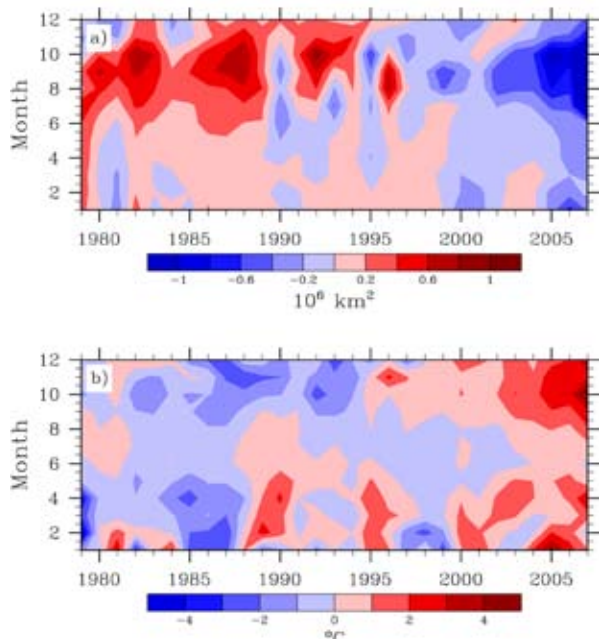


Mark Serreze

with Andrew P. Barrett, Marika M. Holland, Julienne C. Stroeve, and David N. Kindig

The Emergence of Arctic Amplification

A near-universal feature of global climate model simulations is that rises in surface air temperature (SAT) in response to increasing atmospheric greenhouse gas concentrations will be larger in the Arctic than in the Northern Hemisphere as a whole. This is known as Arctic amplification. Arctic amplification is projected to be focused over the Arctic Ocean. As the climate warms, the summer melt season lengthens and intensifies, leading to less sea ice at summer's end. In expanding open-water areas, summertime absorption of solar energy increases the sensible heat content of the ocean. Ice formation in autumn and winter, important for insulating the warm ocean from the cooling atmosphere, is delayed. This promotes enhanced upward heat fluxes, seen as strong warming at the surface and lower atmosphere. Arctic amplification is not prominent in summer itself, when energy is used to melt remaining sea ice and increase the heat content of the upper ocean—these factors limit changes in surface and lower atmospheric temperatures. Loss of snow cover contributes to an amplified temperature response over northern land areas, but this temperature change is not as pronounced as over the ocean.



Anomalies by year (x-axis) and month (y-axis) from 1979–2007 of (a) sea ice extent and (b) surface air temperature, both from the NCEP reanalysis, over the Arctic Ocean.

Satellite data available since 1979 document downward trends in Arctic sea ice extent in all months, most pronounced at end of the melt season in September. Starting in the mid 1990s, Arctic Ocean SAT anomalies turned positive in autumn, and have subsequently grown. Consistent with an anomalous surface-heating source, development of the autumn warming pattern aligns with the observed reduction in September sea ice extent (figure at left), and increases from the lower atmosphere to the surface. Recent autumn warming is stronger in the Arctic than in lower latitudes. There is no enhanced surface warming in summer. All of these observations are consistent with the emergence of Arctic amplification associated with declining sea ice.

All modern coupled global models show declining sea ice during the period of observations. While this is strong evidence of a role of rising greenhouse gas concentrations on the observed sea ice trends, few simulations show September's trend as large as is observed. While natural variability has certainly boosted the downward trends in ice extent, the emerging view is that the models, as a group, underrepresent the sea ice sensitivity to greenhouse gas loading. The Arctic amplification now emerging is, hence, but a harbinger of a more pronounced signal to appear in the near future.

Anne Sheehan

Boulder Creek Critical Zone Observatory: Geophysics

Funding: NSF

The Boulder Creek Critical Zone Observatory (BcCZO) is one of three CZOs set up by the National Science Foundation in the past year. The critical zone is the region that connects the atmosphere to the lithosphere, the zone that includes the surface of the Earth, vegetation, soils, and the bedrock weathering zone. The BcCZO is focused on characterizing the hydrologically active layers of the near surface environment, including the control weathering and transport processes have on the structure of the critical zone, and the impact of the critical zone structure on hydrological, geochemical, and biological functions.

Geophysical investigations are an important component of the Boulder Creek Critical Zone Observatory, and will be applied to determine depth to bedrock, layering, and characteristics of weathered rock and soil in three subcatchments of Boulder Creek. The goal of the geophysical investigations is to provide a three-dimensional image of the bedrock and soil layering surfaces, and constraints or estimates of subsurface physical properties throughout the three-dimensional model (density, porosity, fluid content, electrical resistivity, and seismic velocity). Pilot field studies during the summer of 2008 included shallow seismic refraction, ground penetrating radar, and electrical resistivity tomography in two of the subcatchments (Betasso and Green Lakes Valley). Results from the seismic refraction survey show layering of soils, weathered zone, and depth to bedrock. The weathered zone is thin-to-nonexistent at the high alpine sites, and is thick and well developed at the lower sites. The geophysics component of the Boulder Creek CZO project is collaborative between researchers at the University of Colorado at Boulder and Technische Universität München in Germany.



Seismic refraction data collection at Betasso (left) and Green Lakes Valley (right).



Robert Sievers

with Steve Cape, Chad Braun, Jessica Burger, David McAdams, Jessica Best, Sampada Joshi, Lia Rebets, and Nicolette Wolters

CIRES Aerosol Studies—Important Applications to Problems in World Health

Funding: Aktiv-Dry L.L.C.

Studies of atmospheric aerosols by the Sievers research group led to new methods of synthesizing aerosol microparticles. This processing method was patented in 1996 and has been applied subsequently by several pharmaceutical companies and vaccine scientists. The process consists of stabilizing microparticles of vaccines and pharmaceuticals, then drying and micronizing them to form fine respirable microparticles.

Aerosol scientists, physicians, immunologists, formulation experts, engineers, device designers, and others are working together to make a stable, needle-free inhalable vaccine to reduce deaths from measles (now about 1,000 per day). Because of their expertise in aerosol science, CIRES scientists have been invited to play a leadership role in an international collaboration to develop an inhalable aerosol of live, attenuated measles vaccine. Development through Phase I human trials is being funded by a grant from Aktiv-Dry LLC, as part of the Grand Challenges in Global Health Initiative. The inhalable vaccine is being developed specifically for the developing world.

Methods: The vaccine was supplied by SII (Pune, India). Candidate live and placebo formulations were dried from aqueous suspension to inhalable powder using the CIRES-patented process Carbon Dioxide Assisted Nebulization with a Bubble Dryer® (CAN-BD). Two patent applications have been filed by CIRES scientists Robert Sievers, Steve Cape, and Jessica Best.

Results: Vaccine delivery to mucosal surfaces has some significant advantages over subcutaneous injection into tissue. It is pain-free, and induces an immunogenic response in the respiratory tract tissues likely to become infected by wild measles virus in air. Virtually all liquid vaccines are less stable than corresponding dry powders. Consequently, substituting dry powder aerosols generated by human power without electricity needed for generating wet mists offers major benefits. Dry powder aerosols also offer the advantage that no water for injection or for reconstituting for wet mist administration is required. The cost target for the delivery system and vaccine is \$0.26 per dose, adjusted for inflation.

The team has successfully reformulated the commercial injectable lyophilized measles vaccine cakes into dispersible inhalable microparticles (in which myo-inositol was substituted for sorbitol) with large fine particle fractions less than 3 microns in diameter that can coat the respiratory tract, including the alveoli. The dry powder aggregate, upon dispersion in air from active dry powder inhalers and at-liberty inhalation, deposits in moist respiratory tracts where the microparticles rapidly dissolve within minutes. If proven safe and effective and introduced successfully into developing countries, the Serum Institute of India expects the demand for this CIRES-developed inhaled aerosol vaccine to be 300,000,000 doses per year, saving many thousands of lives.

Photo of new Dry Powder Inhaler (DPI) to deliver aerosols of vaccines and antibiotics to 1- to 5-year-old children.

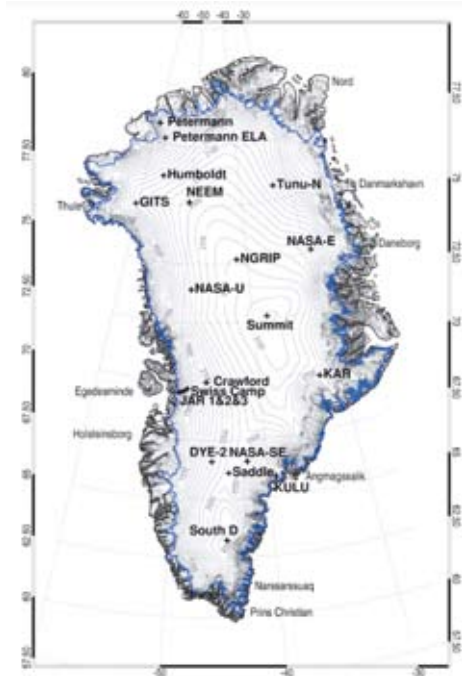


Konrad Steffen

Greenland Climate Network (GC-Net)

Funding: NASA Cryospheric Sciences and NSF OPP

The Greenland Climate Network (GC-Net) consists of 21 automatic weather stations (AWS) distributed over the entire Greenland ice sheet (map below). Eighteen stations are currently active, of which four stations are located along the crest of the ice sheet (2,500 to 3,200 m elevation range) in a north-south direction, eight stations are located close to the 2000 m contour line (1,830 m to 2,500 m), four stations are positioned in the ablation region (50 m to 800 m), and two stations are located at the equilibrium line altitude at the west coast and in the north.

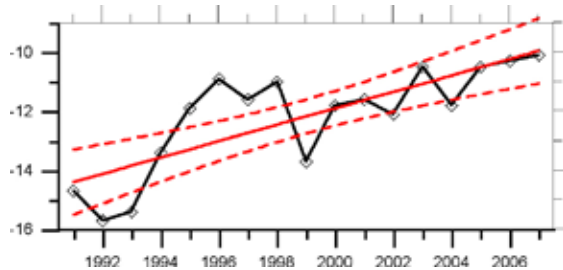


Greenland Climate Network (GC-Net)

The GC-Net was established in the early 1990s, with the intention of monitoring climatological and glaciological parameters at various locations on the ice sheet during a time period of 10 to 20 years. The first AWS was installed in 1990 at Swiss Camp, followed by four AWS in 1995, four in 1996, five in 1997, another four in 1999, one in 2002, one in 2003, and the latest one at NEEM (North Greenland Eemian Ice Drilling) in support of the new deep ice core in 2006. The objectives for the Greenland weather station network are to measure daily, annual and interannual variability in accumulation rate, surface climatology, and surface energy balance at selected locations on the ice sheet, and to measure near-surface snow density at the AWS locations for the assessment of snow densification, accumulation, and metamorphosis.

Data can be ordered for any of the GC-Net stations, including hourly mean values for 30 climate parameters per station, at the following web site: <http://cires.colorado.edu/science/groups/steffen/gcnet/>.

The mean annual temperature has increased by 4.3°C using a linear regression model as shown below. The minimum temperature in 1992 was the result of the aerosol loading caused by the Mt. Pinatubo eruption. The linear regression model at 95 percent confidence shows that the Pinatubo cooling and also the subsequent warming from the mid 1990s were outside the 95 percent level of confidence. The warming that occurred from 2000 to the present shows approximately the same trend as the 15-year time series. The warmest mean annual temperature recorded was -10.1°C, in 2007.



Swiss Camp mean annual temperature 1991-2007 (black) with a linear regression model (red) and 95% confidence levels (dashed red).



Margaret Tolbert

Laboratory Studies of Clouds and Aerosols

Funding: NASA and NSF

Cirrus clouds, composed of water ice, cover up to 30 percent of the Earth's surface at any time and sub-visible cirrus are almost always present in parts of the tropics. Cirrus and sub-visible cirrus clouds play an important role in the climate system as well as in controlling the amount of water reaching into the stratosphere. The clouds are usually optically thin in the visible, allowing most, but not all, sunlight to reach the Earth's surface. In contrast, the outgoing infrared radiation is efficiently absorbed by cirrus ice particles. While the net effect of cirrus clouds on climate is usually a

warming at the surface, the microphysical properties of the clouds dictate the overall climatic impact. The microphysical properties, in turn, depend on the nucleation mechanism of ice in the atmosphere.

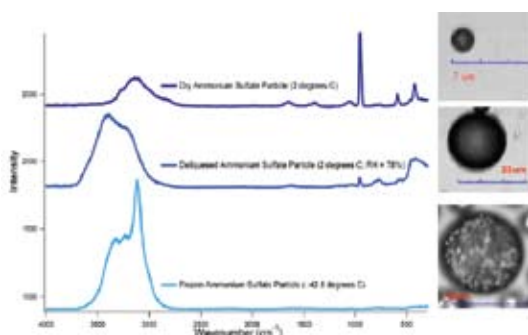
Laboratory studies in the Tolbert research group are using a novel Raman microscope to examine heterogeneous ice nucleation on a wide range of possible atmospheric aerosols including organics, minerals, sulfates, bacteria, and samples collected in the field. The left figure below shows microscope images of an ammonium sulfate particle exposed to increasing relative humidity at low temperature, along with Raman spectra of the individual particle composition. The top panel shows a dry particle at low relative humidity. The middle panels indicate that the particle has deliquesced to a larger liquid particle, while the bottom panel shows ice has nucleated on the particle. Ongoing studies will determine which types of particles are the most favorable for ice nucleation under a range of atmospheric conditions.

In addition to clouds, work in the Tolbert research group is focused on atmospheric aerosols. Atmospheric particles are a complex mixture of inorganic and organic compounds. Upon exposure to increasing relative humidity, the particles can grow through water uptake. Hygroscopic growth affects the optical properties of the particles, which, in turn, influences how the aerosols contribute to visibility degradation and climate change. The Tolbert research group, in collaboration with NOAA, is using cavity ring-down (CRD) spectroscopy to determine the dependence of optical growth on chemical composition of the particles. The right figure below shows a compilation of data for ammonium sulfate mixed with a range of different organics whose water solubilities vary from 0.5 to 72 percent. Surprisingly, all of the organic data can be reasonably fit to one growth line, dependent on the mass fraction of organic, but independent of the water solubility and functional groups on the organic. This result indicates that inclusion of the hygroscopic growth of mixed aerosols into climate models may be more straightforward than originally imagined.

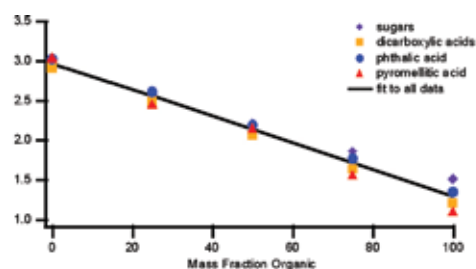


Titan, Mars, and Earth.

The Tolbert research group is also examining aerosol formation and heterogeneous atmospheric chemistry in the environments of Titan, Mars, and early Earth. For Mars, our studies focus on finding abiotic sources and sinks of methane to explain the mysterious observations of methane in the Martian atmosphere. For Titan, we are examining the optical properties of the aerosol haze that shrouds the moon to help establish the chemical composition and formation mechanism of the haze. Finally, for early Earth, our goal is to determine if a Titan-like haze is expected and if so, how such a haze would affect the climate and habitability of early Earth.



Particle images and Raman spectra during ice nucleation.



Hygroscopic growth as a function of composition.

Greg Tucker

How Do Rivers Respond to Growing Mountains?

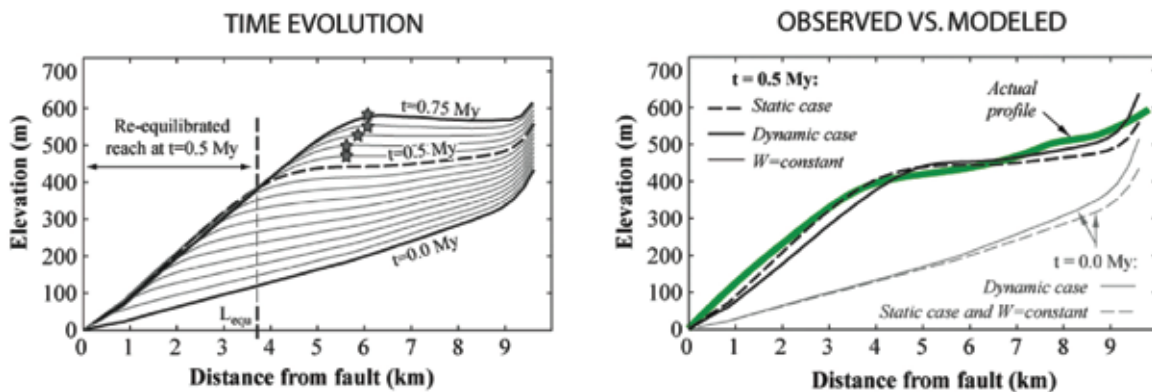
Funding: NSF, UK Natural Environment Research Council

Understanding the interaction between earthquakes, geomorphic processes, and mountain landscape evolution is important from a variety of perspectives, including natural hazard management. One way to discover the physics behind mountain landscape evolution is to study natural experiments in which nature provides enough control that we can test mathematical models. For the past several years, I have collaborated with a team from the U.K. studying a natural experiment in the central Apennines Mountains of Italy. Here, stretching of the Earth's crust has created a network of mountain blocks that are moving relative to one another at well-documented rates. We are examining how rivers in this region have responded to different rates and patterns of rock motion, and are using these data to evaluate mathematical models for landscape evolution.

Our international research team has compiled a database on rivers and fault blocks in the region. The database includes measurements of channel geometry and hydrology obtained from a combination of field surveys and analysis of digital elevation models, and it includes data from several types of fault block. Some have undergone steady vertical motion for two to three million years, and others experienced a three-fold acceleration in rate beginning about 750,000 years ago. Rivers on blocks with steady motion show typical concave-upward profiles with relatively uniform distributions of energy dissipation rate (stream power) and boundary shear stress. By contrast, rivers on accelerated blocks show dramatic steepening in their downstream portions, and pronounced downstream increases in stream power and shear stress, which is consistent with the type of transient response to accelerated fault motion that is predicted by some, but not all, of the current leading models for long-term channel incision. Thus, these findings are helping to elucidate the physics of long-term channel incision into bedrock.



CU-Boulder graduate student Scott McCoy collects samples for cosmogenic radionuclide analysis near the scarp of an active fault in the central Apennines.



Left: Time sequence of simulated river profiles; stars indicate back-tilting and deflection of drainage in upper catchment due to fault-block rotation. (Figures from Attal, Tucker, Whittaker, Cowie, and Roberts, 2008, *JGR-Earth Surface*.)

Right: Thick line shows longitudinal profile of a bedrock river channel on an active fault block whose motion accelerated during the Pleistocene period, resulting in steepening of the lower part of the channel. This is compared with computed profiles using both static and dynamic representations of channel width.



Veronica Vaida

Photoprocessing of Organic Acids in the Earth's Atmosphere

Funding: NSF

In the Earth's atmosphere, rapid oxidation of biogenic and anthropogenic emissions produces organic (acids, alcohols) and inorganic (HNO_3 , H_2SO_4) hydrophilic compounds that are key ingredients in aerosol formation and subsequent cloud nucleation, both of which significantly influence climate. Solar photons perform effective photo-reduction of atmospheric targets. The Vaida research group studies sunlight-initiated chemical reactions proceeding in the ground electronic state by excitation of a vibrational overtone state by visible red light in aqueous environments. This chemistry affects aerosol processing and nucleation.

Aerosols are globally distributed suspensions of small particles in air and known to influence climate through reflection of solar radiation and nucleating clouds. Organics partition to the water-air interface and have a profound effect on climate and chemistry in the atmosphere. Organics emitted from sources such as biomass burning create a coating on the sea surface and on aerosols.

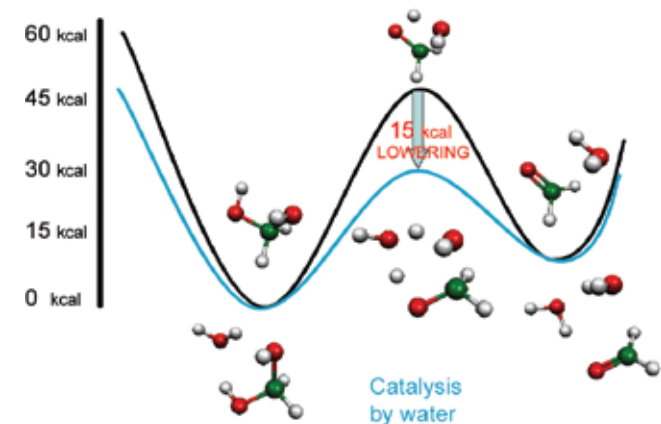
Dr. Vaida has demonstrated experimentally that light-initiated reactions occur in the ground electronic state of oxidized inorganic and organic species by excitation of vibrational levels. Especially challenging to understand are processes occurring in water environments, such as the surface of water and of aqueous atmospheric aerosols, yet recent experimental and theoretical results from the Vaida and Skodje research groups, at the University of Colorado at Boulder, point to significant changes in chemistry in the presence of water. This work continues with a combination of experiment and theory to understand the photo-reaction dynamics of organic acids and alcohols and the potential for water catalysis of these reactions.

The stability, partitioning, oxidative processing, and permeability of these organic films have been investigated in the Vaida lab. The results of these studies are used to explain recent field results, which show that the surfaces of collected aerosols are dominated by long-chain fatty acids. The effect of water on photochemical reactions are being investigated.

Miller, Y., R.B. Gerber and V. Vaida (2007).

Rontu, N. and V. Vaida (2007).

Takahashi, K., Z.C. Kramer, V. Vaida and R.T. Skodje (2007).



The reaction dynamics for methanediol. The blue trace reveals the significant lowering in the energy barrier when catalysis by water occurs compared to the black trace of the unimolecular reaction.

John Wahr

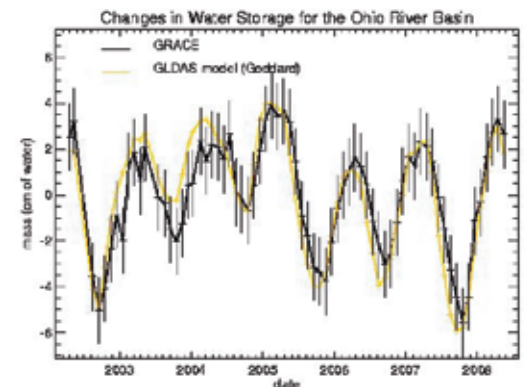
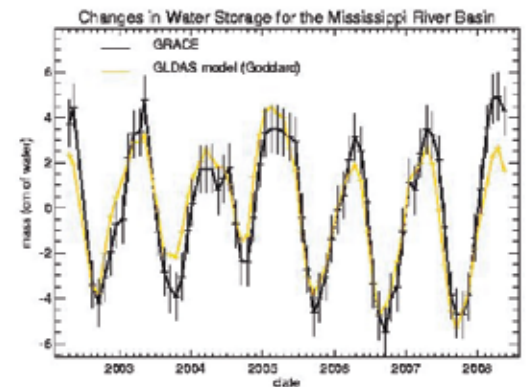
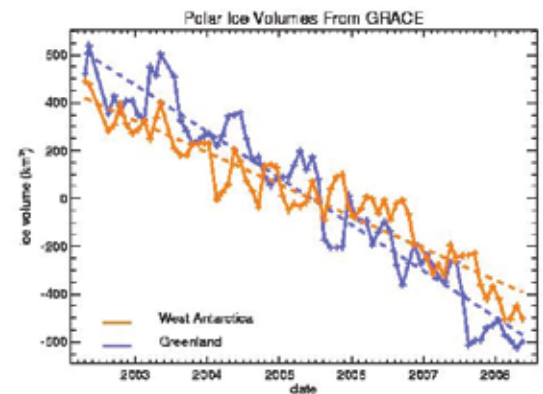
Time-Variable Gravity from GRACE

Funding: NASA/JPL, NSF

NASA, in partnership with the German Space Agency DLR, launched the twin GRACE (Gravity Recovery and Climate Experiment) satellites in March 2002. The ~13-year GRACE mission is mapping Earth's gravity field to spectacular accuracy every month. Time-variations in gravity can be found by removing the temporal mean field from these monthly maps. Since it is mass that causes gravity, this time-variability can be used to estimate month-to-month changes in the Earth's mass distribution. GRACE can recover signals at scales down to about 300 km.

We have been using these data to look at a number of geophysical signals, particularly those that involve the storage of water (including snow and ice) on continents and in the polar ice sheets. For example, because of its large effective footprint and its sensitivity to mass, GRACE offers the best available method for measuring the total mass balance of the polar ice sheets. The top figure at right shows monthly GRACE results for the mass variability of Greenland and the West Antarctic Ice Sheet, between April 2002 and March 2008. The best fitting trends, shown as the dashed lines, are -220 ± 40 km³/yr of ice for Greenland and -130 ± 20 km³/yr of ice for West Antarctica. The Greenland mass loss appears to have accelerated sharply starting in spring 2004.

For other land areas, the GRACE mass results provide the sum of water on the surface, in the soil, and beneath the soil layers, and so can be used to assess land surface water storage models. Before GRACE, there was no practical way of measuring total water storage at regional- to global-scales. The bottom two figures show monthly water storage variations for the Mississippi and Ohio River basins, and compares the results with output from the GLDAS/Noah land surface model (Rodell et al. 2004). The error bars on the GRACE results represent 68.3 percent confidence limits. Note that the errors are larger for the Ohio, reflecting the fact that the Ohio Basin is smaller than the Mississippi Basin. The agreement between GRACE and GLDAS/Noah is excellent for both basins, showing that the GLDAS/Noah model does a superb job of predicting water storage variations there; though it appears as though the model may have underestimated the Mississippi water/snow storage during winter 2008.



Carol Wessman

with Kendra Morliengo-Bredlau

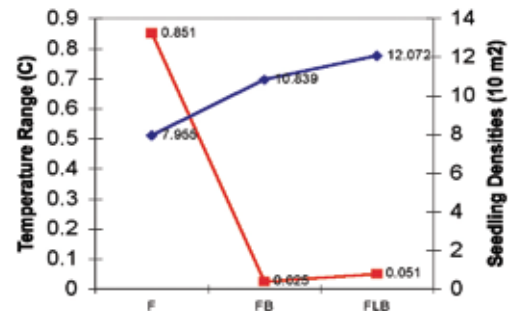
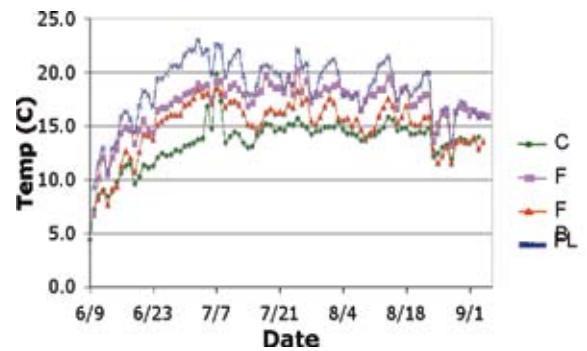
Ecological Resilience: Disturbance Interactions and Regeneration in a Subalpine Forest

Funding: CU's Ecology and Environmental Biology, CIRES, John Marr Memorial Ecology Fund

Non-equilibrium ecology suggests that the structure, composition, and dynamics of ecosystems are contingent on disturbance and management legacies. However, field observations do not yet provide compelling evidence for relationships described by some of the core concepts in non-equilibrium theory, such as the historical contingency of successional pathways.

This study focuses on mechanisms known to be important drivers of forest regeneration at landscape (e.g., recent disturbance history, fire severity, disturbance pattern) and local (e.g., biotic competition, microenvironment) scales. Our study site in Colorado's Routt National Forest recently experienced a series of catastrophic disturbances: a large blowdown in 1997, salvage-logging in 1999-2000, and a large fire in 2002. We are examining subalpine forest regeneration, using a combination of field observations, remote sensing, and geospatial analysis to determine whether compound disturbances increase landscape heterogeneity by creating conditions that vary widely in their ability to support and maintain conifer regeneration.

Our earlier work found that vegetation recovery, surveyed four years after the 2002 fire, is strongly influenced by forest disturbances that occurred within 5 years prior to the fire. However, we have found that the fire set nutrient and coarse woody debris differences to similar levels despite disturbance legacies. Our recent work shows significant differences between soil organic matter and soil temperature (figure at right, top), suggesting a legacy effect on soil physical properties. Landscapes that experienced multiple disturbances show extreme ranges in diurnal soil temperatures and little-to-no seedling (figure at right, bottom) establishment five years following the fire.



Average maximum surface soil temperatures (4-cm depth) in shaded areas increase significantly with additional disturbances (C = green intact, F = Burned, FB = Burned Blowdown, FLB = Burned Logged Blowdown). Open areas do not show significant differences in soil temperature (data not shown), however the ranges in diurnal temperatures are significantly higher in multiply-disturbed areas.

Seedling densities (which are marginally significant between treatments) show a distinctive negative relationship with increasing range in diurnal temperatures. Surface soil temperature extremes may amplify differences in rates of forest regeneration.

Tingjun Zhang

Global Soil Freeze/Thaw Detection (with Richard Armstrong and Rui Jin)

Funding: NASA Terrestrial Hydrology Program

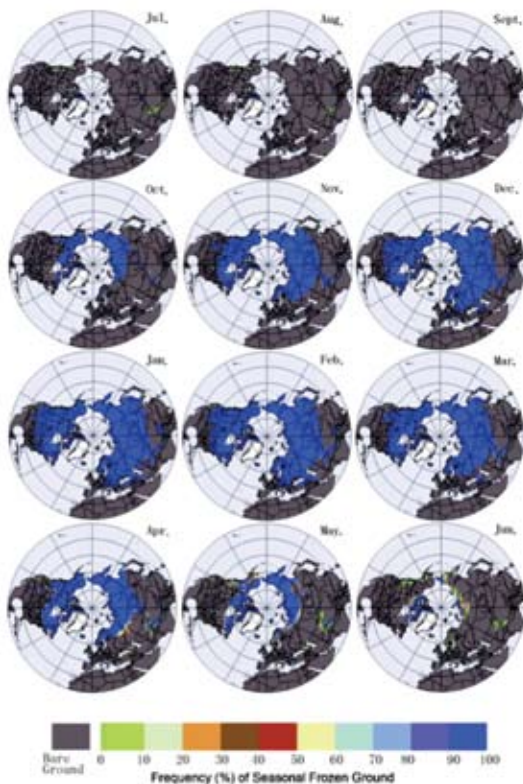
Understanding soil freezing and thawing processes and their interactions/feedbacks in the Earth system is essential for assessing variations in regional water cycles, ecosystem productivity, and processes that link the water, energy, and carbon cycles. The ultimate goal is to develop a comprehensive frozen soil algorithm to produce a blended daily global soil temperature at various depths and daily soil freeze/thaw depth using current and future satellite remote-sensing data, ground-based measurements, and numerical modeling.

As the first step, we have developed a combined frozen soil algorithm to detect the near-surface soil freeze/thaw status using passive microwave satellite remote-sensing data and numerical modeling (i.e., the NSIDC Frozen Soil Algorithm). The NSIDC Frozen Soil Algorithm consists of two parts: over snow-free land surfaces, a passive microwave satellite remote sensing algorithm was used to detect the near-surface soil freeze/thaw cycle; and over snow-covered land surfaces, a one-dimensional heat transfer numerical model with phase change was used to detect soil freeze/thaw status under snow cover. The NSIDC Frozen Soil Algorithm is accurate for frozen soil detection at about 76 percent, and approximately 83 for the correct classification of both frozen and unfrozen soils, with a percent error of about 17 percent.

We used the validated NSIDC Frozen Soil Algorithm to investigate the interannual and interdecadal variability of the timing, frequency, duration and number of days, and the daily area extent of the near-surface soil freeze/thaw cycle from 1988 through 2006 in the Northern Hemisphere. In general, the near-surface soil freeze/thaw, or seasonally frozen ground, is the largest in extent among all cryospheric components. In the majority of the middle-latitude regions, and certainly whole high-latitude regions, the near-surface soil experiences soil freeze/thaw cycle every year. Near-surface soils occasionally experience freeze in summer months over

high-elevation mountain areas. The long-term average maximum area extent of the near-surface soil freeze/thaw, including permafrost regions, is about 65×10^6 km² or 68 percent of the land mass in the Northern Hemisphere (figure at left). The absolute maximum area extent can be up to 76×10^6 km² or 80 percent of the land mass in the Northern Hemisphere.

Climatology of monthly area extent of the near-surface soil freeze in the Northern Hemisphere, from 1988 through 2006, detected using the NSIDC Frozen Soil Algorithm.



Scientific Centers

CIRES is home to five centers: The National Snow and Ice Data Center, the Center for Limnology, the Center for Science and Technology Policy Research, the Climate Diagnostics Center, and the Center for the Study of Earth from Space.

National Snow and Ice Data Center

The National Snow and Ice Data Center (NSIDC) supports research into our world's frozen realms: the snow, ice, glacier, frozen ground, and climate interactions that make up Earth's cryosphere. Scientific data, whether taken in the field or relayed from satellites orbiting Earth, form the foundation of the scientific research that informs the world about our planet and our climate systems.

NSIDC manages and distributes scientific data, creates tools for data access, supports data users, performs scientific research, and educates the public about the cryosphere. NSIDC has led the field of cryospheric data management since 1976. In 2007, the Center added new products to our online data offerings, which now total more than 600 datasets. NSIDC also played a leading role in International Polar Year (IPY) data management, and received continued funding plus several new awards to support IPY nationally and internationally:

- Discovery, Access, and Delivery of Data for IPY (DADDI)
- The IPY Data and Information Service (IPYDIS)
- The Exchange for Local Observations and Knowledge of the Arctic (ELOKA)
- Cooperative Arctic Data and Information Service (CADIS)

Researchers using NSIDC data products are assessing and monitoring changes in the cryosphere that may have profound effects on society. NSIDC scientists and staff help explain the importance of studying sea ice, snow, permafrost, glaciers, and ice shelves through lectures, interviews with journalists, educational presentations, and by providing online content. In 2007–2008, NSIDC delivered dozens of presentations to audiences around the world, and our research was featured on CNN, National Public Radio, the New York Times, British Broadcasting Corporation, and many other major media outlets. NSIDC continued to report on Arctic sea ice in the Arctic Sea Ice News 2007 blog, which provided up-to-the-moment scientific analysis and data imagery throughout the melt season.

NSIDC was honored to host former Vice President Al Gore for a private science briefing in October 2007. In addition, NSIDC participated in the Nobel Peace Prize-winning efforts made by the Intergovernmental Panel on Climate Change.

Research at NSIDC includes activities related to the cryosphere:

Ice sheets and glaciers: Glacier and ice sheet mass balance are key variables in the monitoring of sea-level rise. NSIDC scientists continued to update a map of Antarctica and have been documenting glacier movement rates in critical parts of the Antarctic and Greenland ice sheets.

Sea ice: Sea ice is important as an input to global climate models and as an indicator of climate change. The Sea Ice Index, developed by NSIDC to meet a need for tracking changes in real time, has followed declines in Arctic sea ice extent and area during recent years.

Permafrost and frozen ground: Changes in the extent of permafrost and frozen ground are important climate change responses that impact native communities, terrestrial ecology, and the infrastructure of northern lands. The carbon tied up in permafrost and frozen ground could affect the global carbon balance. Scientists at NSIDC are integrating in-situ data with numerical models to refine predictions of frozen ground extent.

Snow cover and snow hydrology: The extent and variability of seasonal snow cover are important parameters in climate and hydrologic systems, due to effects on energy and moisture budgets. During the past several decades, visible-band and passive microwave satellite imagery of the Northern Hemisphere has allowed NSIDC scientists to perform trend analyses, and to determine the response of snow cover to a changing climate.

Climate change in the cryosphere: Scientists working with near real-time monitoring of snow, sea ice, and vegetation under the Study of Environmental Arctic Change (SEARCH) program are making progress toward documenting that change, using approaches such as the Sea Ice Index.

Impacts of changes on Arctic peoples: The impacts of changes on Arctic peoples are being recognized and incorporated into research projects. An NSIDC scientist has been living in a community in northeast Canada, documenting the observations of and impacts on local people.

Programs/Projects:

NOAA@NSIDC and the World Data Center for Glaciology, Boulder: The NOAA project at NSIDC operates in cooperation with the NOAA National Geophysical Data Center and Arctic Research Office to extend the NOAA National Data Center catalog of cryospheric data and information products, with an emphasis on in-situ data, data rescue, and datasets from operational communities. In 2007–2008, NOAA@NSIDC added information for more than 35,000 glaciers to the World Glacier Inventory, and more than 1,200 glacier photographs to the Glacier Photograph Collection.

The Distributed Active Archive Center (DAAC): The NSIDC DAAC provides access to NASA's Earth Observing System satellite data, ancillary in-situ measurements, baseline data, model results, and algorithms relating to cryospheric and polar processes. The DAAC is an integral part of the multiagency-funded efforts at NSIDC to provide snow and ice data, information management services, and user support. In 2007, the NSIDC DAAC distributed 83.5 terabytes of data.

The Arctic System Science (ARCSS) Data Coordination Center (ADCC): During 2007, ARCSS ADCC received and processed 17 datasets. With the end of the National Science Foundation funding for the ADCC at NSIDC, operations were transferred to the National Center for Atmospheric Research/Earth Observing Laboratory (NCAR/EOL) in August 2007.

Antarctic Glaciological Data Center (AGDC): The NSF Office of Polar Programs funds AGDC to archive and distribute glaciological and cryospheric-system data obtained by the U.S. Antarctic Program. AGDC facilitates data exchange and preservation of both new and historic datasets.

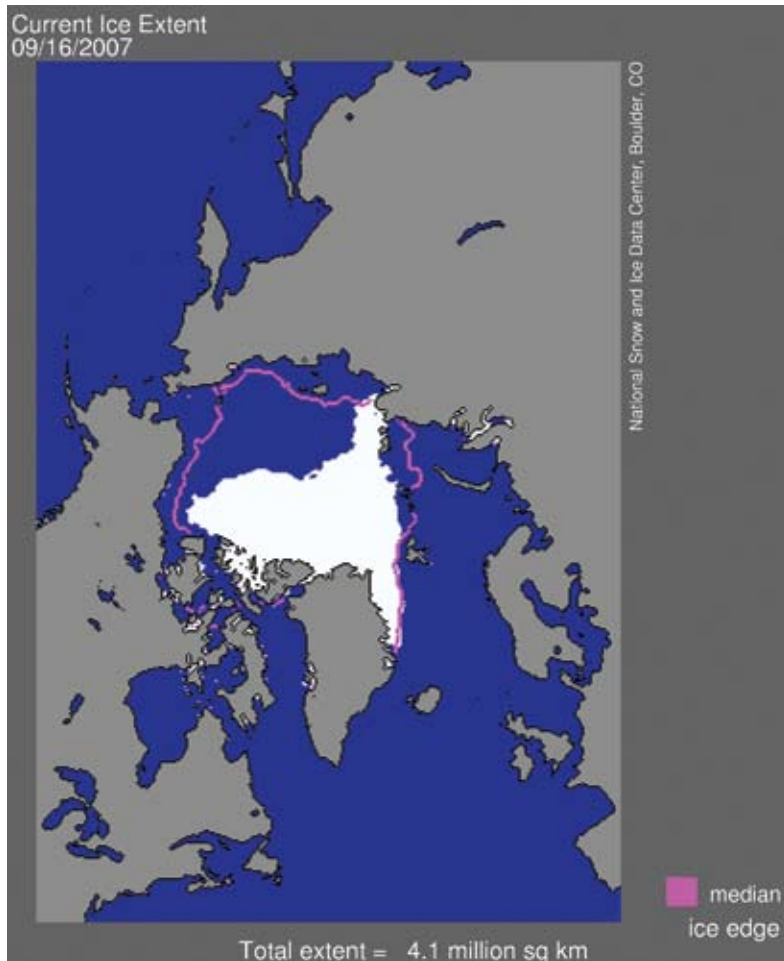
The Frozen Ground Data Center (FGDC): The FGDC is a collaborative effort between the World Data Center for Glaciology, Boulder, and the International Arctic Research Center to collect and distribute permafrost data. Funding for the FGDC ended in 2007, but NSIDC continues to archive and distribute FGDC data products.

Global Land Ice Measurements from Space (GLIMS): GLIMS, a cooperative project with more than 50 institutions worldwide, is designed to monitor the world's glaciers, primarily using satellite data from the NASA Advanced Spaceborne Thermal Emission and Reflection Radiometer instrument. More than 62,000 glaciers are now entered in the GLIMS database.

Arctic sea ice during the 2007 melt season plummeted to the lowest levels since satellite measurements began in 1979. The average sea ice extent for the month of September was 4.28 million square kilometers (1.65 million square miles), shattering the previous record for the month, 5.57 square kilometers, set in 2005.



The NOAA@NSIDC project added more than 1,200 photographs to the Glacier Photograph Collection in 2007. This project is digitizing historic glacier photographs like this aerial snapshot of Greenland's Giesecke Glacier, taken by the U.S. Coast Guard in 1969.



Center for Limnology

During 2007–2008, the Center for Limnology conducted research on the biogeochemistry of nitrogen, the importance of sediments in regulating nutrient content of lake water, sources of organic carbon for stream waters, and the effects of pine beetle–induced conifer mortality on the biogeochemistry of food webs in montane streams and rivers.

The Center for Limnology has developed the use of open channel methods for measurement of denitrification rates in streams and rivers. Denitrification is the process by which nitrate is converted to nitrogen gas in the absence of oxygen. The process is conducted by bacteria, which use the oxidizing power of nitrate to sustain respiration when oxygen is absent, thus producing a reduced form of nitrogen (N_2) as a byproduct. Denitrification is an important natural means by which excess amounts of anthropogenically derived nitrate are cleared from surface waters. The open channel method for estimation of denitrification is based on the estimate of N_2 diffusion from the surface of moving waters. Denitrification occurs within sediments, where oxygen may be absent, and the excess N_2 that is produced through denitrification is lost from the water surface. The open channel method uses empirical measurements of gas exchange rate based on propane exchange, coupled with measurements of N_2 concentrations within the water column of a stream or river, during 24-hour cycles to estimate the total diffusive loss of N_2 , which in turn allows computation of the nitrate conversion rate caused by denitrification.

In 2007–2008, the Center, through the work of Fulbright scholar Tara Higgins of Ireland, documented for the first time a new aspect of N_2 efflux from streams. Higgins and other Limnology Center personnel documented the loss of significant amounts of N_2 gas as bubbles (photograph below and figure opposite, top). The bubble (ebullition) losses must be measured along with the diffusive losses in order to produce an accurate estimate of denitrification.

During 2008, Center personnel, in collaboration with limnologists at the University of Utah, produced an invited paper on paradigm shifts in freshwater science. Drs. Lewis and Wurtsbaugh used this opportunity to present extensive evidence for serious flaws in the phosphorus paradigm for control of algal biomass in lakes. The phosphorus paradigm holds that phosphorus is the master controlling element because it is most likely to be depleted by plant growth. Mounting empirical evidence from many parts of the world, however, shows that nitrogen is as likely as phosphorus to limit algal growth (figure opposite, bottom). Thus, the synthesis by Lewis and Wurtsbaugh argues that the phosphorus paradigm must be discarded in its current form and replaced by an N–P paradigm. Although there is much resistance to this shift, given the long commitment to control of phosphorus as a means of controlling algae, it is likely that concurrent control of nitrogen and phosphorus in inland waters in the future will be viewed as mandatory for control of nuisance algal growth, and that ratios of N to P in natural environments will be shown to explain a large amount of the algal floristic variability among the lakes and streams in both natural and polluted environments.



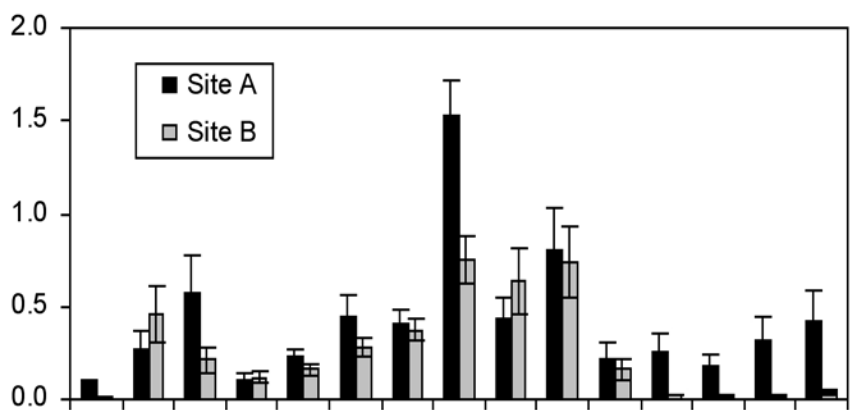
N_2 bubbles in the South Platte River.

During 2007–2008, the Center also embarked on a new study of carbon sources for streams. It has been established by terrestrial ecologists that the age of carbon in soils varies enormously. There is an annual supply of fresh carbon derived from newly decomposed or leached biomass, as well as a large inventory of older carbon. The Limnology Center is implementing a new method (accelerator mass spectrometry of ^{14}C) for determining the ratio of old carbon to new carbon in stream organisms. The hypothesis is that old carbon is very significant as a food source to stream organisms.

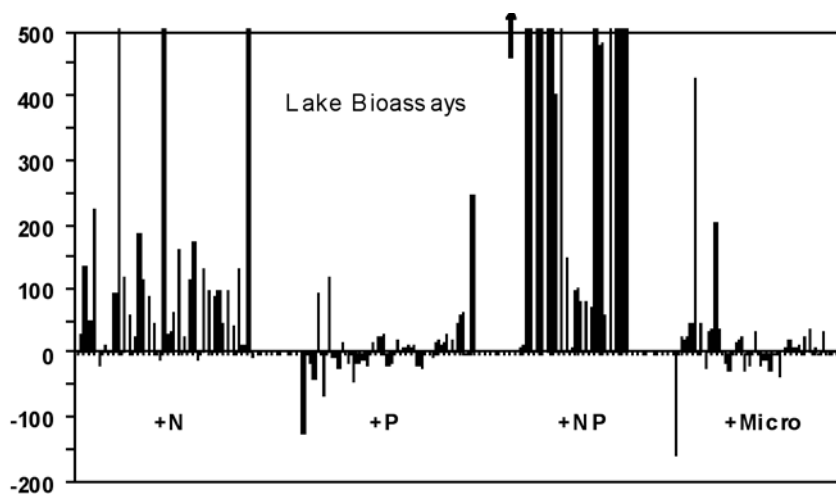
The Center for Limnology finalized its work led by Ph.D. student James Anthony on transfer of nutrients

from sediment to lake water in undisturbed or minimally disturbed lakes. The results show that nutrients (inorganic or small organic forms of N and P) not only emanate from sediments, but also may be taken up by sediments. Thus, the sediment surface equilibrates concentrations of critical inorganic nutrients in unfertilized lakes.

The Center has initiated a study of water-quality changes in montane Colorado that may be caused by massive mortality of lodgepole pine throughout the Colorado Rockies (photograph below). The study, which will be led by graduate students Leigh Cooper and Thomas Detmer, postulates the transfer of large amounts of nutrients from the terrestrial to aquatic ecosystems following tree mortality. The underlying mechanism is the role of plants in retaining nutrients within a terrestrial system.



Ebullition rates at two South Platte River sites.



An example of geographically distributed laboratory and field bioassays for phytoplankton responses to nutrients in lake waters.

Beetle kill of pine forest in the Colorado Rockies.



Center for Science and Technology Policy Research

Since 2001, the Center for Science and Technology Policy Research has contributed to both the CIRES goal of promoting science in service to society, and to the University of Colorado at Boulder's vision of establishing research and outreach across traditional academic boundaries. The Center serves as a resource for science and technology decision makers and those providing the education of future decision makers. Its mission is to improve how science and technology policies address societal needs. The Center fulfills these objectives through activities within the following four goals:

- Help the university educate the next generation of science and technology policy decision makers.
- Help make the nation's science portfolios more responsive to societal needs, examples of which include climate and global change, disasters, nanotechnology, biotechnology, and renewable or sustainable energy supplies.
- Provide means for people with differing perspectives to discuss research and practice related to science in its broader societal context.
- Build a sustainable, diverse, and productive policy institution at the university.

The Graduate Certificate in Science and Technology Policy, a rigorous educational program whose purpose is to prepare students pursuing graduate degrees for careers at the interface of science, technology, and decision making, is completing its fourth year. Eighteen students are currently

enrolled in the certificate program. They come from university institutes like CIRES and JILA and a variety of university departments, including Atmospheric and Oceanic Sciences, Computer Science, Environmental Studies, Geography, Geological Sciences, Journalism and Mass Communication, and Psychology, as well as the following engineering programs: aerospace, civil, chemical, and mechanical. Fourteen others have already completed the program. Program alumni have served on the staff of the House Science Committee, interned for the Office of Management and Budget, staffed a congressional office, and served in postdoctoral positions in science policy.

The U.S. Climate Change Science Program published "The North American Carbon Budget and Implications for the Global Carbon Cycle." Lisa Dilling served as co-lead of the author team. The report analyzes the amounts of carbon emitted by industry sector, the amount of carbon absorbed naturally, and the relationship of these amounts to the global carbon budget as influenced by other regions of the globe, with particular attention given to the certainty with which these budget elements are known.

Ben Hale, newly hired as an assistant professor in Environmental Studies, joined the Center last fall. Ben's expertise is in philosophy and ethics; he is adding humanities expertise to the Center. Lisa Dilling, who has been with the Center for the past few years as a CIRES visiting fellow, joined the Center as an assistant professor in January.

In honor of the 50th anniversary of the appointment of Dr. James Killian, the first presidential science adviser, Roger Pielke, Jr., published a commentary in the November 15 issue of *Nature* titled "Who Has the Ear of the President." He also appeared on National



Public Radio to discuss the *Nature* article and the past 50 years of science advice. Roger Pielke, Jr.'s *Nature* commentary, *Dangerous Assumptions* (with Tom Wigley and Chris Green), generated significant international attention since its publication on April 3. It has been cited, referred to, or commented on at least 68 times by media around the world.

Policy Center graduate student Elizabeth McNie, who recently received her Ph.D. in Environmental Studies, accepted a joint appointment at Purdue University as an assistant professor of Political Science and Earth and Atmospheric Sciences, and will be affiliated with the Purdue Climate Change Research Center. Graduate students Genevieve Maricle and Nat Logar also received their Ph.D.s this year in Environmental Studies, and are working as postdoctoral researchers at Arizona State University.

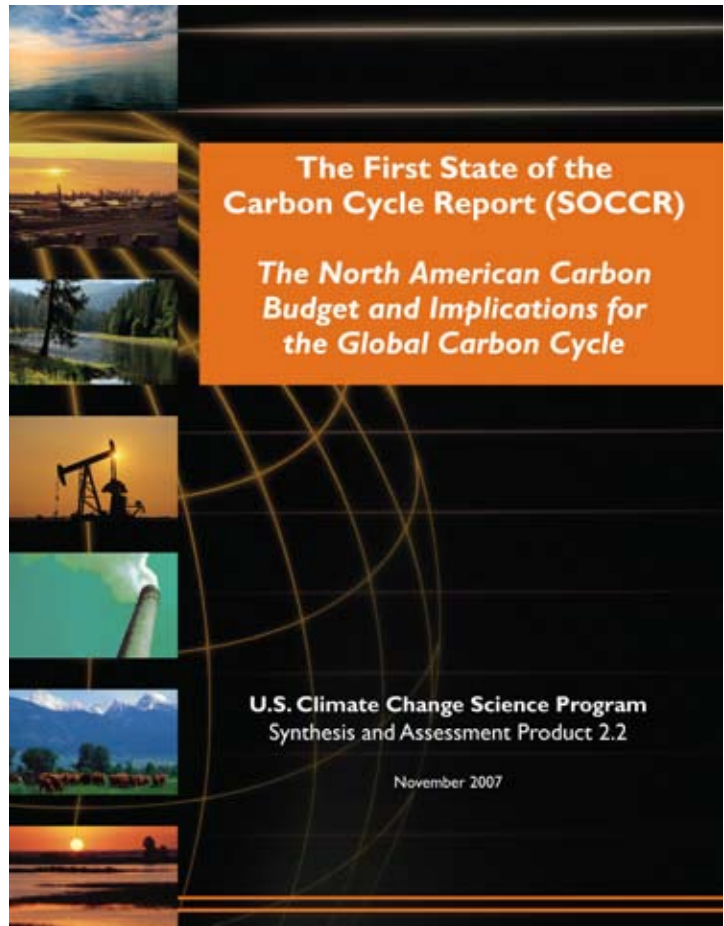
Center staff and students produced 32 peer-reviewed and non-peer-reviewed publications and gave 57 presentations at academic conferences and other events. The Center also hosted 15 talks by affiliates and visitors. Other Center outreach efforts include a quarterly newsletter, a briefing that is sent to more than 3,500 decision makers in Washington, DC and elsewhere, an extensive web site that is one of the most heavily trafficked web sites on the university campus, receiving more than 2 percent of all traffic on university web sites. (Besides the university home page and various housekeeping sites, only four university sites receive more web traffic than CSTPR.)

CSTPR also maintains a well-regarded science policy weblog that has been ranked in the top 0.02 percent of all weblogs by Technorati, a well-recognized authority on weblogs.

Policy Center Acting Director William Lewis testified at an oversight hearing before the House Committee on Natural Resources on July 31. The topic was "Crisis of Confidence: The Political Influence of the Bush Administration on Agency Science and Decision Making." Dr. Lewis testified about his experience as chair of the National Research Council Committee on Endangered and Threatened Fishes in the Klamath River Basin.

Lisa Dilling briefed Congress and members of the media in conjunction with the release of "The North American Carbon Budget and Implications for the Global Carbon Cycle."

Rad Byerly was appointed to serve a three-year term on the Colorado Air Quality Control Commission (AQCC). EPA has delegated to Colorado its legal authority under the Clean Air Act, and the AQCC is the rule-making body for the state. Through his vote on the commission, Dr. Byerly will be making decisions on regulations, based in part on scientific information, and bringing this experience back to the Center.



Climate Diagnostics Center

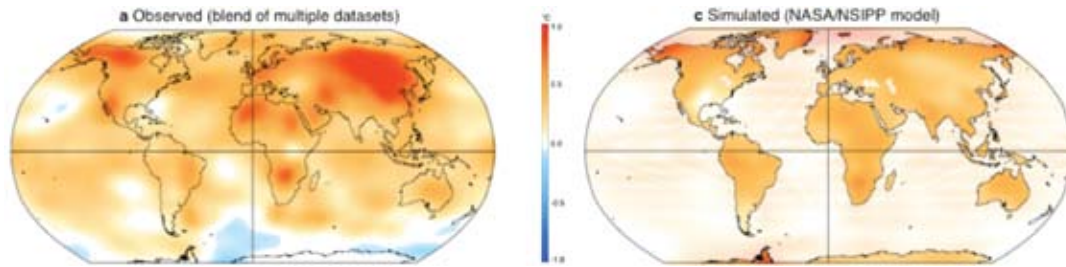
The mission of the Climate Diagnostics Center (CDC) is to improve our understanding of global climate interactions in order to improve regional climate predictions, and to train the next generation of climate scientists in advanced climate system diagnosis and prediction at both global and regional scales. CDC goals include establishing the causes of regional climate variations around the globe, on scales of weeks to millennia, by applying newly developed diagnostic techniques to global observations and model simulations; developing new observational datasets and performing new climate model integrations as needed for this purpose; and developing techniques to diagnose and reduce model formulation errors. Research disciplines include, but are not limited to, atmospheric sciences, oceanography, stochastic physics, remote sensing, numerical computational methods, computer sciences, data management, and complex systems analysis. The development of more skillful and useful climate predictions requires an integration of these disciplines so that advances in the understanding of processes governing climate variability can be applied to improve models and methods used for climate predictions.

In 2007–2008, 22 peer-review papers were published on a range of topics:

- Oceanic influences on recent continental warming.
- Interdecadal variability of El Niño–Southern Oscillation (ENSO) in the Intergovernmental Panel on Climate Change Fourth Assessment Report climate models.
- Forcing of tropical ocean variability from the North Pacific through oceanic pathways.
- The impact of rapid surface wind variability on air–sea thermal coupling.
- Sensitivity of ENSO period in climate models to the mean pycnocline structure.
- Tropical versus stratospheric influences on short-term extratropical climate variability.
- Characteristics of North American summertime rainfall with emphasis on the monsoon.
- An assessment of the multi-scale impacts of atmospheric heating variations in climate.

Scientific input was provided to several national and international programs:

- Providing leadership in the international Global Climate Observing System Surface Pressure Working Group to promote the development of long-term high-quality analyses of atmospheric surface pressure.
- Starting production of a 100-year global climate reanalysis based on ensemble data assimilation techniques, to produce high-quality products even with the sparse pre-radiosonde era observations. This effort will extend our ability to quantify climate variability, provide uncertainty estimates for climate detection, and aid attribution efforts to inform policy decisions.
- Developing new and improved existing climate prediction capabilities through enhanced understanding of dynamical processes and predictability of the principal interacting components of the climate system, on time scales of weeks to millennia, using observational and modeling approaches.

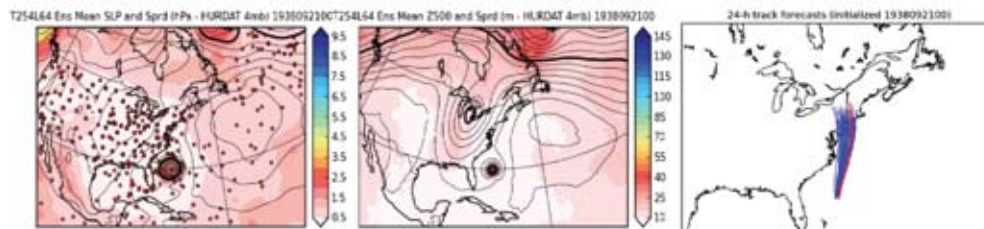


Observed (left panel) and simulated (right panel) recent surface air temperature change, shown as the 1991–2006 average minus the 1961–1990 average. The right panel shows the mean change in 23 NASA/NSIPP atmospheric model simulations with prescribed observed SST changes, but without any greenhouse gas or aerosol radiative forcing changes. In both panels, yellows and reds indicate positive values, while blues indicate negative values. The fields have been lightly smoothed to emphasize regional features (from Compo and Sardeshmukh 2008).

A recently published CDC study showed that the recent worldwide land warming has occurred largely in response to a worldwide warming of the oceans, rather than as a direct response to increasing greenhouse gases (GHGs) over land. In particular, it showed that atmospheric model simulations of the last half-century—with prescribed observed ocean temperature changes, but without prescribed GHG changes—can account for most of the observed land warming (figure above). Given the considerable noise/error in climate model simulations of the observed oceanic warming, this result highlights the importance of improving ocean temperature projections for improving regional climate change projections for the next century.

A unique capability was developed to produce high-quality daily reanalyses of the troposphere from surface pressure observations alone, using a data assimilation system based on the “Ensemble Filter” (Compo, Whitaker, and Sardeshmukh 2006). The combination of recently improved surface observational records, together with this data assimilation method, provides an exciting new opportunity to extend the reanalyses back in time, perhaps providing for the first time a three-dimensional reanalysis dataset of a century or longer.

The figure below illustrates the power of this Ensemble Filter reanalysis technique. It shows the principal features near the surface (left panel) and in the upper-troposphere (middle panel) of the September 1938 “New England” hurricane, the deadliest hurricane to strike the U.S. Northeast. The Ensemble Filter produces an analysis of the large-scale environment associated with this extreme event, including the upper-level trough (middle panel) which steered the hurricane to the unusual track northward along the U.S. East Coast. The objective and quantitative estimate of both the fields and their uncertainty (indicated by the shading) represents a new capability and resource for climate studies. The right panel shows the remarkable ability of the data assimilation system to generate a credible forecast of the track of this storm 24 hours in advance, reflecting the high quality of the upper-tropospheric steering currents analyzed in the middle panel. The Ensemble Filter is able to capture both the surprising northward track and the rapid advance of the storm.



High-resolution (~60 km, T254) reanalysis of the September 1938 New England hurricane for 1938 September 21 at 00 UTC (left and middle panels). Left panel, sea-level pressure. Middle panel, 500 hPa geopotential height. Shading indicates the uncertainty of the analysis at each location. The line contours indicate the most likely estimate of the “true” value. The 1,000 hPa (5,600 m) line contour is thickened, and line contour interval is 4 hPa (50 m). Red dots in the left panel indicate the location of surface pressure observations used in the analysis. Right panel, ensemble of 56 24-hour forecasts of the September 1938 New England hurricane track (blue curves), initialized from the ensemble of reanalysis fields associated with the left and middle panels. The red curve shows the observed track. (From Compo, Whitaker, and Sardeshmukh 2006).

Center for the Study of Earth from Space

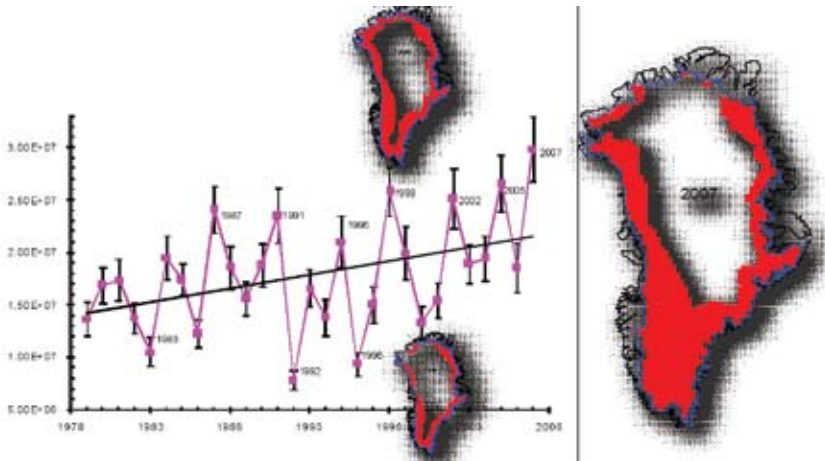
CSES was founded in 1985 to provide a focus for the development and application of modern remote sensing techniques used in the research of all aspects of Earth sciences at the University of Colorado at Boulder. The aim is to work on all scales of problems extending from technique development in small test sites to understanding pattern and process on regional and global scales. The laboratories are dedicated to both research and teaching. CSES had four faculty associates during FY07, 12 graduate students, and four post-doctoral and research associates. The primary areas of study at CSES include Arctic climatology, ecology, hydrology, and remote sensing. A long-term goal of CSES research is to investigate problems in global geosciences—questions of global change, in particular—through use of remote-sensing observations. Below, CSES accomplishments are summarized by topic.

Remote Sensing with Unmanned Aircraft Systems (UAS): At the end of the 2007 Greenland summer field season, researchers demonstrated the use of UAS to gather multi-mode scientific data over the ice sheets and surrounding glacially-carved valleys. Two UAS (below) and their sensors flew eight flights during the week of August 21, 2007, in the vicinity of Kangerlussuaq International Airport. This project was successful in many respects: it demonstrated that scientific UAS missions could be flown from the main International Airport in Greenland, proved the viability of UAS as a platform for synthetic aperture radar or other imaging sensors, showed that hyperspectral imaging of supraglacial lakes can be used for depth characterizations, and demonstrated how small

UAS can be launched and recovered in the Arctic environment. This project further illustrated that international cooperation can allow autonomous unmanned data-collection platforms to be used in the pursuit of new scientific knowledge. The combination of these attributes could be extremely useful in future satellite calibration and validation efforts, such as CryoSat 2.



Manta (left) and Silver Fox (right) UASs.



Melt climatology for the Greenland ice sheet derived from passive microwave satellite data for 1979–2007. Note that the 2007 cumulative annual melt area was 10 percent higher than the previous record in 2005.

Cryospheric Change: The annual melt signal in Greenland since 1979 is highly variable with a standard deviation that is 28 percent of the mean (figure at left). Error bars on the annual total melt area are computed for the first time based on the GC-Net air temperature record. The total melt area in Greenland has increased at 1.4 percent per year since 1979 (91 percent significance.) The record melt year in 2007 lies 10 percent above the previous high in 2005. The 1992 melt year, following Mt. Pinatubo's eruption, is the minimum melt year on record at two standard deviations below the mean, followed closely by 1996. Peak melt occurs, on average, on August 1. Increasing trends during July and August are largely responsible for the overall annual trend. The onset and duration of the melt season have not changed significantly.



Hydrology: In 2008, we completed the last phase of our Hydro-Kansas (HK) pilot project, which is a multi-investigator, multi-disciplinary, multi-institutional project to understand and predict floods in mesoscale watersheds. We installed 12 stream flow gauges at the end of complete Horton-Strahler streams and 14 rainfall-gauging sites in the Whitewater Basin. Rain gauges are being used in tandem with NEXRAD at Wichita for estimating space-time variable rainfall intensity fields. We extended the scope of HK by adding a riparian evapotranspiration component that overcomes the limitations of conventional approaches. A team of new researchers submitted a proposal to NSF in 2007, which was funded for three years in 2008.

Ecology: Rapid sequencing of severe, large-scale disturbances in subalpine forest (photo below)—such as wind throw, logging, and fire within a 10-year time span—appears to create extreme microenvironmental conditions that lead to spatially heterogeneous forest regrowth. Our work suggests that, while high severity fires appear to reset or equalize some landscape variables such as woody debris, legacies of pre-fire disturbance persist or are amplified in other properties, such as surface soil environment. Landscapes that experience multiple disturbances show extreme ranges in diurnal soil temperatures and little-to-no seedling establishment five years following the fire. This suggests a significantly delayed return to typically uniform subalpine forest, or a future landscape structure that is outside the normal variability expected with single disturbance events. Both conditions will influence carbon stocks and, potentially, regional biodiversity.

Climate Modeling: We had several publications in the last year examining the climatic effects of recent massive irrigation projects in India. This is a particularly interesting case of land surface changes due to human activity, because the changes occurred recently, and good observational records are available. Among our major conclusions, we found that irrigating India has reduced early-season monsoon precipitation, because the land surface cannot heat as quickly in spring. Early-season monsoon precipitation is vital for Indian agriculture. We also found that these changes in the land surface dominate other human effects such as atmospheric CO₂ or atmospheric aerosols.

Education and Student Opportunities: CSES acts as a focus for research, campus-wide, in the use of remote sensing for global geosciences studies. So far, master's and Ph.D. candidates from the departments of Anthropology, Geography, Geological Sciences, Electrical Engineering, Ecology and Evolutionary Biology, and the interdepartmental Geophysics Program have carried out thesis research in CSES. In fiscal year 2008, CSES



Area in the Routt National Forest, Colorado, that has experienced wind throw, salvage logging, and fire in the space of five years.

will begin development of a professional master's degree program in remote sensing. This formal program will organize and strengthen the remote sensing curriculum at the university.

Future of CSES: Professor Alexander F.H. Goetz, founding director of CSES, retired in 2006. Dr. Waleed Abdalati, formerly of NASA's Goddard Space Flight Center, has been hired to take over as CSES director, beginning July 1, 2008. We expect to expand the CSES research portfolio through the addition of research associates, professors, and students in a manner that will strategically position CSES to take full advantage of a range of opportunities in airborne and satellite remote sensing.

Education and Outreach

The CIRES Education and Outreach (EO) group extends the expertise of CIRES to meet community needs. The EO provides science education opportunities for educators, students, and scientists. Our work emphasizes scientific inquiry, links with current research, and promotes understanding of the foundational concepts in geosciences education. Examples of programs for educators include workshops and talks related to climate literacy and communications and science, and professional development related to cutting edge research. Programs for students include the National Ocean Sciences Bowl and courses for students underrepresented in science (in partnership with the Math, Engineering and Science Achievement (MESA) program). Programs supporting scientists include a scientist version of the “Making Climate Hot” climate communications workshop, and collaborations with scientists proposing geosciences research. New CIRES EO educational video products are available on the following topics: Arctic climate change, Tibetan Plateau uplift, and solar variability.

Climate Science Education

In 2008, CIRES EO led a series of workshops and events to support climate science education. One popular workshop “Making Climate Hot: Effectively Communicating Climate Change” provides research-based professional development in how to communicate climate change. Participants practice climate communication strategies, including ways to address controversy with the general public and in classrooms. The workshop is widely subscribed and has been provided for NOAA scientists, teachers, environmental educators, undergraduate students, interested citizens, and faculty. A second workshop offering continues our support of the NOAA-led Climate Literacy Framework. This workshop, “Climate 101,” provides an overview of the “Essential Principles and Fundamental Concepts” within the framework and takes each of the elements in more depth. During the past year, CIRES EO coordinated many climate-related events, including CIRES participation in the Focus the Nation “Teach-in on Climate Change,” EcoArts climate science and art events, and the International Polar Year Science Days.





Solar Science for Students and Teachers

CIRES' solar science outreach expanded this year to include several video products, a workshop for teachers, and after-school support of the MESA program for students under-represented in science. Video products are included in kits for use by teachers or scientists, and detail the making of the satellite instrument, a tour of the Laboratory for Atmospheric and Space Physics (LASP) facility, and basics of solar science. CIRES hosted the solar science portion of a weeklong workshop for teachers, which included a talk by NOAA researcher Terry Onsager, a tour of the NOAA Space Weather Prediction Center, Science on a Sphere, and hands-on work with solar science learning resources. The MESA program prepares students to pursue undergraduate degrees in science and other math-based disciplines, with a focus on students from groups under-represented in those fields. This work was funded through NASA as part of the LASP EVE satellite instrument project, scheduled to launch on the Solar Dynamics Observatory mission.

Mountain Mariner Challenge, National Ocean Sciences Bowl (NOSB)

The tenth annual NOSB Mountain Mariner Challenge drew 12 high school teams from four states for this fast-paced quiz bowl event. The Mountain Mariner Challenge is NOSB's regional competition, sponsored by the Consortium for Ocean Leadership. Poudre High School won the challenge for the seventh year in a row and traveled to Seward, Alaska to compete in national finals. Schools from Wyoming, Colorado, Kansas, and Nebraska participated in the only land-locked site of the 25 regional competition sites. More than 50 scientists and staff from CIRES, NOAA, and the community volunteer to make the event enjoyable and challenging for some of the most accomplished students in the region. For more on the Mountain Mariner NOSB competition, see <http://cires.colorado.edu/education/k12/nosb/about.html>.

Upward and Outward: Scientific Inquiry on the Tibetan Plateau

Upward and Outward, a film produced by CIRES EO and CIRES Fellow Peter Molnar, chronicles an international team of geoscientists as they conduct research on the Tibetan Plateau. The scientists seek to answer questions about the geology of the plateau, such as How did the Tibetan Plateau grow to be so large? They also want to understand how the plateau interacts with the atmosphere: How has the growth of the Tibetan Plateau affected climate patterns in China and the rest of the world? The film, along with teaching materials, is intended to help science teachers to teach the process of science as done by scientists. Through this film, teachers and students gain a realistic glimpse into the world of science, by following the scientific team as they pose questions, plan investigations, and gather and interpret evidence. Students see science as a process of human discovery, that requires collaboration and persistence and that is messy, creative, and fun. More information about the film and materials can be found at: <http://cires.colorado.edu/education/k12/TibetOwardUpward/index.html>.

Polar Visions

Polar Visions is a documentary film focused on the effects of polar warming in the Arctic. The filmmaker chronicles scientists who are studying the effects of thawing permafrost in northern Alaska and scientists who work to understand the increasing output from Greenland's glacier outlets. It also examines the effects of disappearing sea ice on critical local travelways. The film includes the perspectives of climate scientists, natives of Alaska and Greenland, and members of the American public. The film is intended for audiences from secondary school through early college.

Impact

The work we do extends the expertise of the Institute into the community to meet real needs. We help scientists increase their professional contributions through the development of science-literate citizens and students. Through these contributions, scientists reap the benefits of increased skills, enjoyment, and satisfaction in their profession. For more information on these or other EO activities, see <http://cires.colorado.edu/~k12>.

Visiting Fellows

With sponsorship by NOAA, CIRES offers Visiting Fellowships at the University of Colorado at Boulder. Every year, CIRES awards several visiting fellowships to scientists at many levels, from postdoctoral to senior. These fellowships promote collaborative and cutting-edge research. Since 1967, about 250 people have been Visiting Fellows at CIRES, including previous CIRES Director, Susan Avery, and current Director Konrad Steffen.



Malcolm K. Hughes

Ph.D., University of Durham, U.K., Ecology

Sponsor: Roger G. Barry

Title: *Is Tree-ring Response to Climate Changing, and If So, Why? Application of a Process-based Model to This Problem.*

Malcolm Hughes is in the business of “thencasting,” as he calls it. He predicts what past climates looked like using tree rings. Hailing from the University of Arizona’s Laboratory of Tree-Ring Research, Hughes visited CIRES during 2007–2008.

Until now, dendrochronologists like Hughes have used a straightforward statistical approach to relate tree rings to climate: the larger the ring, the more likely a favorable climate existed for growth. But Hughes calls this method “scientifically unsatisfying.”

“When looking at tree growth during the 15th century, is using the statistical relationship between growth and climate from the 20th century appropriate?” he asks.

Hughes wants dendrochronological methods to incorporate the internal growth processes at work in the tree. Key to this is testing and refining a model that describes the behavior of cell growth in the soapy layer under the tree’s bark. How many cells are there and of what size? When do the cells start multiplying and dividing? When does the new wood thicken up? These are the kinds of questions Hughes seeks to answer.

Once we understand the internal mechanisms at work in the tree, it will be easier to isolate the role of climate in shaping the tree’s growth, explains Hughes.

Hughes also suspects that some trees, especially at higher elevations, may be changing their relationship with the climate, growing more rapidly during the past 50 years than previously, with no obvious boost from increases in atmospheric CO₂ concentration. He and others have observed this unexpected growth spurt in bristlecone pines at high elevations in the White Mountains along the California–Nevada border.

During his year at CIRES, Hughes spent many hours up at Niwot Ridge, near Colorado’s Continental Divide, investigating high-elevation forests.

Rebecca Ivy Matichuk

Ph.D., University of Colorado at Boulder, Atmospheric Sciences

Sponsor: Fred Fehsenfeld

Title: *Simulations of Aerosol Emissions and Optical Properties Using a Transport Model and Comparisons to Observations during the 2006 TexAQS/GoMACCS Field Study*

The environmental effects of urban pollution near her hometown in the northern suburbs of Detroit, Michigan was all it took to convince Rebecca Matichuk to become an atmospheric scientist.



Today, she works with the Weather Research and Forecasting–Chemistry (WRF–Chem) model to improve our understanding of air pollution formation and the effects various aerosols have on climate. One of her specialties is developing and validating climate models.

“During the Texas Air Quality Study of 2006, satellite instruments observed dust from the Sahara Desert over Texas. Since these aerosols originate outside the model domain, I’m determining how these long–range transported aerosols should be treated in regional models, such as WRF–Chem. I hope the results improve the representation of aerosols in air quality models and help us understand how these aerosols impact the measurements and local aerosol distributions over Texas,” says Matichuk.

Matichuk wasn’t always an atmospheric aerosol modeler. She started her academic career doing fieldwork, collecting measurements of various aerosols and trace gases. This experience helps her bridge the gap between experimentalists and modelers, she says.

Matichuk has also made an effort to teach others about air chemistry and atmospheric science. As an undergraduate, she served three years as the Environmental Sciences Club president at the University of Michigan–Flint, organizing cleanups along highways and watersheds, planting trees, and even teaching elementary school kids how to take weather observations outside their classroom.

“The key is getting kids outside and exposed to the physical environment around them. This helps kids relate the topics discussed in class to reality or something tangible,” she says.

Matichuk plans to continue, and hopefully merge, these two endeavors. She would like to further advance aerosol measurements and modeling, while at the same time informing the public, and especially youth, about the importance of such work.

David P. Turner

Ph.D., Washington State University, Biology

Sponsor: Carol Wessman

Title: Integration of Remote Sensing and Modeling for Monitoring of Terrestrial Carbon Flux

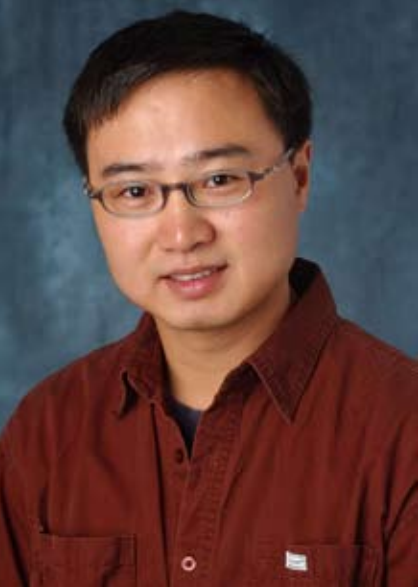
When Oregon decided to get a handle on the amount of carbon the state was producing and capturing, state official called in David Turner to help calculate the carbon budget. Turner, an associate professor at Oregon State University’s College of Forestry, models the flow of carbon between the atmosphere and terrestrial ecosystems, to help pinpoint exactly how much carbon dioxide is being produced or sequestered at any given place.

Carbon dioxide is a greenhouse gas and, according to Turner, understanding its natural sinks and sources can help direct climate change policy decisions.

Turner builds his landscape to regional–scale analyses on land cover information gathered from satellite–based observations. The remotely–sensed images give Turner geographic information about large–scale ecological disturbances, land cover type, and forest stand age, among other factors, all of which influence the uptake and respiration of carbon dioxide by plants and decomposer organisms.

While at CIRES during 2007–2008, Turner worked with Faculty Fellow Carol Wessman, a member of CIRES’ Center for the Study of Earth from Space, to incorporate new remotely–sensed ecosystem information into his carbon flux models. He also continued a long–term project to study the influence of deforestation on carbon fluxes in the Amazon Basin.





Hailong Wang

Ph.D., University of Illinois

Sponsor: Graham Feingold

Title: Large-eddy Simulations of the Impact of Aerosols on Turbulent Dynamics and Shallow Cumuli in the Trade Wind Boundary Layer

When Hailong Wang thinks about his research, he aims for the sky—literally. Wang wants to advance our understanding of how aerosols affect the global climate.

Aerosols can scatter or absorb light and also influence cloud formation by acting as a nucleus on which water condenses. But these aerosol-cloud interactions are still poorly understood, adding greatly to the uncertainty of predicting future climate scenarios.

Wang is demystifying these atmospheric interactions by modeling them using large eddy simulation (LES), a numerical technique used to describe turbulent atmospheric motion and cloud processes.

He believes LES models will also help explain how aerosols affect dynamic processes such as the vertical movement of air, as well as the vertical transport of heat and moisture in the atmosphere. Wang hopes to shed light on how aerosols influence the conditions under which clouds and precipitation form.

What inspired Wang to have his head in the clouds? He claims it was growing up in rural China, in the Anhui Province where his parents farmed for a living. “I was always curious about the weather, about drought and rains and how they affected the crops,” he says.

His passion led him to the University of Illinois, where he earned his Ph.D. in atmospheric science. Wang worked as a post-doctoral fellow with CIRES Fellow Graham Feingold during 2007–2008.



Sarah B. Wise

Ph.D., University of Colorado at Boulder, Evolutionary Developmental Biology

Sponsor: Susan Buhr

Title: Teaching Publically Controversial Science

When NSF GK-12 fellow Sarah Wise first began teaching biology to 8th grade students in Broomfield, CO, she found that evolution was not part of the curricular plan. “The middle school teacher I worked with had never taught evolution to her students in 10 years. She was worried about angry responses from parents,” says Wise.

Now, a Visiting Fellow with CIRES Outreach, Wise wonders whether climate change is another subject K-12 science teachers tend to avoid because of the publicly controversial nature of the topic. During her fellowship, Wise surveyed more than 300 K-12 teachers across Colorado to understand which social factors influence their choices about what to teach.

According to Wise, surveys about teaching evolution in the K-12 classroom are few and far between, and none to date have been published about teaching climate change. While working to understand which factors may affect teaching about climate change, Wise is also preparing educational resources for those teachers who are already enthusiastic about broaching the subject with their students.

“I’m interviewing teachers to find out what resources they need, and I’m organizing a climate outreach group with students and faculty at CU-Boulder to brainstorm new ways to get scientific information to teachers and the public,” says Wise.

Innovative Research Projects

The CIRES Innovative Research Program (IRP) encourages novel, unconventional, or fundamental research that might otherwise be difficult to fund. Funded projects are inventive, sometimes opportunistic, and do not necessarily have an immediate practical application or guarantee of success. This program supports pilot or exploratory studies, which may include instrument development, lab testing, and field observations to model advancement.

The 2007 funded projects are:

1. Optimizing a “green chemistry” bioprocess (Shelley Copley and Ryan Gill)
2. The fate of old carbon in stream ecosystems (William Lewis, Jr. and James McCutchan, Jr.)
3. Measurement of NO₂ by cavity ring-down spectroscopy (Eric Williams, Bill Dubé, and Steve Brown)
4. Using radio transponder tagged clasts to test fluvial sediment dispersion theory (D. Nathan Bradley and Gregory Tucker)
5. Should we care about a variable and noisy Sun? (Tom Chase)
6. New Doppler lidar using double-edge atomic absorption filter with a 3-frequency transmitter to study gravity wave excitation, propagation, and dissipation (Xinzhao Chu, Wentao Huang, and Mike Hardesty)
7. Improved hurricane forecasting (Xuguang Wang, Tom Hamill, and Jeff Whitaker)

1. Optimizing a “Green Chemistry” Bioprocess: Decreasing Toxicity to Microbes During Conversion of Naphthalene to 1-Naphthol

Shelley Copley (CIRES and MCDB) and Ryan Gill (Chemical and Biological Engineering)

Naphthalene is a polycyclic aromatic hydrocarbon found in crude oil and coal tar. It is a priority environmental pollutant because of its toxicity and mutagenicity. Microbes expressing the enzyme toluene 4-monooxygenase can convert naphthalene to 1-naphthol, a valuable chemical that is generally produced using environmentally damaging processes. More than 15,000 tons of 1-naphthol are produced each year in the United States alone. The bioconversion of naphthalene from contaminated soils to 1-naphthol offers the opportunity to both recoup part of the cost of bioremediation and to generate a commodity chemical via an environmentally benign process.

Unfortunately, the toxicity of 1-naphthol limits the efficiency of the bioconversion process. Dr. Gill’s research group has used a novel microarray technology called SCALES3 to identify genes that, when overexpressed, allow *E. coli* cells to resist the toxicity of 1-naphthol. One of these genes is *pspE*, which encodes a protein called thiosulfate sulfurtransferase. We will abbreviate this protein as PspE. The goal of this proposal is to elucidate the mechanism of this protective effect.

PspE is a mysterious protein. It is expressed when cells are subjected to a variety of stresses, including exposure to solvents such as ethanol and hexane, high temperatures, and infection by phages (viruses that infect bacteria). It has been shown to catalyze a reaction between hydrogen cyanide and thiosulfate, to make thicyanate and sulfite—but the KM (which corresponds to the concentration required to achieve half the maximal enzyme activity) for hydrogen cyanide is 27 mM, and for thiosulfate is 4.6 mM. Such high values suggest that catalysis of this reaction may not be the physiological role of the enzyme.



Furthermore, in the experiments carried out in Ryan Gill's lab, hydrogen cyanide and thiosulfate were not present in the reaction medium.

We are exploring two hypotheses for the mechanism of the protective effect of PspE. First, we are examining whether PspE converts 1-naphthol to a less toxic metabolite. This is being done by purifying the protein and determining whether it modifies 1-naphthol, and, if it does, identifying the product. Second, we are determining whether overexpression of PspE protects cells from perturbation of membrane properties by 1-naphthol. Partitioning of 1-naphthol into the hydrophobic membrane would be expected to alter membrane fluidity, and cells might compensate by altering the composition of the membrane lipids. We are analyzing the membrane lipids of cells exposed to 1-naphthol in the presence and absence of overexpressed PspE. We are also examining the effect of 1-naphthol on the proton gradient normally maintained across the cell membrane that is used to generate ATP and drive transport processes. The toxicity of 1-naphthol may be due to its ability to dissipate this proton gradient. If this is the case, we will determine whether overexpression of PspE allows cells to maintain the proton gradient in the presence of 1-naphthol.

An understanding of the mechanism by which PspE decreases susceptibility to the toxic effects of 1-naphthol would allow us to engineer strains in which this protective effect is optimized and would enhance the utility of the bioconversion process. It would also have broader significance because of this protein's role in response to other stressful processes.

2. The Fate of Old Carbon in Stream Ecosystems

James McCutchan, Jr. (CIRES Research Associate) and William Lewis, Jr. (CIRES Fellow)

In forested streams, carbon pathways are influenced by strong linkages between the terrestrial and aquatic environments. Shading by riparian forests limits photosynthesis by algae in many streams, but forests also provide a subsidy of organic matter (e.g., from terrestrial vascular plants) to stream food webs. Although some heterotrophs in shaded streams depend on algal carbon, most of the organic matter available in forested streams originates from terrestrial vascular plants.

Carbon derived from terrestrial vascular plants enters streams in particulate form (e.g., leaf litter and large woody debris) and as dissolved organic carbon (DOC). Some DOC is produced within streams, but recent studies have shown that much of the DOC in streams comes from the watershed and this DOC often is very old (i.e., it is derived from plants that grew thousands of years ago). Furthermore, the flux of DOC from the watershed far exceeds primary production in many streams. Few consumers in streams can assimilate DOC directly, but DOC assimilated by heterotrophic microbes can support production of higher trophic levels (e.g., invertebrates and fish). Stream ecologists have assumed that terrestrial DOC is unimportant to aquatic consumers. It is possible, however, that this abundant form of carbon in streams is an unrecognized source of trophic support for aquatic food webs.

Studies of soil carbon suggest that the lability of terrestrial DOC is strongly affected by temperature. Thus, the relative importance of terrestrial DOC to stream food webs may vary with latitude and with elevation. In addition, changes in climate and land use may affect the flux of DOC to streams, the quality of terrestrial DOC, and ultimately the carbon base for stream food webs.

Tests of atomic weapons greatly increased the level of ^{14}C in the atmosphere and this signal has been incorporated into plant biomass during the past several decades. Much older DOC exported to streams does not have the strong ^{14}C signal that is present in recently-fixed carbon, and ^{14}C decays over time. Thus, ^{14}C provides a means of tracing the fate of old versus new (recently fixed) carbon in aquatic ecosystems. Traditional methods of carbon dating require large samples, but new analytical techniques (i.e., accelerator mass spectrometry) have made it possible to analyze very small samples (e.g., $<25 \mu\text{Mol C}$) as would be required for analyses of DOC, microbial biofilms, and small invertebrates.

The objectives of the study were 1) to measure the ^{14}C -age of DOC from streams that span a range of latitude, elevation, land use, and disturbance history, 2) to test the assumption that "old" DOC of terrestrial origin contributes to heterotrophic production in running waters, and 3) to support the preparation of an NSF proposal for a larger study of the fate of "old" carbon in aquatic ecosystems.

Changes in climate and land use can affect the cycling of carbon in soils and also the quantity and quality of DOC delivered to running waters. If terrestrial DOC represents an unrecognized source of carbon for stream consumers, accelerated export of DOC to streams and changes in the lability of DOC may have a significant effect on stream food webs. Accelerated export of DOC to streams also may greatly affect the flux of CO_2 from running waters and the export of organic carbon to the world's oceans. If results of this study support the hypothesis that old terrestrial carbon contributes substantially to aquatic food webs, the results of the study will form the basis for a proposal to NSF.



Recent studies of ^{14}C by accelerator mass spectrometry demonstrate the potential to use ^{14}C as a tracer to follow carbon pathways in aquatic ecosystems, but ^{14}C has not previously been used for this purpose. This research builds on recent advances in terrestrial biogeochemistry and will enable a better understanding of the source and fate of terrestrial carbon in running waters.

The research is divided into three parts: sample collection, carbon dating of bulk DOC, and carbon dating of additional samples from selected sites.

Samples: Water, microbial biofilms, and benthic invertebrates are being collected from 15 streams in Alaska, Colorado, Maryland, and North Carolina. Sampling locations span a range of latitude and elevation, and also a range of watershed characteristics (e.g., land use and disturbance history). Streams in AK, MD, and NC were sampled once during summer; streams in CO were visited twice (once during early summer and once during fall). Bulk DOC is isolated from each water sample, and DOC also is separated into humic and non-humic fractions with XAD-8 resin. Samples of biofilm and invertebrate tissue from each site are dried and homogenized; these samples, along with the DOC fractions, will be stored pending results from Part 2.

Carbon dating of bulk DOC: Bulk DOC from each site is being analyzed for ^{14}C content ($\Delta^{14}\text{C}$) by accelerator mass spectrometry. Results of the preliminary analyses will be used to identify a subset of seven sites for additional analyses.

Carbon dating of DOC fractions, biofilm, and invertebrates: For each of seven sites identified in Part 2, the following samples are under analysis: humic and non-humic DOC fractions, microbial biofilm, and three samples of benthic invertebrates.

3. Measurement of Nitrogen Dioxide by cw Cavity Ring-Down Spectroscopy

Eric Williams (ESRL CSD and CIRES), Bill Dubé (CSD and CIRES), Steve Brown (CSD)

Our objective was to design and build a prototype instrument to provide versatile, fast-response, absolute, direct measurements of nitrogen dioxide (NO_2) in ambient air via the application of recently-developed techniques for high-sensitivity, direct absorption spectroscopy.

The accurate determination of NO_2 in ambient air is critical for understanding the photochemistry that produces ozone (i.e., photochemical smog) in the troposphere. Currently, the most widely used research technique is photolysis of NO_2 to nitric oxide (NO), followed by measurement of the increase in NO via chemiluminescence. While this technique is both accurate and sensitive, it has several limitations. First, it requires two independent NO detectors for high-frequency (i.e., 1 min or less) measurements of both

NO and the sum, $\text{NO} + \text{NO}_2 (= \text{NO}_x)$. Because the NO_2 measurement is the difference between two signals, it suffers from potential artifacts due to timing fluctuations and changes in background levels, particularly near the detection limit. Second, since the detection principle is the reaction of NO with excess ozone to produce electronically excited (i.e., luminescent) NO_2 , the instrument has requirements for compressed gases, corrosive materials (e.g., concentrated O_3), pumping capacity and exhaust gas disposal. The latter requirements also serve to increase the size, weight, and power consumption, making the instrument less versatile during field deployments (e.g., aircraft, ships, etc.). Development of a method for direct detection of NO_2 (i.e., not based on conversion to NO) would address many of these difficulties.

Recent advances in absorption spectroscopy using high-finesse cavities are directly applicable to the measurement of NO_2 , which has absorption bands throughout the visible region of the absorption spectrum. Cavity ring-down spectroscopy (CRDS) is one such technique. It is based on the measurement of the time rate of decay of light, intensity from an optical cavity (in the simplest case consisting simply of a pair of high-reflectivity mirrors) rather than on a change in light intensity over a fixed path length, as in conventional absorption spectroscopy. Its sensitivity comes from the long effective path length that the light travels within the cavity, which is on the order of 10–100 km. Its sensitivity and dynamic range allows for NO_2 detection over nearly its entire atmospheric concentration range, from mixing ratios = 0.05 to well over 100 ppbv, with a time response of 1 s or less. Because the instrument calibration is based on an absorption cross section, it is an inherently absolute measurement, although validation via the use of calibration standards will be an important component of the instrument development. The detection principle also allows an instrument design that is low-cost, lightweight, compact, and has low requirements for power, compressed gases, and hazardous materials relative to the standard photolysis-chemiluminescence method.

There has been considerable development of CRDS instruments based on pulsed lasers within the Chemical Sciences Division at NOAA, including a recent demonstration of NO_2 detection in the green (532 nm) that has been incorporated into an existing instrument for optical detection of other reactive nitrogen species. However, pulsed laser sources are relatively large and have high power consumption, making them cumbersome for use in field instruments. Furthermore, NO_2 detection in the green suffers from interference due to O_3 , which also has visible absorption bands. Recent developments in diode lasers make them attractive light sources due to their low cost, compact construction and low operating power. Diode lasers with performance characteristics suited to CRDS are now available at wavelengths in the blue region of the visible spectrum, near the peak in the NO_2 absorption. Detection of NO_2 in this region has the added advantage of removing the interference due to optical absorption by O_3 , which absorbs only weakly in this region. The main challenge to the use of such continuous wave (cw) light sources in CRDS is the suppression of interference effects that are inherent to the coupling of cw light source to high-finesse optical cavities. Several interference suppression techniques for CRDS with cw lasers have been reported in the recent literature, and their application to NO_2 detection have been an important part of this IRP research.

We are building a prototype instrument using a combination of components purchased through the CIRES IRP and components already available in our laboratory. We requested funding for the purchase of a diode laser, high reflectivity mirrors, detectors, associated electronics, a data acquisition computer and machining, and fabrication of custom mounting components. The laser is being constructed on an existing optical bench available for design and testing of optical systems within the CSD laboratories. Initial design of the optical system, characterization of the sensitivity and precision, calibration of the NO_2 absorption cross section using existing standards (already available at CSD), design and testing of a method for accurately zeroing the measurement, and assessment of potential interferences, are all taking place with the breadboard prototype.

The development of a small, fast, sensitive and versatile NO_2 detector will be of enormous value to existing field measurement efforts at NOAA. It may also open up the possibility for additional, new scientific investigations, some of which could be highly interdisciplinary. For example, the rapid time response of this instrument would make it applicable to the measurement of deposition fluxes for reactive nitrogen, which are of interest both to the atmospheric and the biogeochemical sciences. The small size might enable deployment in remote locations and on non-traditional platforms, such as light aircraft, balloons, and tall towers. The development effort is in itself highly interdisciplinary, bringing together expertise from the fields of laser spectroscopy, photonics, analytical chemistry, and atmospheric science. Finally, detection of NO_2 can be viewed as a means to further ends—development of this expertise within the NOAA and CIRES communities will likely lead to ideas for measurements of other atmospheric trace gases and/or optical properties of the atmosphere via CRDS and related techniques.

4. Using Radio Transponder Tagged Clasts to Test Fluvial Sediment Dispersion Theory

D. Nathan Bradley and Gregory Tucker

Contaminant transport and dispersion occur in environments ranging from the troposphere down to aquifers. A mathematical description of the motion of contaminants is critical to accurate hazard prediction and effective remediation. Many environmental pollutants travel in the solid phase, adsorbed onto sediment grains and transported by streams. For example, during the cleanup of the Rocky Flats Nuclear Weapons Plant, researchers found that plutonium and americium were not traveling in solution, but instead adhering to mineral grains and being transported by streams. Despite the critical environmental role of waterways, our understanding of the dispersion of fluvial sediment grains is rudimentary. We are developing a novel method of tracking sediment to test a recently developed hypothesis about the nature of fluvial sediment dispersion. Verifying this hypothesis will contribute to a quantitative description of contaminant transport, and represents a step towards a statistical model of sediment transport that is important to applications such as cosmogenic radionuclide budgeting and grain weathering.

Some form of the familiar advection-diffusion equation (ADE) is typically applied to describe the transport and dispersion of contaminants, but there is evidence that this approach is not always adequate. Studies of the dispersion of pollutants through heterogeneous aquifers have shown that the ADE often does a poor job of predicting the spatial distribution of the contaminant and the temporal evolution of the contaminant plume. Chemical tracer plumes often exhibit a peak concentration and a long leading tail that are very poorly described by the ADE. This type of behavior is typical of transport in heterogeneous porous media, and is known as anomalous dispersion. Anomalous dispersion occurs in a variety of dispersive systems, and there are theoretical and empirical reasons to believe that anomalous dispersion of sediment grains may be common in stream networks.

In the 1960s, the U.S. Geological Survey tracked the motion of radioisotope-tagged sand in the North Loup River, Nebraska. Results were very similar to those from tracer tests in a heterogeneous aquifer from the Macrodispersion Experiments (MADE) in Mississippi. Observed concentrations differed from the model in the same way that the MADE results differ from the ADE-based model. The peak and the downstream tail of



the plume both contain a higher fraction of the tracer material than the models predict. These models would under-predict the hazard from a highly toxic contaminant.

Recent theoretical work also supports the hypothesis that fluvial sediment dispersion may be similar to the anomalous dispersion of contaminants in groundwater if the likelihood that some particles become trapped in sedimentary deposits for long periods of time is sufficiently high. If this is the case, a mathematical description other than the ADE may be required to adequately predict the distribution of a contaminant.

The simplest and most direct way to test this hypothesis is with a time series of the positions of uniquely identifiable tracer particles. Because anomalous dispersion is most evident in the tails of the spatial distribution, an experiment like this requires thousands of tracers and a high recovery rate. Until recently, this has been difficult in a long-term study because tracers such as magnetically tagged stones must be dug out of the streambed to be identified. The recovery process is time consuming and it disturbs the system we wish to study.

Passive Integrated Transponder (PIT) tags are a relatively new technology that have been used extensively to monitor migrating fish but only recently as tracers in fluvial systems. A PIT tag is a passive radio transponder encased in small (~3 cm) cylindrical glass case. When the antenna on the detection system passes nearby, the electric field generated by the antenna induces a current in the tag that gives it enough power to transmit its unique identification number to the receiver. Depending on the size of the antenna, the detector has a lateral range of about 1 m and can detect buried tracers down to a depth of about 1 m. Manufacturers estimate that PIT tags will function for 50 years.

We are conducting a pilot study of the feasibility of using PIT-tagged clasts as tracers of fluvial sediment dispersion. We implanted PIT tags in about 1,000 rocks and released them in Half Moon Creek, a small gravel bed river that drains Mt. Elbert and Mt. Massive, southwest of Leadville, Colorado, that has been extensively studied. We obtained the necessary detection equipment and relocated the tracers after each high-flow event during the course of the study. We are evaluating 1) the optimal technique for preparing a large number of tagged particles, 2) antenna design and tuning and other strategies for maximizing recovery rates, and 3) strategies for surveying the tracer position in the most efficient manner.



5. Should We Care about a Variable and Noisy Sun?

Tom Chase

A time series of the observed solar constant shows significant natural variability and structure in the solar energy reaching the top of Earth's atmosphere. Observations include a quasi-sinusoidal sunspot cycle at approximately 11 years, with higher-frequency variability superimposed. This higher-frequency variability itself has structure, with higher amplitudes at the crest of the sunspot cycle, and lower amplitudes in the troughs. There is also a great deal of random variability (noise) imposed on the more ordered fluctuations, which is evident in the observation that no single fluctuations are exactly alike. The maximum amplitude of these variations is approximately 6 W/m^2 which can be compared to the current radiative forcing due to anthropogenic greenhouse gasses of approximately 2.3 W/m^2 .

Interestingly, even the most complex climate models still use a constant measure for the amount of solar radiation reaching the top of the atmosphere, an average of the time series often put at about $1,366 \text{ W/m}^2$. This is for two reasons. First, it has been assumed that the variability and noise in the solar constant would average out over time—it is not until recently that the field of non-linear geophysics has developed an appreciation of the role of stochastic processes. Second, climate models were very expensive to integrate, and the large ensemble simulations necessary to characterize the effect of this variability were too costly to attempt.

Recently, there has been evidence—from theory and from examples from simple non-linear models—that variable and stochastic processes have a strong influence on the climate statistics and need to be more completely included in model simulations. For example, the addition of simple white noise to a model of ENSO has been shown to greatly amplify model variability.

My objective was to test the hypothesis that variability and noise in the solar constant will significantly affect climate model statistics both in the average state and in the variance of circulation patterns (e.g., the North Atlantic Oscillation).

I am using the Planet Simulator, a well-known, low-resolution, three-dimensional General Circulation Model (GCM) developed at the University of Hamburg to examine noise and variability in its solar constant on the simulated atmospheric circulation. It is computationally inexpensive but includes all key elements of a full GCM, including all feedback processes such as ice albedo and water vapor feedbacks. It includes enough complexity to reasonably reproduce the observed atmospheric circulation and precipitation patterns, and it is simple enough to be useful for examining large ensembles of simulations, which is vital for bracketing the range of model variability. For example, a 125-year simulation can be run overnight on our local Linux machine.

I am examining this question in three steps. First, by adding a white noise generator (equal power at all frequencies) to the solar constant, and then by introducing an idealized red noise generator (higher power at lower frequencies—similar to the sun) for comparison. Finally, I am generating a long synthetic time series with the full observed structure of the solar constant to compare with the first two sets of simulations.

To test this concept, I ran a 100-year control experiment with a solar constant of 1,366 W/m², a second experiment where I added white noise with amplitude of approximately 6 W/m² (approximately the amplitude observed), and a third experiment where the amplitude of the noise was approximately 4 W/m² (approximately the amplitude of the largest observed high frequency variability). Two results from these simulations were of great interest—the 95 percent significant sea level pressure (SLP) anomalous dipole in the North Pole, and a negative anomaly in Europe. Apparently, the noise has affected the model simulation of the North Atlantic Oscillation, which is of great significance to Northern Hemisphere climate and climate change. Other simulations with lower levels of NOISE had similar SLP anomalies related to the NAO indicating a robust response.

While this is an atmospheric model experiment it is also fundamentally an experiment in non-linear geophysics, which spans and will affect all the Earth sciences. Theoretically, noise should change the characteristics of non-linear model simulations in all disciplines. Our initial results indicate that adding idealized noise can affect major modes of atmospheric circulation significantly. However, it has been previously untested in a systematic way, allowing an unchanging solar constant to continue force present climate change simulations.

6. New Doppler Lidar Using Double-edge Atomic Absorption Filter with 3-Frequency Transmitter to Study Gravity Wave Excitation, Propagation, and Dissipation, from Ground to Upper Atmosphere

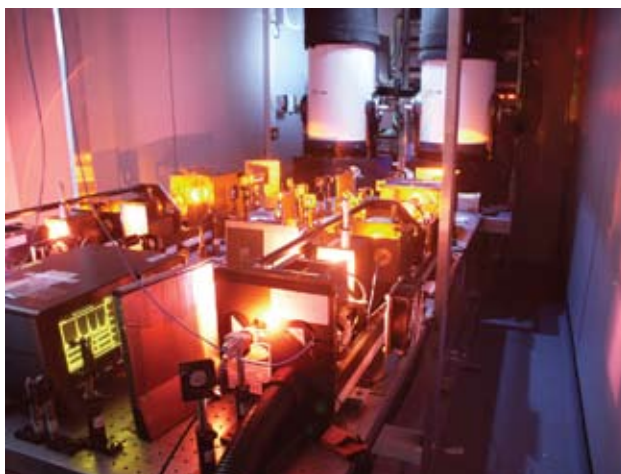
Xinzhao Chu, Wentao Huang, and Mike Hardesty

The project is demonstrating a new lidar technology using double-edge atomic absorption filters with a 3-frequency lidar transmitter to measure wind, temperature and aerosol simultaneously from the ground to the middle atmosphere. We are addressing very challenging issues in the weather, climate, and atmospheric chemistry communities: the characterization of small-scale gravity waves (GW), and the parameterizations of gravity waves for use in atmospheric general circulation models.

Atmospheric GW exist by virtue of the stable density stratification of the atmosphere under gravity. Disturbances to a balanced state can result in excitation of atmospheric GW with a variety of spatial and temporal scales. Gravity waves are important for several reasons: They can transport energy and momentum from one region of the atmosphere to another; they can initiate and modulate convection and subsequent hydrological processes; they disturb the smooth, balanced state through injection of energy and momentum into the flow; and, when the waves break, turbulence hazardous to aviation is generated and chemical species are mixed. Small-scale GW are a key element in defining the large-scale circulation, the thermal and chemical constituent distributions, and the variability of the atmosphere from the troposphere to the lower thermosphere.

The poor representation of GWs in modern climate models is a leading source of model uncertainty. Current atmospheric general circulation models cannot resolve GWs (usually a few to 100s of km) self-consistently because of the coarse model resolution (minimum of 2.5°). Therefore, parameterizations of GWs are needed

for use in the models. Owing to our very limited knowledge of GW spectrum, propagation, dissipation, and source distributions, GW parameterizations are currently very poor. Improving GW characterization has been identified by the United States and international atmospheric science communities as one of the most challenging and urgent issues. (Tracking GWs through wind and temperature perturbations from their source regions in the troposphere and lower stratosphere to the upper stratosphere, mesosphere and lower thermosphere demands high-quality measurements of wind and temperature simultaneously). In the upper stratosphere, mesosphere, and lower thermosphere, GWs dissipate, break, and deposit energy and momentum to the background atmosphere. However, none of current instruments (including radar, lidar, and satellite) is able to make such measurements, due to the limited detection regions of each instrument.



We are addressing this issue by developing an innovative Doppler lidar that can measure temperature and wind simultaneously from ground to mesosphere. This is achieved by using a 3-frequency lidar transmitter with a narrowband lidar receiver armed with double-edge sodium (Na) absorption filters to resolve the Doppler-broadened spectrum of the returned molecular scattering signals. Combining this with our existing Na Doppler lidar, which is capable of wind and temperature measurements in the mesosphere and lower thermosphere, we can profile the wind and temperature from ground all the way to the middle and upper atmosphere for the first time. This will enable the comprehensive study and improvement of GW characterization and parameterization for use in atmospheric models.

The new lidar uses the Doppler frequency shift and broadening produced when laser photons are scattered from air molecules in random thermal motion. The Maxwellian distribution of molecular velocities has a width of ~ 300 m/s that produces Doppler broadening of ~ 1 GHz. In contrast, aerosols and other particulate matter move with velocities determined by the wind (~ 10 m/s) and turbulence (~ 1 m/s), producing Doppler broadening of ~ 30 MHz and ~ 3 MHz, respectively. As a result, the frequency distribution of light backscattered from the atmosphere consists of a narrow spike near the frequency of the laser transmitter, caused by particulate scattering riding on a much broader distribution produced by molecular scattering. By measuring the Doppler shift and broadening of the molecular scattering, the atmosphere wind and temperature can be determined simultaneously.

The double-edge Na absorption filter is composed of a Na vapor cell placed in a strong magnetic field. Lidar returns are selected by a polarizer to a linear polarization, then decomposed to a left and a right circular polarization in the Na vapor cell under a magnetic field. Due to the Zeeman splitting of Na energy levels caused by the strong magnetic field, two circularly polarized lights experience different absorption lines in the Na vapor cell. The two absorption lines act as a double-edge filter with opposite slopes. The transmitted signals passing through the two filters will have different intensities. The difference between the two filtered signals strongly depends on the Doppler frequency shift and broadening. Thus, the ratio of the difference to the sum of the two signals is a sensitive function of the radial wind and temperature. A quarter wave plate, a polarized beam splitter, and two photomultiplier tubes are used to separate and detect the signals from the two filters. With the lidar sequentially transmitting three frequencies produced by an acousto-optic modulator shifting laser frequency up and down, three ratios are obtained for deriving temperature, wind, and aerosol information simultaneously.

We are performing a comprehensive quantum mechanics calculation of the Na absorption filter, and then designing and building two filters using parts purchased from Mojave Solar Inc. Detailed characterization of the filters is ongoing at the CIRES lidar laboratory, using a narrowband ring dye laser, and calibrated against quantum mechanics calculations. The setup will be installed in the receiver of a 3-frequency resonance fluorescence Na Doppler lidar that Chu and Huang are building at the university. Sky return will be obtained from the NOAA/CU Lidar Observatory at Table Mountain. Since the very low atmosphere returns (below 5 km) involve Brillouin scattering, the resulting pressure broadening will introduce extra complexity into the lidar data analysis. To get a better handle on this, the lidar data will be compared against balloonsonde data and NOAA wind lidar data in the lower atmosphere provided by the Hardesty research group.

This project is innovative because no current lidar can determine wind and temperature simultaneously from the ground to the mesosphere. Current instruments either take temperature and aerosol backscatter ratio

profiles from models when deriving radial wind, or they assume the vertical wind to be zero in order to derive temperature. The 3-frequency lidar transmitter and the double-edge Na absorption filters proposed here enable us to obtain sufficient spectral information for simultaneous determination of wind, temperature, and aerosol profiles. Furthermore, since the natural Na absorption lines are calculated precisely from quantum mechanics and measured precisely with a single frequency laser, the proposed lidar does not experience the long-term drifting problem of etalon-based lidars, since etalons are environment-sensitive.

This project is also interdisciplinary. Simultaneous wind and temperature measurements are a key issue to both lower and upper atmosphere science communities, especially when concerning the gravity wave excitation, propagation, dissipation, and impact to the background atmosphere. It is also a great challenge to the international lidar community. The work is enhancing the collaboration between NOAA optical remote sensing group and CIRES lidar group, putting the Chu research group (mainly middle and upper atmosphere lidar) in direct collaboration with Hardesty research group (mainly lower atmosphere and ocean lidar).

This is the first step for lidar and atmospheric science communities to achieve the capability of fully profiling temperature and wind from the ground up to 120 km. It is pushing the observations and studies of gravity waves to a new level, helping improve the gravity wave parameterization and reducing climate model uncertainty. It is a proof-of-concept for the innovative idea of using multiple-frequency lidar transmitter and double-edge atomic absorption filters to measure wind and temperature from the troposphere to mesosphere. Initial results may drive a major proposal (~\$1M) to the Department of Defense or NSF Lower Atmosphere Division. Furthermore, the proposed work will meet the lidar technology needs of national and international researchers. Many scientists on campus asked Dr. Chu and her colleagues to extend lidar measurements to the lower atmosphere and Earth's surface. This work is a first step toward extending the university lidar program, and as such, it should attract funds internationally.

7. Improving the Initialization of Hurricane Forecast Using an Ensemble-based Data Assimilation Technique

Xuguang Wang (CIRES CDC), Tom Hamill (NOAA ESRL), and Jeff Whitaker (ESRL)

Numerical predictions of hurricanes have improved greatly in the past few years because of advances in numerical weather prediction models. There has been less progress in improving initialization for these models, which limits the accuracy of hurricane predictions.

We propose a pilot study to answer two questions: Can ensemble-based data assimilation (Ens-DA) techniques improve the quality of initial conditions (analyses) and the subsequent intensity and track forecasts relative to those initialized from the current standard, three-dimensional variational (3D-Var) techniques? And does using an ensemble of multiple physical parameterization schemes in Ens-DA to represent the uncertainty of the model further improve the analyses and forecasts?

Data assimilation is a process of blending together prior short-term forecasts with new observations. Error statistics are required for both the forecast and the observations in order to know how to combine the two. The widely used 3D-Var data assimilation (DA) technique typically utilizes a simple, unchanging model for the forecast error statistics, one that assumes, for example, that forecast errors are the same in the eye wall of a hurricane as they are 500 km from the eye. Such a forecast-error model provides a poor approximation to the complex, flow-dependent error structure around hurricanes. In Ens-DA, parallel DA and forecast cycles are conducted, and flow-dependent error statistics are estimated using ensemble forecasts. The improved covariance model offered by the ensemble may result in a more appropriate adjustment of the forecast to the observations, deeper and more realistic initial vortices, and improved hurricane forecasts.

In Ens-DA, the ensemble of short-term forecasts should produce a realistic diversity of forecasts, capturing the error growth due both to initial-condition errors (chaos) and numerical model imperfections. One source of model error is the representation of subgrid-scale physical processes (physical parameterization). One way to represent such model error is to use different physical parameterization schemes, which are conveniently available from the WRF model used in this work. We suspect that using multiple physical parameterization schemes (multiphysics) in the ensemble will produce a more realistic representation of the distribution of possible hurricane forecast states, which consequently will improve the adjustment to observations in the Ens-DA.

The pilot work may demonstrate a dramatically better hurricane initialization and forecast method. Also, if hurricanes can be more appropriately modeled with Ens-DA techniques, this may open a new frontier of research into understanding the causes of rapid hurricane intensification. The diversity of hurricane simulations, with some strengthening and others weakening, can be used to understand what are the dynamical characteristics required for intensity changes.

Application of Ens-DA techniques to hurricanes is just beginning. To our knowledge, the use of Ens-DA in conjunction with a multiphysics ensemble has not been tested.

This project requires expertise in both meteorology and statistical estimation theory. The methodology can be extended to analyze tropical cyclogenesis, which is one of the frontier areas in hurricane research.

We are running a 40-member Ens-DA and forecast cycle for hurricane Rita 2005. We run WRF on a spatially extensive domain centered on the northern Caribbean Sea with 15-30 km resolution. A version of the Ens-DA scheme in the Data Assimilation Research Testbed (<http://www.image.ucar.edu/DAReS/DART>) is being used and tested against a control run with WRF 3D-Var. We are assimilating the standard conventional operational observations, as well as observations collected by the NOAA G-IV and WP-3D aircraft.

In the first experiment, we are running Ens-DA with a single set of the physical parameterization schemes. In other words, the ensemble only reflects the errors in the initial condition. To determine if the Ens-DA improves the analyses relative to the 3D-Var, we run forecasts initialized from the Ens-DA's ensemble mean analyses, and compare them with those initialized from the 3D-Var analysis. Common hurricane verification metrics such as the track and intensity error are being compared with the National Hurricane Center Best Track data.

In the second experiment, we are running Ens-DA with multiple combinations of physics parameterization schemes. In particular, we combine several bulk microphysical schemes in conjunction with a number of convective schemes available in WRF. We then determine whether the inclusion of the multiphysics ensembles in Ens-DA further improves the analysis.



Graduate Student Research Fellowships

ESRL-CIRES Graduate Research Fellowship

With NOAA ESRL support, CIRES began offering a new fellowship in 2008 to foster interdisciplinary research and academic excellence for exceptional, prospective, CIRES graduate students. Ryan Neely was selected as the first recipient of a four-year ESRL-CIRES Fellowship, which includes full tuition, a stipend, and other benefits. Neely is pursuing a Ph.D. at the university and also conducting research with world-renowned scientists at ESRL.

Neely, who earned a B.A. in Physics at North Carolina State University is no stranger to Boulder. In 2007, he interned at NOAA's Boulder lab after winning the first "Taking the Pulse of the Planet" Award (2005) for calculating the uptake of carbon dioxide by trees in a carbon-rich environment. As part of the internship, Neely worked with Russ Schnell from NOAA's Global Monitoring Division, and analyzed wintertime ozone production in rural Wyoming. He also developed meteorological analysis software for NOAA's baseline observatories, and operated the division's lidar—an instrument that measures atmospheric variables using pulses of laser light.

"I really found working with lidar to be fun and exciting. The possibilities of using lidar to nail down exactly how clouds work, and to understand the energy exchange between clouds and atmosphere, seems unlimited," said Neely.

Neely plans to incorporate lidar development into his graduate research to study cloud processes and aerosols. He hopes to spend a season at the South Pole to learn more about the dynamics and chemistry of the atmosphere over the Antarctic.

CIRES Graduate Student Research Fellowships

CIRES has long supported a Graduate Student Research Fellowship program to attract outstanding students at the outset of their graduate careers, and to let current students emphasize the completion and publication of their research results. Support ranges from a summer stipend to tuition, stipend, and partial health insurance for 12 months. Fellowships are restricted to graduate students advised by a CIRES Fellow, or any prospective or current graduate student who might be advised by a CIRES fellow.

Evaluation by a committee of CIRES Fellows is based on the candidate's university application, accomplishments, and the likelihood of their contribution to environmental science. Independence, passion for science, and ability to communicate are considered.

This year, CIRES awarded fellowships to seven students to explore topics ranging from the use of field and remote sensing methods to track changes in grassland carbon storage to development of new techniques for measuring precipitation changes over Greenland.

CIRES Graduate Student Research Fellowship Recipients

Bryan Brandel

B.S., 2000, Albertson College of Idaho
Department: Ecology and Evolutionary Biology
Academic Advisor: Carol Wessman

Research Area: Changes in ecosystem properties, including carbon storage, across a creosotebush (*Larrea tridentate*) and grassland transition using field measurements and remote sensing.

Nikolaus Buenning

B.A., 2003, University of Colorado at Boulder, Astronomy
Department: Atmospheric and Oceanic Sciences
Academic Advisor: David Noone

Research Area: The impact of future climate change on terrestrial processes and the spatial distribution of $\delta^{18}O$ of atmospheric CO_2 .





Christa Hasenkopf

B.S., 2003, Pennsylvania State University, Astronomy and Astrophysics

Department: Atmospheric and Oceanic Sciences

Academic Advisor: Margaret Tolbert

Research Area: Exploring the direct and indirect effects of organic haze particles on early Earth climate



Scott W. McCoy

B.A., 2005, University of Washington, Business Administration

B.S., 2005, University of Washington, Geology

Department: Geological Sciences

Academic Advisor: Greg Tucker

Research Area: Debris flows and landscape evolution, across space and time scales through numerical modeling, remote sensing and field observation.



Shalini Mohleji

B.A., 2000, University of Virginia, Environmental Sciences

M.S. 2002, Purdue University, Atmospheric Sciences

Department: Environmental Studies

Academic Advisor: Roger A. Pielke, Jr.

Research Area: Homeland security science research and development funding/management.



Kathryn L. Plath

B.S., 2004, Santa Clara University, Chemistry

Department: Chemistry

Academic Advisor: Veronica Vaida

Research Area: Vibrational spectroscopy and overtone-induced photochemistry of atmospherically relevant organic acids.



Keah Schuenemann

B.S., 2004, University of Wisconsin, Madison, Atmospheric and Oceanic Sciences

M.S. 2006, University of Colorado at Boulder, Atmospheric and Oceanic Sciences

Department: Atmospheric and Oceanic Sciences

Academic Advisor: John Cassano

Research Area: Precipitation over Greenland and the organization of synoptic weather patterns in the Greenland region through the use of self-organizing maps as an analysis of the past, present, and future state of the Greenland climate system and mass balance of the ice sheet.

Diversity and Undergraduate Research Programs

Significant Opportunities in Atmospheric Research and Science Program (SOARS)

SOARS is a learning community and mentoring program for promoting ethnic and gender equity in the atmospheric and related sciences. The National Center for Atmospheric Research created and administers the highly regarded program, and CIRES partners with NCAR to provide a wider range of research options for students, called protégés. SOARS provides four years of mentorship—and summer research experience—for undergraduate and graduate protégés majoring in an atmospheric science or related fields. For more information, please see <http://www.ucar.edu/soars/>.

SOARS Protégés 2007

McArthur Jones Jr.

Research topic: The Daily Cycle of Winds at Estacion Obispo, Mexico during the North American Monsoon
Mentors include Leslie Hartten and Sarah Tessendorf of NOAA ESRL and CIRES.

Karen Diaz

Research topic: Investigation of the Global Atmospheric Oxidation Chemistry by Ozone–Non–methane Hydrocarbon Correlation Analysis
Mentors included Detlev Helmig of INSTAAR, Bryan Johnson and Pete Henderson of NOAA ESRL, and Michael E. Trudeau of NOAA ESRL and CIRES.

Undergraduate Research Opportunities Program (UROP)

The Undergraduate Research Opportunities Program (UROP) creates research partnerships between faculty and undergraduate students. UROP-supported work is diverse, including traditional scientific experimentation and the creation of new artistic works. The program awards stipends and/or expense allowances to students who undertake an investigative or creative project with a faculty member. Although projects are normally designed around some aspect of the faculty sponsor's research, they may also develop from original ideas of the student, endorsed by a faculty sponsor. For more information, please see <http://www.colorado.edu/Research/UROP/>.

UROP Students 2007

Thomas Detmer

Title: Understanding the Effects of Mountain Pine Beetle Infestation on Water Chemistry

CIRES sponsor: William Lewis, CIRES Associate Director, Director of the Center for Limnology, CIRES Fellow

George Fosmire

Title: Mathematical and Geostatistical Analysis of Laser–Altimeter Data from ICESat to Study Changes in Antarctic Glaciers

CIRES sponsor: Ute Herzfeld, Senior Research Associate

Anna Lieb

Title: Mathematical and Geostatistical Analysis of Laser–Altimeter Data from ICESat to Study Changes in Antarctic Glaciers

CIRES sponsor: Ute Herzfeld, Senior Research Associate

Cordelia Holmes

Title: Coastal Change Along the North Slope of Alaska: First–Pass Remote–Sensing Analysis

CIRES sponsor: Cameron Wobus, Research Associate

Danielle Lirette

Title: Geostatistical Analysis of Laser Altimeter Data from ICESat to Study Changes in Antarctic Glaciers

CIRES sponsor: Ute Herzfeld, Senior Research Associate

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Scientific Themes

Six scientific themes inspire CIRES research and align the Institute's work with the goals and mission of our partner, NOAA. These themes cross organizational boundaries at CIRES, fostering an interdisciplinary approach to research challenges. In the following pages, we describe how CIRES met 54 goals set in the Institute's Fiscal Year 2008 Workplan, arranged by theme.

AMOS: ADVANCED MODELING AND OBSERVING SYSTEMS

CIRES researchers characterize and predict the state of the Earth system on a variety of scales using direct observations and mathematical techniques for projecting outcomes. This theme includes work in diverse disciplines, including atmospheric chemistry, atmospheric and oceanic processes, cryospheric processes, space weather, nonlinear systems applications, data centers, and data management.

AMOS-01 INSTRUMENTATION DESIGN, PROTOTYPING AND ANALYSIS

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CSD-01 Instrumentation for Atmospheric Observation and Analysis

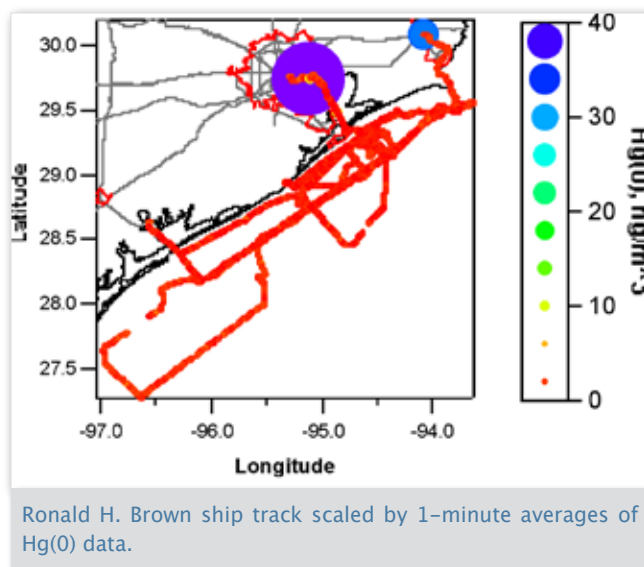
Goal: Design and evaluate new approaches and instrumentation to make atmospheric observations of hard-to-measure species that are important players in the chemistry of the troposphere and stratosphere.

Milestone 1:

Develop fast response, state-of-the-art instrumentation suitable for airborne measurements of atmospheric mercury (Hg).

Accomplishment: Gas-phase elemental mercury (Hg(0)), while long-lived in the atmosphere, is thought to be the primary source of mercury (II) and particulate mercury species, which are far more toxic, soluble, and bioavailable. Anthropogenic sources of Hg(0) to the atmosphere include emissions from coal-fired power plants, waste incineration, cement and steel manufacturing, smelting, petroleum refining, and industrial processes such as used in chlor-alkali plants. A prototype instrument to be evaluated and redesigned for use in aircraft studies was deployed during the TexAQS 2006 study. Using this instrument, gas-phase Hg(0) was measured aboard the NOAA research vessel Ronald H. Brown to evaluate potential emissions sources of this compound along the Texas coastline and in industrialized harbor areas.

A modified Ohio Lumex instrument was used to detect atmospheric Hg(0) using absorption of the 253.7 nm emission line of a mercury lamp in a 10-m multipath sample cell. Specificity was afforded by high-frequency modulation of the emission lamp into three polarized Zeeman components, with the σ -line uniquely absorbed by atomic mercury. Instrument zeroes were regularly checked by sampling ambient air through an iodinated charcoal trap, and instrument calibration was routinely evaluated by adding a known standard of Hg(0) to the ambient sample. 1-sigma uncertainties of the 1-second data averaged $\pm 2 \text{ ng/m}^3 + 16 \text{ percent}$ of the reported value. Mercury data were reported at 1-second intervals for the TexAQS 2006 Ronald H. Brown cruise, which sampled extensively in the Gulf, Galveston Bay, and the Houston Ship Channel; for a full day in the Beaumont-Port Arthur area; and for several hours in Matagorda Bay. The Ronald H. Brown ship track in the TexAQS

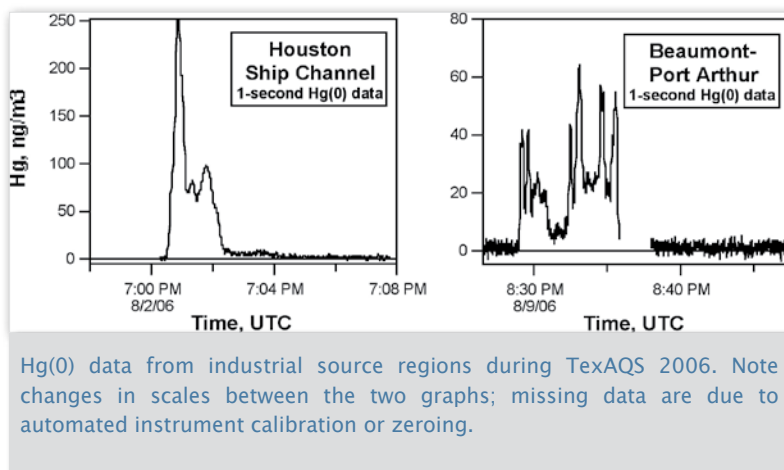


2006 study region is shown above, scaled by 1-minute averages of Hg(0) concentration measured aboard the ship.

Outside of the industrialized source areas, the data show an average Hg(0) concentration of $1.5 \pm 1.4 \text{ ng/m}^3$, broadly consistent with the expected background value of 1.7 ng/m^3 for this season and latitude. No strong signature of Hg emissions is seen outside of the industrial areas, despite extensive sampling very close to oil and natural gas drilling and production platforms in the Gulf, and in the very concentrated plumes of large commercial vessels burning a variety of bunker fuels.

Within the industrialized Houston Ship Channel and Beaumont-Port Arthur areas, the data show very concentrated, spatially narrow plumes, as shown in detail below.

The Hg(0) plume in the Houston Ship Channel, shown



Hg(0) data from industrial source regions during TexAQS 2006. Note changes in scales between the two graphs; missing data are due to automated instrument calibration or zeroing.

above, was encountered on each of four transits in approximately the same location when local winds were southerly, suggesting a single source. No enhancement was seen when winds were northerly. Peak enhancements for this plume ranged from 250 to 15 ng/m³, with the variability potentially affected by differences in dilution, transport, and source strength, during each transit. A second plume (not shown) was encountered at a different geographic location in The Houston Ship Channel, indicative of a separate source. The Beaumont–Port Arthur PA plume was observed during the single Ronald H. Brown visit to Beaumont. Winds were steadily onshore during the visit to Matagorda Bay, precluding sampling the decommissioned chlor–alkali plant emissions by the instrument aboard the Ronald H. Brown.

Most interesting is that all observed Hg(0) enhancements were completely uncorrelated with any of the very wide range of other measurements made on The Ronald H. Brown. A list of these measurements is available at <http://esrl.noaa.gov/csd/2006/>. This complete lack of correlation rules out most known source types, which can be expected to co–emit one or more of the suite of species measured concurrently aboard the Ronald H. Brown. Further, the Ronald H. Brown mercury observations are not consistent with the latest TCEQ, AIRS, EGRID, and TRI inventory source locations for known Hg emitters in this region.

The development of a fast–response Hg(0) detector suitable for aircraft applications is moving slowly forward. The aim will be to develop a much more sensitive detector for Hg(0) using absorption of the 253.7–nm emission line with the cavity ring–down method that has been pioneered by CIRES scientists.

Milestone 2:

Modify and construct a field-worthy single-particle cavity ring-down instrument, deploy it, and analyze the data. Write up results on the molecular speciation of marine aerosol organic content. Plan for airborne data acquisition.

Accomplishment: The Aerosol Scattering–to–Extinction Ratio (ASTER) instrument moved past the proof–

of–concept development phase in the last work period. This culminated in the acceptance for publication of a manuscript describing the operation of the instrument, data collection and analysis procedures, and laboratory results highlighting the capabilities of the instrument. ASTER simultaneously measures extinction and scattering by single particles from which the single–scattering albedo is obtained for each particle. The measured ratio of forward–to–total scattering provides a measure of particle size as well.

The potential for ASTER in providing new types of aerosol optical measurements was evident in results obtained from

samples of ambient air. One of the central motivations for the ASTER development is to make measurements of scattering and absorption of light by single aerosol particles. Measurements on single particles provide more detailed information and will serve as a complement to existing bulk measurements. The ambient air data showed a large majority of the particles measured with single–scattering albedos very close to unity (they are nearly pure scatterers). However, there was also a discernible population of particles with single–scattering albedos near 0.4 (they have significant absorption and could be thought of as very dark in color). In a bulk measurement, this population of strong absorbers would be masked due to the averaging inherent in the measurement. The mean albedo would still be very close to unity, giving the appearance of a population of exclusively scattering particles. It is only by measuring the optical properties on a single particle basis that information about the varying characteristics of the entire sample population can be obtained.

The laboratory results also provided information on ways to improve the performance of ASTER and the quality of the data. These improvements are being made as the instrument is modified for field deployment. The plan is to initially deploy ASTER locally to determine its mobility and ease of operation outside of a controlled laboratory setting. Initial tests would include the observation of changes in albedos on heavy pollution days and comparison with other optical properties instruments that have shown to be successful in the field. ASTER’s ability to correctly size ambient particles will also be studied by comparison with data from particle sizing instruments. The ultimate goal is to have ASTER deployable not only at ground sites, but also on ships and aircraft. This will include a higher degree of automation in the instrument and increased insensitivity to rapidly changing environments encountered on ships and aircraft.

Product: Sanford, T., D. Murphy, D. Thomson, and R. Fox (2008), Albedo Measurements and Optical Sizing of Single Aerosol Particle, *Aerosol Science and Technology*, accepted for publication.

Sanford, T. (2007), Albedo Measurements and Optical Sizing of Single Aerosol Particles, poster presentation at the American Geophysical Union Fall Meeting, San Francisco, CA.

Sanford, T. (2007), Albedo Measurements and Optical Sizing of Single Aerosol Particles, oral presentation at the annual meeting, American Association for Aerosol Research, Reno, NV.

Milestone 3:

Develop an aircraft-based lidar to measure wind and turbulence profiles.

Accomplishment: The NOAA/ESRL High-resolution Doppler Lidar (HRDL) was modified during the past year to make the instrument ready for installation on the NOAA Twin Otter, N48RF. The instrument has typically resided in a seagoing container and has been used for ship-based studies of relative aerosol backscatter and dynamics in the lower troposphere. The work done in 2007–2008 provided initial analysis and testing of the instrument structure and performance on an aircraft, as well as a proof-of-concept of the type of data to be provided by such a system. Test flights will be performed with the lidar pointing nadir through a hole in the belly of the aircraft, enabling acquisition of vertical velocities. During 2007–2008, CIRES employees worked on the following aspects of the project:

1. Engineering Analysis and Design: To achieve instrument certification for installation on the NOAA Twin Otter, engineering analysis of the proposed mechanical, electrical, and optical sub-systems were performed. Although no major modifications were made to the instrument to make it robust to aircraft conditions, a full analysis of the mechanical structure of the system along with some minor modifications were required to receive the aircraft certification, enabling installation of the system on the NOAA Twin Otter.
2. Mechanical and Optical System: Modifications to the system to achieve said aircraft certification and to partially isolate the instrument from aircraft vibration were performed. These included changes to system cabling, reinforcement of system panels to handle 9g force requirements,

design and installation of aircraft mounting and vibration isolation hardware, protection for fragile optical fibers, etc.

3. Computer System: Modifications to the computers and other hardware components of HRDL enabled them to safely perform at high altitude in an un-pressurized aircraft cabin.
4. Installation: The instrument will be installed on the N48RF in early August 2008. The installation is estimated to take about 2.5 days with initial on-ground testing at the end of the third day.
5. Test Flights: Three test flights will be performed with the instrument.
6. Data Analysis: Analysis of the test flight data and of the aircraft vibration and sound spectra (and their effects on the instrument behavior) will be performed.

Milestone 4:

Develop lidar systems to measure atmospheric constituent profiles.

Accomplishment: As aerosols swell with water uptake in the more humid environment just below clouds, light scattering increases. The radiative effects of aerosols are an important, but not fully quantified contribution to global climate change. Aerosol hygroscopic growth factors were calculated from lidar profiles in a well-mixed cloud-capped boundary layer for a range of pollutant concentrations. These growth factors were compared to ones derived from a pulsed cavity ring-down aerosol extinction spectrometer and from nephelometers. The data for this study were taken aboard a ship during the TexAQS 2006 experiment, a multi-agency air pollution study in east Texas and the Gulf of Mexico during August and September of 2006. On the ship during the TexAQS 2006 experiment, the required instances of clouds atop a well-mixed boundary layer were infrequent and brief, demonstrating that this technique is not ideal for use over water near/in the Gulf of Mexico. The next step is to try this technique with land-based measurements from Houston, where there is more substantial cloud cover, and better results may be expected.

PSD-08 Sensor and Technique Development

Goal: Design, develop, enhance, and evaluate remote and *in-situ* sensing systems for use from surface and other platforms of opportunity in order to measure critical atmospheric, surface, and oceanic parameters.

Milestone 1:

Complete construction of a roving calibration standard for ship flux measurements.

Accomplishment: The system was completed in Fall 2007. More information is available at ftp://ftp.etl.noaa.gov/user/cfairall/oceanobs/portable_standard/

Milestone 2:

Evaluate results of field test fast ozone sensor on Houston A/Q field program for ship-based ozone flux measurements.

Accomplishment: A new ozone sensor was built at INSTAAR (with Detlev Helmig leading the project). The system was deployed on the Ronald H. Brown in

the TexAQS field program in later summer 2006. The system was deployed again on the GOMECC-2007 and GASEXIII-2008 cruises.

Product: Bariteau, Lang, Helmig, and Fairall (2007), Ozone deposition velocity by ship-based eddy correlation flux measurements by, presented at the Symposium on Boundary Layers and Turbulence, AMS, Portland, OR, August 2007.

A manuscript is in preparation for publication in the *Journal of Oceanic and Atmospheric Technology*.

Milestone 3:

Field test roving flux standard on one ship deployment

Accomplishment: The system was deployed on R/V Knorr during the ICEALOT field program in March–April, 2008.

Product: Wolfe, D.E., D. Forcucci, D. Chayes, T. Bolmer, and C.W. Fairall (2008), Shipboard Meteorological Measurements: Interpretation and Quality Assessments, presented at the 2nd GOSUD/SAMOS Sorkshop. Seattle, WA.

CET-01 Remote Hydrologic Sensing

Goal: Develop microwave remote sensing capabilities to facilitate NOAA measurements of key hydrological variables.

Milestone 1:

Develop a ground-based microwave profiling system for long-term Arctic cloud and water vapor measurements.

Accomplishment: A Ground-based Scanning Radiometer (GSR) for precise measurements of Arctic temperature profiles and total integrated water vapor has been demonstrated. The GSR was deployed in Barrow, Alaska, from March through mid-August 2007, and was successfully remotely operated. A calibration and retrieval algorithm showed substantial improvements in the accuracy of integrated water vapor retrieval relative to conventional 22.235-GHz microwave radiometers.

Product: Cimini, D., E.R. Westwater, A.J. Gasiewski, M. Klein, V. Leuski, and S. Dowlathshahi (2007), The Ground-Based Scanning Radiometer: A Powerful Tool for Study of the Arctic Atmosphere, *IEEE Trans. Geosci. Remote Sensing*, 45 (9) pp 2759–2777, September 2007.

Cimini, D., E.R. Westwater, A.J. Gasiewski, M. Klein, V. Leuski, and J. Liljegren (2007), Ground-based Millimeter- and Submillimeter-Wave Observations of Low Vapor and Liquid Water Contents, *IEEE Trans. Geosci. Remote Sensing*, 45 (7), Part II, pp. 2169–2180.

Westwater, E.R., D.C. Cimini, V. Mattioli, A.J. Gasiewski, M. Klein, V. Leuski, and D.D. Turner (2008), Deployments of Microwave and Millimeter-Wave Radiometers in the Arctic, 10th Microwave Radiometry Specialist Meeting, Florence, Italy.

Milestone 2:

Develop submillimeter microwave radiometers for ground-based and airborne cloud sensing.

Accomplishment: Progress on the calibration system for a fast-switching internally calibrated radiometer operating at the 424 GHz oxygen absorption line was made. The radiometer front-end was designed, beam efficiency calculations were made, and the radiometer IF boards were fabricated. The system is being readied for

final assembly and use within the Polarimetric Scanning Radiometer/submillimeter scanhead in airborne imaging studies of clouds and precipitation. At lower (millimeter wave) frequencies, a full complement of up- and down-looking cloud radiometers, along with radiation probes, was developed and integrated into the NASA DC-8 in preparation for the Arctic Mechanisms of Interaction between the Surface and Atmosphere (AMISA) field experiment. The AMISA project is part of a NASA-sponsored International Polar Year project with the goal of understanding the surface and atmospheric radiation and dynamical processes leading to Arctic sea ice freezeup.

Product: Persson, O.G., M. Shupe, M. Tjernstrom, A. Gasiewski, I. Brooks, B. Brooks, T. Markus, P. Johnston, V. Leuski, T. Uttal, and C. Fairall (2008), Plans for Cloud and Boundary-layer Research during the Arctic Summer Cloud–Ocean Study, presented at the 2008 EGU meeting, Vienna, Austria.

Milestone 3:

Develop all-weather radiance assimilation of satellite passive microwave observations.

Accomplishment: To assess the operational capabilities of candidate geostationary microwave sounding systems for NOAA forecasting applications, a set of observation system simulation experiments (OSSEs) using two leading concepts (GEM and GeoSTAR) are being conducted. An assessment of the two system concepts requires that the simulated data be considered in the context of severe weather forecasting, and specifically, quantitative precipitation forecasting. To this end, the spatial and temporal sampling capabilities of two the candidate systems, along with the spectral and spatial ranges of their data, are being considered. Since the two system concepts provide distinct types of brightness information, the assessment is best carried out in the framework of radiance assimilation into a numerical weather prediction model. A simulator has been developed using the discrete ordinate tangent linear radiative transfer (DOTLRT) scattering-based

radiative transfer model to address the challenge of locking a high-resolution numerical weather prediction model onto microwave brightness imagery from a simulated landfalling hurricane. In developing the OSSE, the strong impact of the background error covariance matrix on the model update has been demonstrated. Use of a nonlinear iterative D-matrix algorithm provides good innovation convergence over a simulated hurricane, but can also result in the growth of instabilities in the null space of observations without proper stabilization of the solution. The ability of the model to be locked onto the data is currently being assessed, along with the potential for using geostationary microwave imagery to drive regional numerical weather prediction models by direct radiance assimilation.

Product: Gasiewski, A.J., B.L. Weber, and A. Jash (2008), Development of an Observational System Simulation Experiment (OSSE) for a Geostationary Microwave



Imager, presented at the International Geoscience and Remote Sensing Symposium, Boston, MA.

Also presented at the 10th Microwave Specialist Meeting, Florence, Italy, and the 2008 URSI National Radio Science Meeting, Boulder, CO.

AMOS-02 DATA MANAGEMENT, PRODUCTS, AND INFRASTRUCTURE SYSTEMS

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NGDC-01 Geospatial Technology for Global Integrated Observing and Data Management Systems

Goal: Develop methods and processes for integrating multiple types of observations (gridded satellite products, *in-situ* measurements) using new Geographic Information System (GIS) data management and access tools; develop methods and processes for partnering with scientists to facilitate interoperability by producing metadata for scientific observations that are compliant with Federal Geographic Data Committee and International Standards Organization standards; and create tools that allow the mining of vast environmental archives for the purpose of knowledge extraction, data quality control, and trend detection.

Milestone 1:

Integrate near real-time observations into Data Center access systems.

Accomplishment: A software system was developed to ingest satellite observations of wildfires across North America, enabling a spatial database to be loaded every 15 minutes. This database backs an interactive map of wildfires available on the Web (example on next page).

Product: Satellite Fire Detections <http://map.ngdc.noaa.gov/website/firedetects>.

Milestone 2:

Design, develop, and demonstrate archive systems that provide integrated access to data in spatial databases and file systems.

Accomplishment: A software system was developed to inventory 250,000 solar image data files to a database.

Another system, the Interface Database, was used by the solar data manager to provide public access to the images.

Product: NGDC/WDC STP, Boulder-Solar Radio Data via FTP from NGDC: <http://www.ngdc.noaa.gov/idb/struts/results?t=102827&s=1&d=3>.

An image from the solar image database.





Screenshot of the interactive wildfire map system at NOAA's National Environmental Satellite, Data, and Information Service (NESDIS).

NGDC-02 Marine Geophysics Data Stewardship

Goal: Contribute to a streamlined, more fully automated, accessible, and web-based management and stewardship process for marine geophysical data in support of seafloor research at CIRES and throughout the environmental science community.

Milestone 1:

Develop and test accurate, efficient, and effective system status monitoring software and metrics for management and oversight of rates of acquisition, evaluation, archiving, and access of marine geophysical data.

Accomplishment: Capabilities have been added to the NGDC Tracking System to add, update, and monitor process steps and data volumes. The system has been populated for multibeam bathymetric data and is now being used to monitor size and dates of data received, quality controlled, assimilated, placed online, and archived.

Milestone 2:

System integration and extension, to provide user friendly, highly navigable web access to all marine geophysical and geological data.

Accomplishment: The NGDC MultiBeam Bathymetric Data Base (MBBDB) has been integrated with the NGDC Data Tracking System and the NOAA Metadata Manager and Repository to maintain consistency between databases and to reduce redundancy. Transfer of newly processed data from the MBBDB to NGDC web servers has been automated to provide timely access to new datasets. The ArcIMS web map interface used for many NGDC datasets including multibeam bathymetry and marine geology, has been extended to marine trackline geophysical data, providing users with a common interface and interactive geospatial searching for marine geological and geophysical datasets.

SWPC-03 Information Technology and Data Systems

Goal: Determine the necessary research data systems and infrastructure required to implement successfully the empirical and physical scientific models of the space environment, such as those envisioned in SWPC-01 and SWPC-02 (AMOS-03 Prediction, Model Development and Evaluation) with fast and efficient access to appropriate data sources.

Milestone 1:

Complete the Phase II migration of older and non-supported computing platforms to newer platforms. Migrate existing Data Display system and its supporting software components to the new shared services architecture. Complete and deploy next-generation Space Weather Prediction Center (SWPC) status monitor and lay down a project plan for integrating existing applications to the new status monitor. Complete next version of the data bridge server and clients to provide aggregate and atomic domain-name-based data retrieval, and auto-switching between main and warehouse data stores.

Accomplishment: Phase II was completed, with several improvements to the next-generation SWPC status monitor system. Big Brother software is now better integrated with systems that require monitoring for process health, network availability, and up time.

Further Phase II activities were accomplished by starting the development of the AIMED system, replacing older COMEDS software. This system is responsible for decoding messages received via the U.S. Air Force AFWA network, containing planetary A and K indices, magnetometer analysis data, solar flare reports, sunspot observations, and radio flux measurements. The next version of the data bridge server project has been postponed due to resource unavailability.

Milestone 2:

Develop and deploy a secure and reliable data ingest, storage, processing, and dissemination system for space weather data streams. Re-architect four to five existing applications to reduce complexity and increase reliability by integrating them with the new SWPC shared services.

Accomplishment: Several new data ingest, storage, processing, and dissemination systems were developed

for SWPC. The Real Time Ground Magnetometer team developed a much needed application to handle the retrieval and storage of magnetometer data from a new U.S. Geological Survey data source. Additionally, the COSMIC ingest was developed to process COSMIC data generated by neighboring UCAR labs.

Milestone 3:

Complete development of the GOES-N ground data systems IT infrastructure needed for post-launch test. Provide analysis and technical support to algorithm development, instrument checkout, and data verification.

Accomplishment: The SWPC GOES-N ground data system preprocessor was improved and expanded, in preparation to support further post-launch testing. Many important improvements were made to magnetometer, particle, extreme ultraviolet, and x-ray sensor processing algorithms to support scientific model development. Further modifications were made to increase reliability, optimize system operations, improve logging, expand configurability, and create more detailed documentation. A prototype Solar X-ray Imager data processing system was developed, to begin refining the image processing functionality of the ground data system.

SWPC-04 Space Environment Data Algorithm and Product Development

Goal: Explore new techniques for analyzing and modeling GOES space environment data, and develop and validate new algorithms and products.

Milestone 1:

Develop and validate new algorithms and products to be generated with the GOES-N and the GOES-R series satellites.

Accomplishment: New algorithms to process GOES-R magnetometer, energetic particles, and solar ultraviolet imager data were developed, documented, coded, and tested. The magnetometer algorithms include the conversion to alternate geophysical coordinate systems, the one-minute averages, and the comparison to quiet fields. The energetic particles algorithms include the one-minute and five-minute averages, density and temperature moments, and the conversion of five-minute differential proton flux values to integral flux values. The solar ultraviolet imager algorithms currently being developed and tested are the composite images, the fixed difference images, and the running difference images.

Milestone 2:

Explore new models and analysis techniques to improve the accuracy and to expand the scope of operational products derived from the GOES data.

Accomplishment: In the development of new algorithms to process the GOES-R data, alternative

techniques were analyzed and tested to determine the most accurate and best-suited algorithms for the SWPC operational applications. Alternate methods of computing averages of time series data were examined. The goal is to have a common method for all types of data, but the impact of implementing this is still being evaluated and tested. For the magnetometer algorithms for comparison to quiet fields, several quiet field models were evaluated and the best alternatives—the OP-77 field model based on the work of Olson and Pfitzer and the IGRF10—were selected based on reliability, ease of use, and accuracy. In the development of composite images algorithms for the solar ultraviolet imager, new analysis techniques were explored and evaluated to maximize the clarity of the images for space weather impact analyses. A technique to provide weighted averages across pixels was developed and has proven effective. In the development of the energetic particle density and temperature moments algorithm, new extrapolation techniques were developed to improve the accuracy of the moment calculations for all energy levels of interest. This has resulted in a more comprehensive specification of the moments.

AMOS-03 PREDICTION, MODEL DEVELOPMENT, AND EVALUATION

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CSD-02 Chemical Transport Model Research

Goal: Undertake research that contributes to the ability to forecast regional air quality and improves the understanding of the budget of ozone in the upper troposphere. Design and evaluate state-of-the-art model capabilities to describe the transport and chemical evolution of pollutants in the atmosphere. Focus is regional air quality with an emphasis on ozone and particulates. The regional chemical transport model will integrate

the emission, the vertical and horizontal transport, and the chemical conversions of pollutants. Evaluation by comparison of the model results with integrated field studies will lead to an improved model system and its components. Detailed tracer transport studies, meteorological analysis including satellite observations, and coordinated measurements with a network of ozonesondes will lead to an improved understanding of the ozone budget over the United States during the summertime.

Milestone 1:

Measurements of ozone, aerosols, and their precursors made during TexAQS/GoMACCS 2006 to evaluate the forecast capability of the current tracer and chemical forecast models.

Accomplishment: As part of TexAQS 2006, seven air quality forecast models from various forecast centers, research centers, one university, and one private corporation were operational in real time during a two-month period that overlapped with intensive aircraft measurements made aboard the NOAA WP-3 aircraft. Several gas-phase and aerosol species from the archived forecasts were analyzed statistically against both the aircraft measurements and surface data collected as part of the U.S. Environmental Protection Agency AirNOW monitoring network. The multi-model comparisons are designed to identify biases and errors in physical, photochemical, and emission parameterizations within individual forecast models. They also serve as measure of collective scientific understanding, and ability to forecast air quality over a region with roughly 4 million inhabitants.

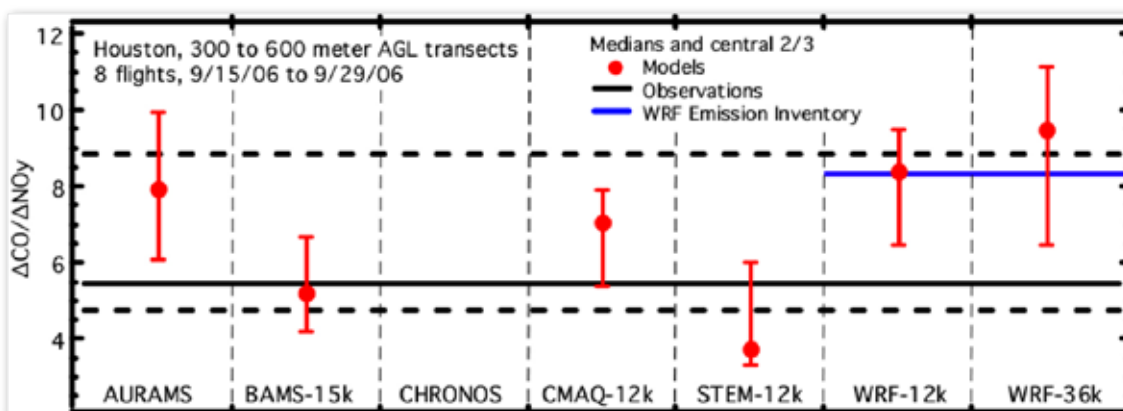
Many of the NOAA WP-3 flights were designed specifically for upwind and downwind sampling of the Houston and Dallas urban corridors. A significant result of the model analysis for these flights is a methodology that uses concentrations from measurements or model predictions to quantify integrated emission ratios over the urban areas. This methodology is found to accurately reproduce the emission ratios imposed as flux conditions within the models, and is used to assess the accuracy of the emission inventories used in the real-time forecasts. The figure below summarizes CO/NO_y emission ratios from eight flights (and upwind

transects) and 29 transects in Houston, showing how well concentration difference ratios for the WRF/Chem model represent the emission inventory and the results from four other forecast models. A web site has been constructed to display the results of the NOAA WP-3 statistical analysis, emission flux, and emissions ratio comparisons: <http://www.esrl.noaa.gov/csd/2006/modeval/tex06/>.

Milestone 2:

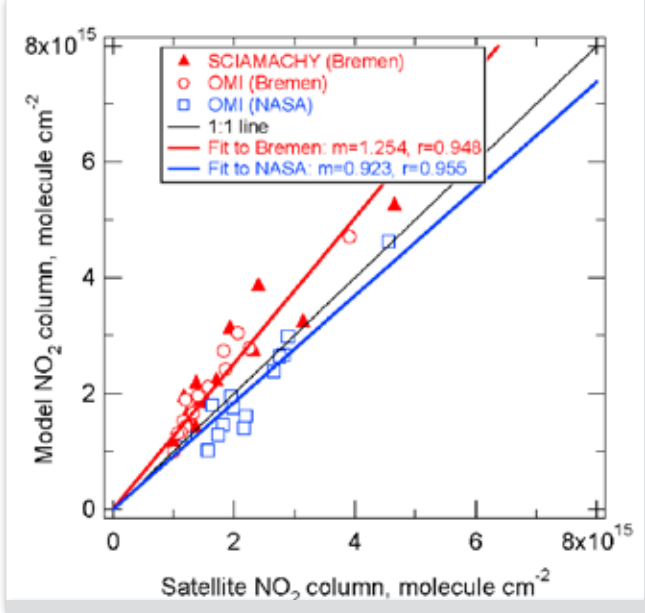
Continue to use model sensitivity studies to examine the effects of changing power plant emissions of nitrogen oxides (NO_x) on the formation of ozone over the eastern United States.

Accomplishment: Spatial distributions and temporal trends in NO_x emissions were determined from polluted areas using satellite measurements and chemical-transport model simulations of NO₂ vertical columns. The NO₂ vertical column is the total amount of NO₂ in a rectangular column extending from Earth's surface to the top of the atmosphere. These analyses provide a top-down evaluation of conventional bottom-up inventories prepared using complex source activity models. A study of satellite NO₂ columns over the Ohio River Valley demonstrated substantial reductions in atmospheric NO_x levels since the late 1990s in response to a series of EPA-mandated emission control programs targeting eastern U.S. power plants. More recently, satellite retrievals and model calculations of NO₂ vertical columns were used to distinguish between the NO_x emissions from western U.S. power plants and urban areas. Because NO_x emissions are independently monitored at U.S. power plants, satellite-model comparisons over isolated plants allow for the assessment and optimization of algorithms for



CO/NO_y concentration difference ratios (WP-3 observations and models) from 29 transects between 10 km upwind and 50 km downwind of the Harris County courthouse in Houston between 9/15/06 and 9/29/06. The 11:00am to noon (CDT) emission inventory ratios used by WRF/Chem for a 1000 km² area containing Houston is also shown.

retrieving NO₂ columns from satellites and calculating them in chemical-transport models (figure opposite, left). Upcoming work will include a detailed analysis of these optimized satellite and model NO₂ columns over western U.S. cities. This analysis will provide a quantitative evaluation of inventory predictions of urban NO_x emissions and their day-of-week and year-to-year trends between 2003 and 2007.



Comparison of modeled NO₂ vertical columns with several different satellite retrievals of NO₂ vertical columns for a number of western U.S. power plants for the summer of 2005.

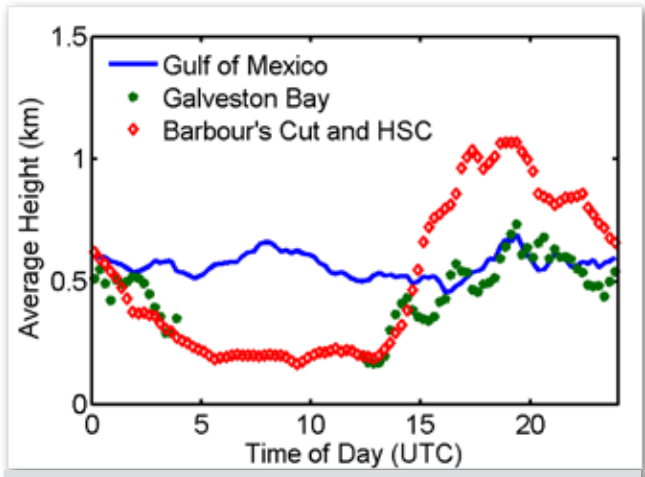
Milestone 3:

Compare remote sensing observations with model forecasts to assess representation of boundary-layer characteristics in various forecast models.

Accomplishment: Boundary-layer measurements were obtained during TexAQS 2006 study using both ship-based and airborne lidars. The ship-based lidar measured boundary-layer heights and characteristics every 15 minutes based on estimates of wind, turbulence, and aerosol backscatter profiles. A paper has been submitted to an American Meteorological Society journal describing the lidar measurements of boundary-layer heights. The observations indicated that boundary-layer height exhibited little diurnal variation over the Gulf of Mexico, and significant variation when the ship was located at Barbour’s Cut or in the Houston Ship Channel (figure at right). Measurements also indicated that the boundary-layer height must be

taken into account to accurately represent important processes such as the ozone-forming potential of oxygenated volatile organic compounds. Initial comparisons of lidar and WRF model estimates of boundary-layer height showed fairly good agreement—these efforts are continuing.

Aircraft lidar measurements of aerosol backscatter profiles characterized mixing layer depth over different regions in southeast Texas. Mixing layer depths typically increased with increasing distance from the Gulf of Mexico coastline. A heat island effect was also observed downwind of Houston. Although a deeper mixing layer tends to dilute ozone concentrations, an investigation of the correlation between mixing layer depth and ozone enhancement above background levels showed no effect of mixing layer depth on ozone enhancement for the ensemble of cases studied. This likely indicates that processes that enhance ozone formation—such as higher temperatures, increased photochemistry, and stagnant conditions—affect mixing layer depth and, in general, offset dilution effects.



Diurnal cycle of mixing layer heights measured by ship-based lidar during the Texas experiment for locations in the Gulf of Mexico, Galveston Bay, and Barbour’s Cut.

PSD-09 Environmental Modeling and Prediction

Goal: Improve numerical model performance through development of new data streams that directly impact forecast ability and through focused observational campaigns supporting geophysical process studies.

Milestone 1:

Publish two peer-review journal articles discussing the High Resolution Infrared Radiation Sounder (HIRS) intercalibration method, and comparison of HIRS-corrected observations with HIRS simulated radiances from GFDL climate model.

Accomplishment: Correction of the 30-year HIRS radiance satellite record is generally thought to benefit the climate community in better understanding trends in tropospheric temperature, water vapor, cloud cover, and outgoing longwave radiation (OLR). One journal article was published describing a diurnal correction

of HIRS radiance observations. A HIRS intercalibration method was presented at a poster session last fall at the AMS Satellite Meteorology and Oceanography conference. Current work involves using the HIRS intercalibrated data to derive OLR so that gaps in the current satellite record for OLR can be filled, and using these corrected data to improve satellite cloud climatologies.

Product: Jackson, D.L., and B.J. Soden (2007), Detection and correction of orbital drift on spectral radiances from HIRS/2 observations, *J. Atmos. Oceanic Technol.*, 24, 1425–1438.

Jackson, D.L., B.J. Soden, and L. Shi (2007), Examination of the effect of increasing greenhouse gas concentrations on HIRS intercalibrated and diurnally-corrected observations, EUMETSAT Meteorological

Satellite Conference and 15th Satellite Meteorology and Oceanography Conference, Amsterdam, The Netherlands.

GSD-01 Numerical Weather Prediction

Goal: Design and evaluate new approaches for improving regional-scale numerical weather forecasts, including forecasts of severe weather events.

Milestone 1:

Continue ESRL/GSD testing of North American Rapid Refresh 1-h intermittent assimilation cycling, paying particular attention to performance of GSD enhancements in the use of surface observations and cloud and radar data in the Gridpoint Statistical Interpolation analysis and initialization of hydrometeors, and to the performance of physics suites in the WRF forecast component.

Accomplishment: The Rapid Refresh (RR) has been running in cycling mode since October 2007, when workarounds for problems with writing large files (induced by NOAA security patches) were tested and validated, and various other file-system difficulties on the supercomputer were overcome sufficiently to allow the minimum reliability necessary for cycling. For reference, cycling refers to the sequence of making a forecast and saving this forecast to use as an estimate for the next analysis, produced by combining this estimate with the most recent data. This analysis is then used as the initial data for the next forecast. For RR, as well as for the operational (at the National Weather Service) Rapid Update Cycle (RUC), this sequence happens hourly.

During the year, a number of enhancements deemed necessary for RR application were added to the 1-hour cycle. Among the most important was the Digital Filter Initialization (DFI). The purpose of the DFI is to reduce imbalance in the initial state of the forecast so that large-amplitude spurious gravity waves are not initiated at the start of the forecast. A similar DFI is part of the operational RUC and is considered vital to reducing the amplitude of spurious gravity waves in the 1-h forecast used as the guess for the next analysis. In this process, the model is run backward with only the reversible terms in the equations turned on (no physics or dissipation), the output being saved every time step, and then filtered in time to remove the high-frequency modes. These filtered fields constitute the initial state for the forward-in-time part of the DFI, in which the complete model (including physics and dissipation) is run forward. The filtering process is repeated for the forward portion of the DFI, and these filtered fields are then used as the initial conditions for the forecast. In the present application to the RR, the duration of both the backward and the forward part of the integration for the DFI is 40 min.

In April 2008, the forecast component of RR was upgraded to run with version 3.0 of the WRF-ARW

model and the March 2008 release of the Gridpoint Statistical Interpolation (GSI) 3dVAR analysis. This permitted access to some new features of both the model and analysis. Later, a serious cold bias in daytime temperatures was tracked down to erroneous updating of the top level of soil moisture coming through the GSI.

Verification against rawinsonde observations for 12h indicates that the RR 1-h cycle is producing wind forecasts with comparable RMS error to the RUC developmental cycle (Dev13) running at GSD, but temperature forecasts are somewhat worse, particularly at the shorter forecast ranges. This deficiency is being examined. Physics routines currently being used in the RR testing underway at GSD are:

- Dudhia shortwave radiation (including cloud effects)
- Rapid Radiative Transfer Model (RRTM) longwave
- RUC (Smirnova-CIRES) Land Surface Model
- Mellor-Yamada-Janjic surface layer and planetary boundary layer (identical to what is being used in the operational North American Mesoscale maintained by NCEP)
- Grell-Devenyi (CIRES) convective parameterization
- NCAR (Thompson) mixed-phase bulk microphysics

It is anticipated that this will be the physics configuration used in the operational RR, pending the outcome of further testing. Such testing will focus on improvements to the convective scheme with the goal of improving precipitation and upper wind forecasts, and to the land surface and surface layer schemes to improve low-level temperature forecasts under conditions of low-level warm advection over snow-covered land. In addition, on the analysis side, work will continue toward more meteorologically consistent use of surface data by the GSI. Also, three-dimensional radar reflectivity data will be used in conjunction with the DFI to produce initial conditions for the model forecast that have better consistency between the divergent component of the horizontal wind and observed areas of clouds and precipitation. The procedure used to accomplish this has been under development for the RUC for about three years and will soon also be implemented in the RR. For more on the Rapid Refresh, see <http://rapidrefresh.noaa.gov>.

Milestone 2:

Port well-tested ESRL/GSD code for North American Rapid Refresh to NCEP and begin pre-implementation testing at NCEP/EMC, in preparation for Rapid Refresh implementation into NCEP operations in 2008.

Accomplishment: The RR code is now approaching a level of reliability and maturity to make porting to NCEP computers practical. The plan is to begin porting code to the new NCEP developmental machine “haze,” with the goal of setting up a RR 1h-cycle there later this year. This will run in parallel to the existing GSD 1h-cycle, but will incorporate NCEP features into the file management of the cycling to avoid having to read and write large NetCDF files.

Milestone 3:

Conduct real-data testing with the global FIM model.

Accomplishment: The Flow-following Finite-Volume Icosahedral Model (FIM) was originally conceived by Dr. Alexander MacDonald, Director of ESRL. A number of scientists have contributed to its development and success in making credible 7-day global forecasts. The immediate purpose of this work, which is in partnership with the Environmental Modeling Center of the National Weather Service’s Environmental Centers for Environmental Prediction (NCEP), is to introduce FIM into the Global Ensemble Forecast System of NCEP, and so introduce further diversity into this set of ensemble forecasts. The ensembles are at present all based on NCEP’s Global Forecast System (GFS). The GSD-NCEP goal is to introduce FIM into the ensembles during 2010. An important emerging forecast application for FIM is tropical-cyclone track prediction, particularly recurvature, and the transition of tropical cyclones to extratropical.

Twice-daily forecasts of the FIM model out to seven

days began in late February 2008. These forecasts are being made at G8 horizontal resolution (polygon diameter of roughly 30 km) with 50 layers in the vertical defined by the hybrid isentropic vertical coordinate designed by R. Bleck (CIRES), and a model top of 20 mb. Physical parameterizations are identical to those used by the GFS. These forecasts are initialized from GFS spectral coefficient files ftp’d from NCEP twice daily.

Since February, rectification of several significant deficiencies have improved FIM forecasts to the point where FIM’s anomaly correlation scores for 500mb heights in the Southern Hemisphere are now comparable with NCEP’s operational GFS running at T382 resolution (approximately equivalent to 40km grid spacing). In the Northern Hemisphere, FIM still lags the GFS in 500mb anomaly correlation scores for most forecasts.

Currently, there are still at least two significant problems with FIM that have yet to be thoroughly tracked down and fixed. Further improvement in FIM forecasts is expected when these are fixed. In addition, use of the Web for display of FIM real-time forecasts has been steadily improving.

The possibility exists for several research applications of FIM aside from the immediate goal of its use as a forecast model as noted above. For example, FIM has potential use for long range chemical transport studies, and as a model component of a global analysis of record that is under discussion within the ESRL.

For more on FIM, see <http://fim.noaa.gov>.

Product: Lee, J.L., R. Bleck, A.E. MacDonald, J.W. Bao, S. Benjamin, J. Middlecoff, N. Wang, and J. Brown, FIM: A vertically flow-following, finite-volume icosahedral model, Preprints, 22nd Conf. Wea. Analysis Forecasting / 18th Conf. Num. Wea. Pred., Park City, UT, Amer. Meteor. Soc, 2007.

GSD-03 Verification Techniques for the Evaluation of Aviation Weather Forecasts

Goal: Design and evaluate new verification approaches and tools that will provide information about the quality of aviation forecasts and their value to aviation decision makers.

Milestone 1:

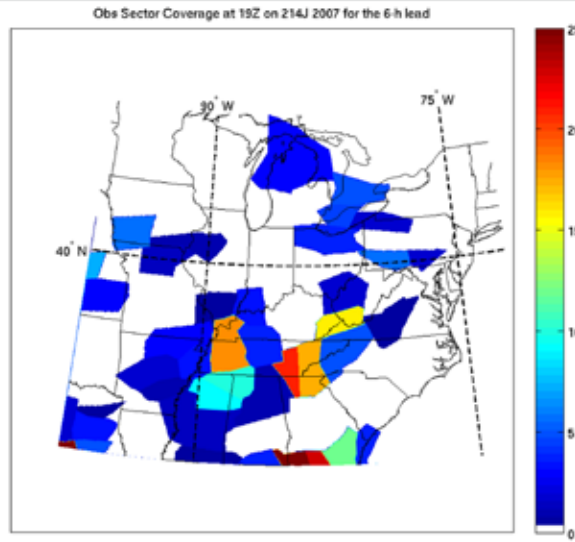
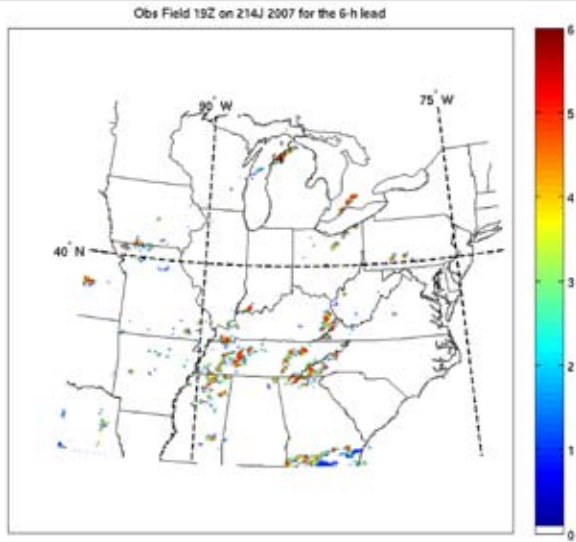
Continue with the redesign of the Real-Time Verification System (RTVS) by enhancing the functionality of the database, web-interface, and real-time processing modules of the system to support verification of aviation parameters, such as icing, turbulence, and convective weather.

Accomplishment: Upgrades to the RTVS web site have been completed. The upgrades will allow ease of use and quick access to on-going statistical information for operational aviation forecasts. Continuing is the transition of the RTVS to the NWS. An interface to the NWS datasets has been completed.

Milestone 2:

Investigate and develop new verification techniques appropriate for volcanic ash forecasts and turbulence forecasts in data-sparse oceanic regions.

Accomplishment: New verification techniques were developed and tested. These approaches included aviation flight sector-based verification approaches for convective forecast, automated confidence intervals, forecast calibration techniques, and techniques for evaluating the usefulness of *in-situ* turbulence observations for verification of automated turbulence forecasts. The figure (next page top) illustrates the transformation from the convective observations to the sector coverage. The sector coverage is used to verify convective forecasts as used by an air traffic decision maker.



The transformation from the convective observations (left panel) to the sector coverage (right panel). Hotter colors indicate high coverage and potential impact to the flow of air traffic across the country. The sector coverage is used to verify convective forecasts as used by an air traffic decision maker.

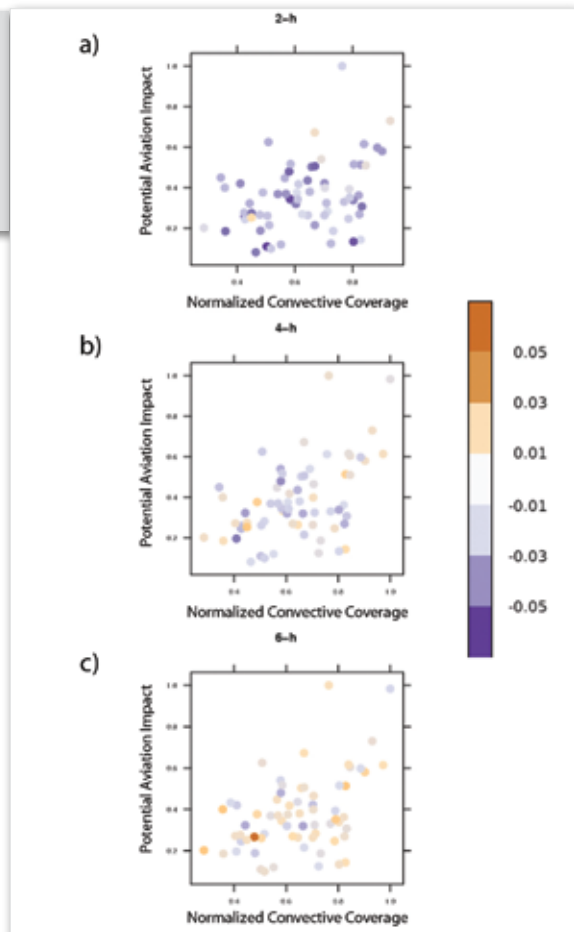
Milestone 3:

Summarize results from statistical evaluations of turbulence, convective weather, icing, volcanic ash, and cloud top height forecasts in written reports.

Accomplishment: Several forecast evaluations were completed. These included: the evaluation of the Forecast Icing Potential, the calibration of the Current Icing Potential, and an in-depth evaluation of various convective forecast products. A sample of the results

from the convective intercomparisons is shown above. The figure below shows the difference between the average critical success index (CSI) score for two convective forecast products for aviation impact as a function of normalized convective coverage within an aviation sector. The light colors at the 6-h time period (c), indicate that one forecast algorithm is better at forecasting the high-impact weather cases at the longer forecast lead than the other. As time decreases to 2-h (a), the order of algorithm performance reverses.

The difference between the average critical success index (CSI) score for two convective forecast products for aviation impact as a function of normalized convective coverage within an aviation sector. The light colors at the 6-h time period (c), indicate that one forecast algorithm is better at forecasting the high impact weather cases at the 6-h forecast lead than the other. As time decreases to 2-h (a), the order of algorithm performance reverses.



NGDC-03 Space Weather

Goal: Assess the current state of the space environment from the surface of the Sun to the upper atmosphere; use data-driven physical models to construct a realistic and authoritative gridded database of the space environment; and place that description into its long-term climatological perspective.

Milestone 1:

Develop automated quality-control techniques for ionospheric data.

Accomplishment: Deployed new version of Assimilative Mapping of Ionospheric Electrodynamics (AMIE) and ran model for years 2002 through 2006. A new version of the Simple Inner Magnetosphere Model (SIMM) was deployed, as was new processing software for Polar Orbiting Environmental Satellite (POES) data, which creates view graphics and user-friendly NetCDF files.

Milestone 2:

Integrate the Comprehensive Large Array Stewardship System (CLASS) with NOAA data management systems.

Accomplishment: CLASS hardware configuration was completed and CLASS has been determined to be operational. NOAA environmental data is being loaded into CLASS and integrated with NOAA data management systems.

Milestone 3:

Develop a generalized Virtual Observatory and support the Electronic Geophysical Year (EGY).

Accomplishment: The Virtual Radiation Belt Observatory (VIRBO) has been deployed. Environmental spacecraft data for NOAA POES missions are being processed and loaded into VIRBO.

Milestone 4:

Create a unified magnetics data management system.

Accomplishment: Difficulties in openly sharing and disseminating data have been identified and potential solutions evaluated. Although a comprehensive database of all accessible geomagnetic campaigns cannot be created, use of a number of processing routines have allowed the reformatting of different data types into one format that can be more easily accessed and used by researchers. This is being used as a basis to reformat all geomagnetic data in on single World Data Center Format, which will greatly improve the accessibility and useability of magnetics data.

SWPC-01 Solar Disturbances in the Geospace Environment

Goal: Improve the prediction of traveling solar disturbances that impact the geospace environment. Such disturbances, which are associated with both coronal holes and coronal mass ejections from the Sun, can cause substantial geomagnetic effects leading to the crippling of satellites, disruption of radio communications, and damage to electric power grids.

Milestone 1:

Calibrate GOES x-ray Instrument: Use selected solar observations and 2006 rocket underflight data.

Accomplishment: The Solar X-ray Imager (SXI) and disk-integrated X-ray Sensor (XRS) currently flying on GOES-12 and GOES-13 have undergone sounding rocket underflight calibrations. Results from this effort have been published in the Proceedings of SPIE. This calibration effort included the development of a forward model to account for each component of the two instruments. The forward models were used to compare the "solar truth" data from the rocket underflight with the observations by SXI and XRS, and the forward models were adjusted to determine the best fit to the data. This process has improved understanding of SXI and XRS instrument response, and the improved measurements will be beneficial to space weather forecasting.

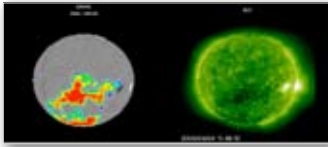
In addition, the imaging processing system is being updated to process data from the GOES-13 (and soon the GOES-14) SXI imager. This process involves rotating the image so that solar north is at the top of the

image, centering the image, accounting for vignetting, background subtraction, and bias. Once a system is in place, these images will be available in real time for forecasting needs.

Milestone 2:

Global Solar Wind Predictions: Further improve the SWPC predictions system by utilizing data from various observatories, and by extending the domain farther out into the heliosphere.

Accomplishment: The improved 2.5-degree resolution Wang-Sheeley-Argge (WSA) model has been automated to make daily solar wind and interplanetary magnetic fields at Earth. Results are available daily on the SWPC web site. This new version is also the input to the ENLIL MHD model, and is providing input once per day. Side-by-side comparisons of the WSA model predicted coronal holes and the observed coronal holes from SOHO/EIT images are provided for daily model validation (figure next page, top). The WSA model is in use at SWPC, the Community Coordinated Modeling Center, Sacramento Peak Observatory, and Air Force Research Labs.



Coronal hole as a high-speed solar wind region predicted by the WSA model (left) and as a reduced emission region observed by the SOHO/EIT (right).

Milestone 3:

Coronal Mass Ejection (CME) Locator: Develop and implement polarization technique to complement the purely geometric method used in the CME Locator, and to enhance understanding of CME properties.

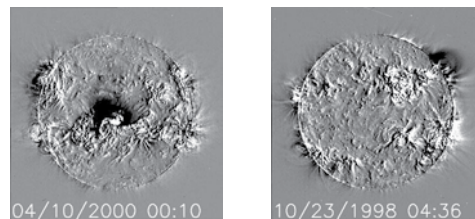
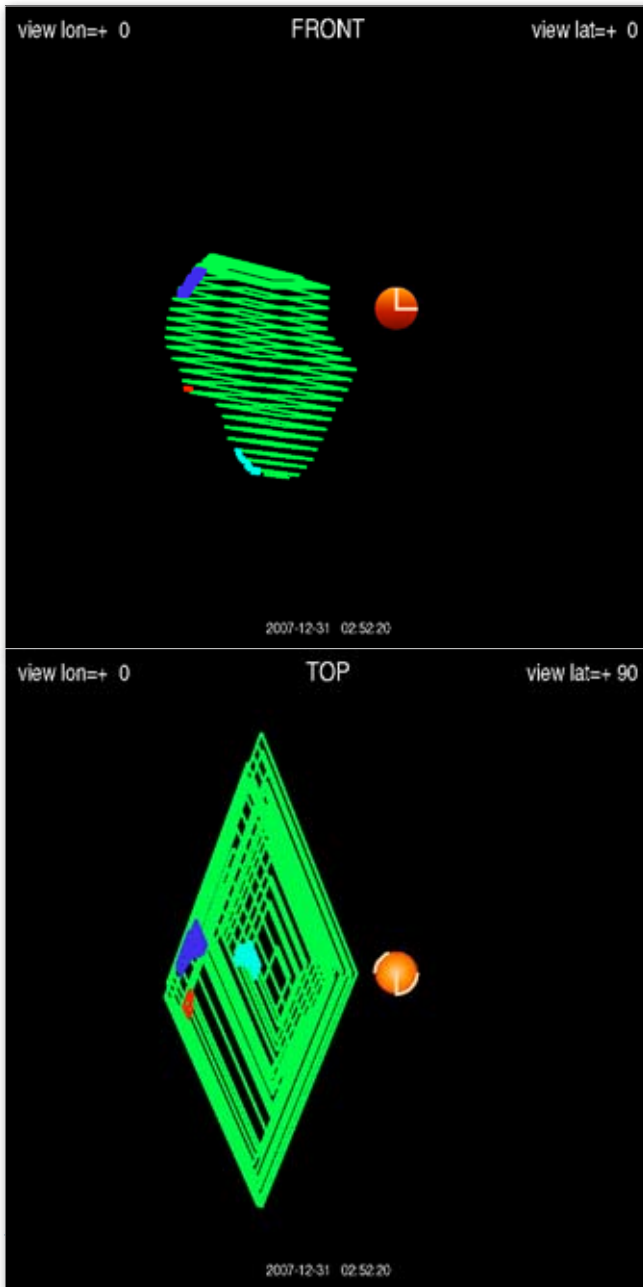
Accomplishment: The aim of this project is to develop, test, and implement methods and forecast tools for the analysis of data from the NASA/STEREO spacecraft mission, which was launched on October 26, 2006. The primary tool in this regard is a geometric localization technique developed by Pizzo and Biesscker (2004) for determining in near-real-time the position, shape,

and speed of coronal mass ejections (CMEs) using STEREO coronagraph observations (figure at left). The tool is presently being used in research mode, rather than forecast mode, to calculate the three-dimensional location and velocity of CMEs observed by STEREO. Collaborations have begun with researchers who are using other CME reconstruction techniques, to cross-compare results and to exchange model and method details. Thus far, results are very encouraging in that the different methods yield similar CME velocities.

Milestone 4:

EIT waves and dimmings: Determine if any clear association exists between the characteristics of a given dimming and the subsequent CME. If so, utilize dimmings to predict CME properties.

Accomplishment: Coronal dimmings are a phenomenon frequently associated with coronal mass ejections (CMEs). The figure below shows two examples of dimming events. On the left, a dimming is present in the center of the solar disk and on the right, a limb dimming is present in the upper right-hand corner of the image. A statistical analysis has been conducted of CME-associated dimming regions observed with the Extreme ultraviolet Imaging Telescope (EIT) on board the Solar and Heliospheric Observatory (SOHO) spacecraft. A paper has been published in the *Astrophysical Journal* detailing the average duration, risetime, recovery time, and area of nearly 100 dimming events. In addition, a study has begun, comparing dimming characteristics with heliospheric observations of CMEs. Some weak correlations have been found between dimming area and the total magnetic flux of a CME, as well as certain composition signatures. This effort is ongoing and is expected to provide further insight into CME origins and, more relevant for space weather forecasting, predictions of CME characteristics days before these events impact the Earth.



Two examples of dimming events, in the center of the solar disk (left) and on the solar limb (right).

Three-dimensional reconstruction of CME location observed by STEREO on Dec 31, 2007.

SWPC-02 Modeling the Upper Atmosphere

Goal: Understand responses of the upper atmosphere to solar, magnetospheric, and lower atmosphere forcing, and the coupling between the neighboring regions. Since many of the space weather effects occur in the ionosphere and neutral upper atmosphere, it is important to develop an understanding of the system to the point where accurate specification and forecasts can be achieved.

Milestone 1:

Obtain the operational version of the data assimilation model Global Assimilation of Ionospheric Measurements (GAIM). Implement in a test mode, using available global ground-based GPS and ionosonde data, and perform a preliminary validation of differential TEC using GPS dual frequency phase data.

Accomplishment: The Global Assimilation of Ionospheric Measurements (GAIM) model was developed by Utah State University and is currently running operationally at the Air Force Weather Agency. The code ingests data from a fairly sparse global ground-based GPS network, a few ionosonde stations, and satellite data. The model reconstructs the global three-dimensional electron density every 15 minutes, in real time. The output from the model can be used to estimate the vertically integrated total electron content (TEC). GAIM output is now routinely being transmitted to the SWPC for validation, and eventually for distribution to space weather customers.

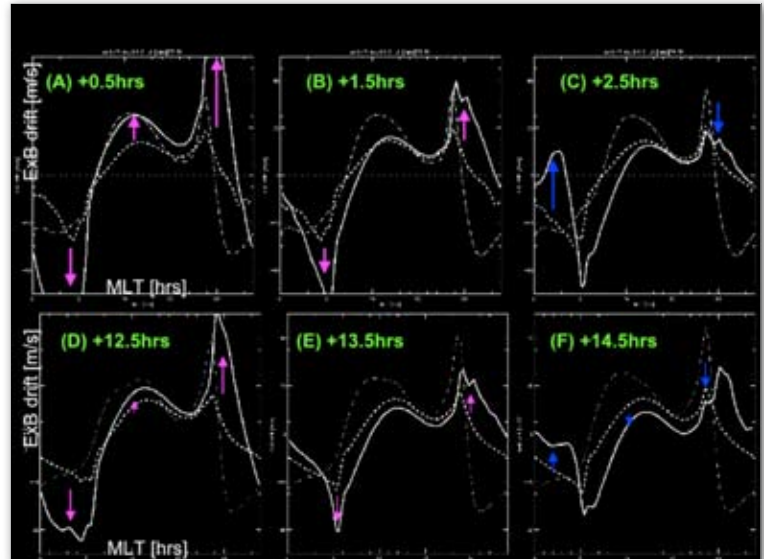
The U.S. Total Electron Content (TEC) model was developed in CIRES and is running operationally at SWPC in real time. The code ingests a dense network (>100) of ground-based GPS stations over the continental United States and estimates the TEC over this region. A physics-based coupled thermosphere-ionosphere-plasmasphere model with self-consistent electrostatics (CTIPE) is also running at SWPC and can produce the equivalent estimates of TEC but without data ingestion.

The three codes will be intercompared to validate the various estimates of TEC during July 2008. This project was a joint project between a SOARS Program student, SWPC, and CIRES.

Milestone 2:

Couple the thermosphere-ionosphere-plasmasphere-electrodynamic (CTIPE) space model with the Rice University Magnetospheric Convection Model (RCM).

Accomplishment: The main goal of the project is to understand and realistically model the mid- and low-latitude electrodynamic response of the thermosphere, ionosphere, and inner magnetosphere during geomagnetic storms. This has been achieved by coupling a Coupled Thermosphere Ionosphere Plasmasphere electrostatics (CTIPE) model with the Rice University Inner Magnetosphere Convection Model (RCM). The two models are complimentary, and together capture the interaction between the prompt penetration and disturbance dynamo electric fields.



An example of the equatorial vertical ExB drift at the magnetic equator as function of MLT, a) 0.5 hours from the storm commencement; b) 1.5 hours; c) 2.5 hours; d) 12.5 hours; e) 13.5 hours; and f) 14.5 hours. Solid lines show the coupled model storm simulation, the dashed lines show the coupled model quiet time simulation. The dashed-dotted lines show the climatology from the Fejer and Scherliess model.

RCM models the global inner-magnetosphere convection electric field, including simulating shielding timescales, and uses the ionospheric conductance and neutral winds from the thermosphere-ionosphere model. CTIPE models for the properties of the neutral and ionized species in the thermosphere and ionosphere, including self-consistent electrostatics. In the coupled model, the inner magnetosphere and thermosphere-ionosphere systems are treated self-consistently, including shielding time constants in response to the prompt penetration of magnetospheric electric field, and the neutral wind dynamo. In this coupling project, the region 2 field-aligned currents are provided by RCM everywhere in, and equatorward of, the auroral zone. These currents are then included into the electrodynamic solver of the CTIPE model, which includes the ionospheric dynamo electric field self-consistently. This technical development will allow, for the first time, description of all processes: direct penetration and shielding, the disturbance dynamo, and their mutual interaction. Realistic electrostatics enables simulation of the redistribution of ionospheric/plasmaspheric plasma in response to the disturbed electric fields during geomagnetic events. The coupled model will be used to interpret the observations of such features in the mid-latitude ionosphere as recently

observed in GPS-TEC indicating the global transport of plasma during large geomagnetic storms.

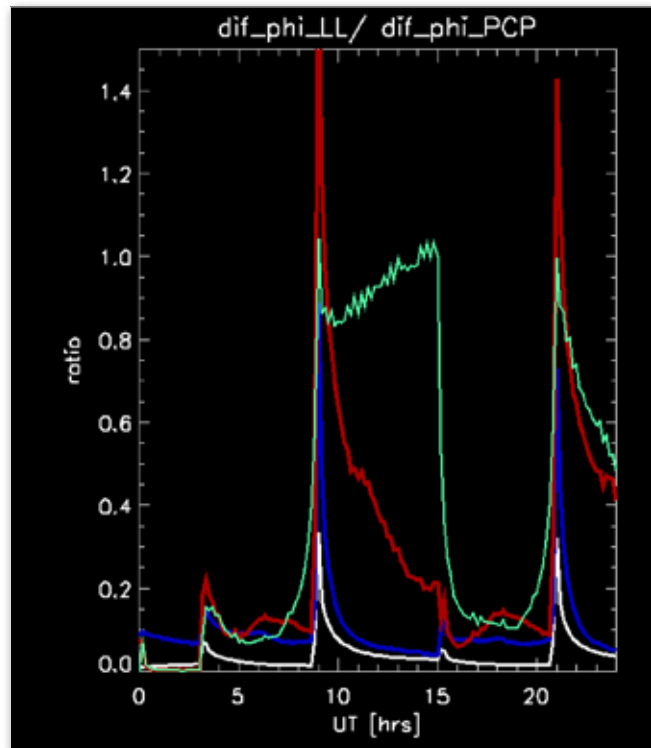
Physical model coupling. To describe the storm-time electric fields, the components have been coupled in the following steps:

1. Extract the region 2 field-aligned currents (FACs) from the RCM.
2. Use the global ionospheric conductivity and neutral wind from CTIpe to calculate the field line integrals of ionospheric wind dynamo current component.
3. Use these three inputs in the potential solver, in which the ionospheric current continuity equation is solved.
4. Obtain the global electric field by taking the gradient of the potential.
5. Map the electric field back to the RCM to drive hot plasma transport in the inner magnetosphere.
6. Map the electric field back to the ionosphere to transport the plasma in the ionosphere and plasmasphere.
7. Finally, use the electric field to calculate the joule heating and ion drag for the thermospheric dynamics and energetics. The coupling processes described above are now calculated self-consistently within the coupled RCM-CTIpe physical model. Furthermore, the coupled code is used to identify and understand the interaction between the prompt penetration (PP) and disturbance dynamo (DD) effects, which were previously simulated independently within the stand-alone RCM and CTIpe codes.

Validation of the storm-time electric field. The two sources of the disturbed electric fields have been identified in the results of the coupled model. The figure on the previous page shows an example of the ExB drift at the magnetic equator as a function of MLT, obtained from the coupled model. PP is dominant in panel A, where the response of the ExB drift is shown 0.5 hours after an enhancement of the CPCP from 25 to 150 kV. The PP features can be identified as an enhancement of the eastward electric field during the day and in the evening. During the night, the PP effect causes an enhancement of the westward electric field. The PP response is qualitatively consistent with the results from previous studies. In panel B, 1.5 hours from the CPCP enhancement, the PP effect is decaying. The DD features become dominant in panel C, 2.5 hours after the CPCP enhancement. The DD features can be identified as a reduction of the evening pre-reversal enhancement, whereas in the post-midnight sector, the zonal electric field reverses from westward to eastward. The qualitative features and the timescale of the DD response are generally consistent with previous finding. The PP causes positive potential at dawn and negative at dusk, as the same pattern “penetrates” from high

latitude. In panel C, the nighttime disturbed neutral winds drive an equatorward dynamo current, which tends to charge the low-latitude ionosphere positively around midnight and lead to reduction or reversal of the normal E-field, which is consistent with the original Blanc and Richmond dynamo theory. The net equatorial electric field is determined by the balance between the two processes.

The simulations clearly indicate that the magnitude of the storm-time response of the electric field depends on previous conditions, even with the same increase in the cross polar cap potential. Panels D and E show the responses of the equatorial vertical ExB drift to a 2nd enhancement of the cross polar cap potential by the same amount as the 1st (i.e., 25 to 150 kV), 12 hours after the 1st enhancement. The same qualitative features of the PP and DD effects are captured in panels D and E as those from the 1st enhancement shown in A-C. The magnitude of the response, however, is significantly smaller in the 2nd enhancement. The timescale and magnitude of the storm-time electric fields was highly variable, depending on the magnetospheric pressure



Responses of the low-latitude disturbed potential to the given CPCP variations, as a function of time. The ratio of the potential maximum-minimum differences is taken between the low latitude and the polar cap. White line is standalone RCM with the default MSIS/IRI conductance with the self-consistent auroral (electron) precipitation; Blue line is standalone RCM with the CTIpe conductance; Red line is coupled RCM-CTIpe results; Green line is the same coupled RCM-CTIpe model results with slower/larger CPCP variations.

distribution, field-aligned currents, ionospheric conductance, disturbance neutral wind, and the time history of high latitude forcing, indicating a system preconditioning effect. The figure (opposite page) shows the response of the low-latitude disturbed potential to the changing CPCP. The findings from the figure can be summarized as follows:

1. The over-shielding effect is larger than the under-shielding effect, which is mostly caused by magnetospheric preconditioning;
2. Over-shielding of the low-latitude disturbed potential lasts longer and is larger by including

the neutral wind, which is consistent with the fossil wind theory;

3. The neutral wind produces stronger shielding;
4. Slower enhancements produce weaker under-shielding since the shielding electric field can be established before the under-shielding effect maximizes. It is interesting to note that the 2nd under-shielding effect can disappear when the increase in the CPCP is slower and its magnitude is larger (green line).

AMOS-04: OBSERVING FACILITIES, CAMPAIGNS AND NETWORKS

GMD-01 Central Ultraviolet Calibration Facility
GMD-02 Surface Radiation Network

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GMD-01 Central Ultraviolet Calibration Facility

Goal: Provide a central facility for the calibration and characterization of solar ultraviolet broadband and spectral measurement systems to improve the long-term stability and comparison of measurements across national and international networks.

Milestone 1:

Collaborate with the National Institute of Standards and Technology's (NIST) Optics Division to compare vertical and horizontal irradiance scales as part of the interagency project between the Central UV Calibration Facility (CUCF) and NIST. The comparison provides a validation of the irradiance scale that is subsequently used by national and international agencies involved in UV monitoring and research. The interagency collaboration will publish and report a summary of the results.

Accomplishment: As a World Meteorological Organization (WMO) regional calibration center, the CUCF is tasked with ensuring the quality and comparability of the calibration systems and irradiance transfer systems. The WMO listed as an important task the comparison between different UV calibration regional centers around the globe. In fulfillment of this task, several calibration centers participated in an erythema intercomparison campaign from broadband radiometers in Davos, Switzerland. Data from seven international centers compared their simultaneous erythema broadband measurements, and spectral response and angular response measurements between PMOD in Switzerland and the CUCF. These centers are:

1. Physikalisches-Meteorologisches Observatorium Davos / World Radiation Center, Davos,

Switzerland

2. Aristotle University of Thessaloniki, Laboratory of Atmospheric Physics, Thessaloniki, Greece
3. Innsbruck Medical University, Division for Biomedical Physics, Innsbruck, Austria
4. National Oceanic and Atmospheric Administration, ESRL, Central UV Calibration Facility, Boulder, CO, United States.
5. Norwegian Radiation Protection Authority, Osteras, Norway
6. Nacional de Técnica Aeroespacial, Estación de Sondeos Atmosféricos El Arenosillo, Mazagon, Spain
7. STUK, Radiation and Nuclear Safety Authority, Non-Ionizing Radiation Laboratory, Helsinki, Finland

The results are presented in a paper submitted to the *Journal of Atmospheric Chemistry and Physics (ACP)*.

Product: G. Hulsen, J. Grobner, A. Bais, M. Blumthaler, P. Disterhoft, B. Johnsen, K. O. Lantz, C. Meleti, J. Schreder, J. M. Vilaplana Guerrero, and L. Ylianttila (2008), Intercomparison of erythemal broadband radiometers calibrated by seven UV calibration facilities in Europe and the U.S.A, *Atmos. Chem. Phys.*, accepted.

GMD-02: Surface Radiation Network

Goal: Collect long-term, research-quality upwelling and downwelling broadband solar and infrared radiation data at seven U.S. sites. Collect long-term, broadband ultraviolet radiation data to evaluate variations in the erythemal doses. Collect long-term, spectral filter data to measure column aerosol optical depth and cloud optical depth. Collect cloud cover data to assess the effect of clouds on the surface radiation budget.

Milestone 1:

Publish results of an objective comparison of automated total-sky imager cloud fraction retrievals and sky cover determinations from trained observers at Eglin Air Force Base and the Desert Rock radinsonde station.

Accomplishment: High-quality data continue to be collected, for normal archiving activities and for the research described here. A fundamental change was

made in the instrument operation this past year that will further improve the accuracy of the measurements. The change was to increase the frequency of samples, made possible by the acquisition of additional memory for the logging systems.

Product: Aerosol optical depth continues to be produced at each of the seven surface radiation monitoring sites.

CSV: CLIMATE SYSTEM VARIABILITY

Climate variability affects all natural systems and human activities. Climate directly influences agriculture, water quality, and human health. Understanding and predicting climate change is of critical interest to the public and to a broad array of decision makers within federal and state government, industry, resources management, and hazard mitigation. CIRES work in this theme addresses changes that occur on time scales from seasons and decades to millennia.

CSV-01 DETECTION OF CLIMATE MODES, TRENDS AND VARIABILITY

GMD-03 Climate Trend Analysis	105
PSD-04 Decadal Climate and Global Change Research	106
NGDC-04 Paleoclimatology: Understanding Decadal- to Millennial-Scale Climate Variability	107

GMD-03 Climate Trend Analysis

Goal: Interpret operational data (ozone column, ozone profile, aerosol extinction, broadband spectral radiation, and other environmental parameters) collected by NOAA ground-based and NCAR aircraft-based instruments. Assess data for long-term quality. Evaluate stability and interannual variability in the ground-based and aircraft-based datasets. Provide scientific community with information relevant to climate research, and evaluate usefulness of data for validation of other independent measurements, including satellite observations.

Milestone 1:

Develop ozone profile retrievals from the automated Dobson and Brewer radiometric measurements. Quantify aerosols interference in ozone retrievals

Accomplishment: This work evaluated the quality of ozone information derived from the ground-based Dobson and Brewer measurements. Quality-assured Umkehr Dobson data showed no significant differences in stratospheric ozone trends among stations in the northern middle latitudes. Trend differences found in stratospheric ozone depletion over Lauder, NZ (southern hemisphere compared to the Northern hemisphere) are most likely related to the starting date of the record. Upper tropospheric ozone trends are positive over the Northern latitudes. Umkehr and sonde-derived Quasi-Biannual Oscillation and Solar Cycle signals become more similar after the Umkehr Averaging Kernel smoothing is applied to the sonde profiles. In addition to the ozone trend analysis, the long-term Umkehr data records provide ground truth for homogenized SBUV and TOMS satellite data record. The new Brewer ozone algorithm PC-based software was developed in collaboration with Martin Stanek of the International Ozone Service, Canada. The work to further optimize the Brewer ozone profile retrieval is undergoing. The new ozone time-series data are available for six NOAA/EPA UV Brewer (NEUBrew) U.S. sites. Extended data will be available for future satellite mission validation and ozone recovery analysis. The impact of the Umkehr ozone profile retrieval algorithms on the derived trends shows that the UMK04-derived ozone time-series are in better agreement with trend analysis results performed on other ozone datasets in both the upper troposphere and stratosphere as

compared to the previous UMK92 results. Umkehr retrieved ozone profile time series are valuable assets in determining ozone interannual variability and trends in both stratosphere and troposphere.

Milestone 2:

Continue to retrieve ozone column data from photo-actinic flux hyper-spectral measurements onboard an aircraft under a variety of atmospheric conditions. Provide data to OMI/AURA satellite validation campaigns.

Accomplishment: This research is in support of Aura satellite validation activities. The Ozone Monitoring Instrument (OMI) total ozone columns and Microwave Limb Sounder integrated ozone profiles were validated in the tropical region. In the summer of 2007, the NASA DC8 aircraft took part in the Tropical Composition, Clouds, and Climate Coupling (TC4) campaign based in Costa Rica. Multiple *in-situ* and remote-sensing instruments aboard the aircraft were set to measure atmospheric composition of the tropical tropopause layer (TTL). The partial ozone column above the aircraft products were derived from the CCD Actinic Flux Spectrometer (CAFS) instrument (R. Shetter, NCAR) measurements as part of the continuous validation of the Aura ozone products. These instruments measure the down and upwelling UV and visible actinic flux as a function of wavelength. Both the combined stratospheric ozone columns derived from the CAFS measurements and the Differential Airborne Lidar ozone profile measurements aboard the NASA DC8 aircraft detected several spatial ozone gradients in the TTL. The analysis of the *in-situ* aircraft data and the data above the aircraft with regards to the TTL properties showed the influence by both slow ascent and by rapid transport in the deep convection conditions. The

transport trajectories and correlated measurements of the water vapor and other boundary-layer tracers were used in the ozone analysis. The new OMI total ozone column product was validated during the TC4 campaign. Analysis suggest that observed changes in the new OMI ozone columns derived over the clouds are caused by the new procedure applied for the detection of the effective cloud top pressures.

Product: Petropavlovskikh, I., L. Froidevaux, R. Shetter, S. Hall, K. Ullmann, P. Bhartia (2007), In-flight validation of Aura MLS ozone with CAFS partial ozone columns, *J. Geophys. Res.*, 112, doi:10.1029/2007JD008690.

Kroon, M, I. Petropavlovskikh, R. Shetter, S. Hall, K. Ullmann, J.P. Veefkind, R. D. McPeters, and P.F. Levelt (2007), OMI Total Ozone Column Validation with Aura-AVE CAFS Observations, *J. Geophys. Res.*, 112, doi:10.1029/2007JD008795.

R. McPeters, M. Kroon, G. Labow, E. Brinksma, D. Balis, I. Petropavlovskikh, J.P. Veefkind, P.K. Bhartia, and P.F. Levelt (2007), Validation of the Aura Ozone Monitoring Instrument Total Column Ozone Product, *J. Geophys. Res.*, 112, doi:10.1029/2007JD008.

Milestone 3:

Develop new products for Brewer NOAA network, such as tropospheric ozone and NO₂ column. Evaluate and characterize new products against well-established and co-located measurements. Provide data to OMI/AURA satellite validation campaigns.

Accomplishment: This work evaluated the quality of tropospheric ozone information derived from the ground-based Brewer zenith sky measurements. The re-established NOAA/EPAUV Network (NEUBrew) at six locations across the United States (Bondville IL, Fort Peck MT, Raleigh NC, Boulder CO, Mountain Research Station at Niwot Ridge CO, and Houston TX) takes automated direct sun and zenith sky ozone measurements. A recently developed Brewer Umkehr ozone profile retrieval algorithm is implemented at all NEUBrew sites to derive daily ozone profiles. Monitoring of the day-to-day and diurnal tropospheric ozone changes is one of the science objectives at the NEUBrew data center. In addition, this work is supported through the EPA Star grant for studies of changes in surface UV levels caused by tropospheric ozone. UV radiation drives photochemical reactions rates that are essential in pollution formation, and exposure to UV radiation can be a human health hazard. Tropospheric ozone data are validated through comparisons with co-incident ozonesonde measurements of high vertical resolution. The analysis concentrated on the short-term and long-term tropospheric ozone variability detected by co-incident and co-located Brewer data along with ozone profiles from ozonesondes available from Boulder, CO. Analyses suggest that the Brewer Umkehr technique is capable of monitoring short-term variability in tropospheric ozone. It can explain about 50 percent of the variability measured by ozone sonde.

PSD-04 Decadal Climate and Global Change Research

Goal: Improve understanding of long-term climate variations through analysis of observations and hierarchies of general circulation model (GCM) experiments. Seek dynamical explanations of oceanic variability and changes through observational analyses and GCM experiments. Provide attribution for long-term regional climate changes.

Milestone 1:

Diagnose impacts of ENSO-related and non-ENSO related tropical SST changes during the last 130 years.

Accomplishment: A major assessment of the contribution of ENSO-related variations to 20th century climate change was undertaken. For this purpose, ENSO was identified with the four dynamical eigenvectors of tropical SST evolution that are most important in the observed evolution of ENSO events. This definition was used to isolate the ENSO-related component of global SST variations on a month-by-month basis in the 136-yr (1871–2006) HadISST dataset. The analysis showed that previously identified multidecadal variations in the Pacific, Indian, and Atlantic oceans all have substantial ENSO components. The long-term warming trends over these oceans were also found to have appreciable ENSO components, in some instances up to 40 percent of the total trend. The ENSO-unrelated component of 5-yr average SST variations, obtained by removing the ENSO-related component, were interpreted as a

combination of anthropogenic, naturally forced, and internally generated coherent multidecadal variations. Two surprising aspects of these ENSO-unrelated variations were found: 1) a strong cooling trend in the eastern equatorial Pacific Ocean, and 2) a nearly zonally symmetric multidecadal Tropical-Extratropical seesaw that has amplified in recent decades. The latter was found to have played a major role in modulating SSTs over the Indian Ocean.

Milestone 2:

Continue assessing importance of coupled air-sea interactions, decadal ocean dynamics, land-surface feedbacks, and land-use changes on decadal and longer-term atmospheric variability.

Accomplishment: The utility of atmospheric general circulation model (GCM) integrations with prescribed SSTs is increasingly being questioned in the contexts of climate diagnosis, climate model error diagnosis, and short-term climate predictions. The basic issue is to what extent the errors in surface heat fluxes caused

by decoupling air–sea interactions in this manner affect climate variability and the mean climate. This issue has been investigated by generating and comparing multi-century coupled GCM simulations with corresponding atmospheric GCM simulations with prescribed SSTs obtained from the coupled simulations. When the SST time series is prescribed at the full (half-hourly) temporal resolution of the coupled model output, the uncoupled simulations have a negligibly small mean climate bias, small variance errors on subseasonal scales, and slightly larger variance errors on interannual and decadal scales. Even on decadal scales, the errors are notably smaller than anticipated from reduced local thermal damping considerations alone.

Overall, these results show that the errors introduced by prescribing SSTs, though not negligible, are generally much smaller than the atmospheric response to the SSTs themselves. To that extent, they justify performing and using such uncoupled integrations for diagnostic and prediction purposes.

Milestone 3:

Diagnose impacts of subseasonal tropical and stratospheric variability on longer-term global climate variability and the mean climate.

Accomplishment: An overall assessment of the impact of diabatic forcing variations on atmospheric variability and the mean climate was attempted by comparing with observations a long simulation of the northern winter climate by a dry adiabatic general circulation model forced only with the observed time-mean diabatic forcing as a constant forcing. Remarkably, despite the total neglect of all forcing variations, the model reproduced most features of the observed circulation variability and the mean climate, with biases similar to those of some state-of-the-art GCMs. In particular, the spatial structures of the circulation variability were remarkably well reproduced. Their amplitudes, however, were progressively underestimated from the synoptic to the subseasonal to interannual and longer time scales. This underestimation was attributed to the neglect of the variable forcing. It was argued that results of this study suggest a role for the stochastic, and not only the coherent, components of transient diabatic forcing in the dynamics of climate variability and the mean climate.

NGDC-04 Paleoclimatology: Understanding Decadal- to Millennial-Scale Climate Variability

Goal: Improve understanding of observed long-term climate variations through compilation and analysis of data from the pre-instrumental record and provide access to both data and information from the paleoclimatic record.

Milestone 1:

Extend Tree Flow data and information products to include other regions.

Accomplishment: The Tree Flow project involves creating reconstructions of past river flow from tree rings. This information is useful for water management because the reconstructions provide longer records, and therefore more robust statistics, of streamflow variability. In FY 2008, the Tree Flow web site was migrated to a University of Colorado at Boulder web site (http://www.colorado.edu/tree_ring/). Tree flow reconstructions were extended to the Rio Grande and a prototype was created for other regions based on this work (http://www.colorado.edu/tree_ring/riogrande/index.html). In addition, other hydroclimatic variables for the Rio Grande Basin have been reconstructed, including annual precipitation, cool season precipitation for climate divisions in New Mexico, and summer drought severity indices. web-based tools for data visualization and analysis have been developed.

Milestone 2:

Improve climate reconstruction datasets by adding new data and by creating a searchable index (catalog) and database.

Accomplishment: Reconstruction datasets are quantitative time series of past climate, for example temperature or precipitation, based on paleoclimate

proxies. The quantitative nature of these datasets makes them particularly useful for describing and understanding past climate variability. In FY 2008, a searchable index was created of the 170 reconstruction datasets currently archived. Also archived were 32 new reconstruction datasets, ranging from temperature reconstructions over glacial cycles to high-resolution reconstructions of drought and atmospheric circulation patterns.

Milestone 3:

Create a catalog of paleoclimate data needed to compare numerical climate model simulations with paleoclimate and improve climate models. This effort will archive new paleoclimate data useful in data-model comparisons.

Accomplishment: Paleoclimate proxy data provide an important benchmark for testing the skill of climate models. The existing catalog of paleoclimate data was expanded to include nearly all of the datasets currently archived. This brings the total number of datasets in the catalog to 4731, including the 114 new datasets archived this fiscal year. Descriptions of climate model output are also being added to the data catalog, allowing users to search for simulations from particular models or time periods.

CSV-02: MECHANISM AND FORCINGS OF CLIMATE VARIABILITY

CSD-03 Chemistry, Radiative Forcing, and Climate	108
PSD-01 Modeling of Seasonal to Interannual Variability	109
PSD-02 Understanding and Predicting Subseasonal Variations and their Implications for Longer Term Climate Variability	110
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CSD-03 Chemistry, Radiative Forcing, and Climate

Goal: Observe and model the radiative forcing due to stratospheric ozone changes and tropospheric radiatively active gases. Carry out upper-troposphere airborne experiments and diagnostic analyses that characterize the dynamical and chemical processes that influence the radiative balance in the global atmosphere. Quantify the chemical and optical properties that determine the lifetimes, abundances, and trends of greenhouse gases. Use passive cloud observations to develop techniques that can be used to estimate cloud properties.

Milestone 1:

Present and publish the results from the Gulf of Mexico Air Quality and Climate Change Study (GoMACCS).

Accomplishment: Analyses of aerosol, gas-phase and radiative measurements conducted aboard the NOAA R/V Ronald H. Brown during the TexAQs/GoMACCS 2006 campaign have been completed. One analysis has shown that direct emissions of particulate material (PM) from ships are significant. In particular, Lack et al. (2008a) have shown that emission of black carbon is a factor of two larger than previous estimates. This finding is of concern not only for potentially deleterious effects on local (ports) and regional (coastal and inland waterways) air quality, but also for direct and indirect warming effects in relatively pristine regions such as the Arctic. Further analyses of particulate matter (PM) emissions from ships (Lack et al., 2008b) has shown that the sulfur content of the fuel consumed by commercial ships has a strong influence on the properties of the emitted aerosol, such as the particle albedo and size distribution. Mass-based emission factors of PM parameters were determined and were used to calculate a global estimate of PM emissions from ships. The estimate was in good agreement with previous results except for the composition of the PM, which was found to be approximately evenly weighted between organic and sulfate components, with a smaller fraction (16 percent) in the form of black carbon.

Analysis of aerosol and radiative properties throughout the Gulf of Mexico study region has also been conducted (Bates et al., 2008). Background aerosol imported to the Houston-Galveston region during this period had been influenced by Saharan dust and emission from ships to the point that the aerosol mass was significantly larger than that observed for typical clean marine air masses. This background aerosol had more mass in the supermicrometer component than in the submicrometer. The aerosol mass burden near the urban and industrial source regions was greater than that over the Gulf of Mexico and was enriched in reduced organic mass and the $\text{SO}_2/(\text{SO}_2+\text{SO}_4)$ ratio. Submicrometer mass dominated in this near-source region. With offshore transport, the aerosol was

found to have been chemically processed, indicated by enrichment in oxygenated organic material, and was composed of a greater submicrometer mass than supermicrometer. The information gained from these analyses will be valuable for improved parameterization of aerosol processing and transformation in air quality forecast models and for radiative forcing calculations in climate models.

Product: Bates, T. S., P. K. Quinn, D. Coffman, K. Schulz, D. S. Covert, J. E. Johnson, E. J. Williams, B. M. Lerner, W. M. Angevine, S. C. Tucker, W. A. Brewer, and A. Stohl (2008), Boundary-layer Aerosol Chemistry during TexAQs/GoMACCS 2006: Insights into Aerosol Sources and Transformation Processes, *J. Geophys. Res.*, doi:10.1029/2008JD010023, *in press*.

Lack, D., B. Lerner, C. Granier, T. Baynard, E. Lovejoy, P. Massoli, A. R. Ravishankara, and E. Williams (2008a), Light absorbing carbon emissions from commercial shipping, *Geophys. Res. Lett.*, 35, L13815, doi:10.1029/2008GL033906.

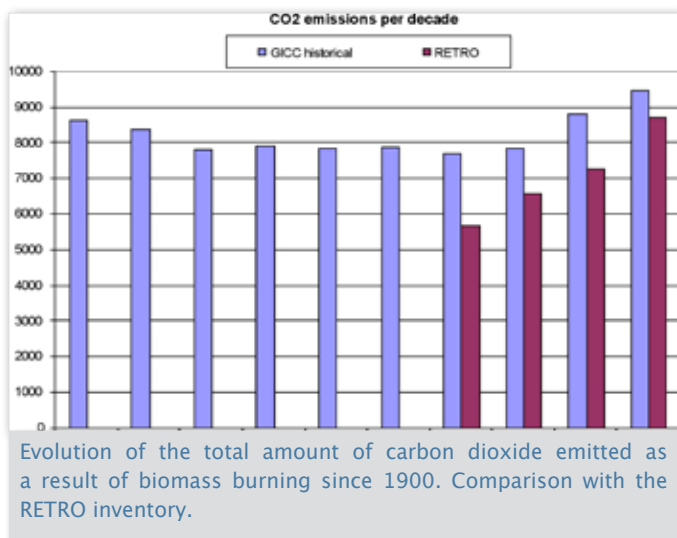
Lack, D., B. Lerner, P. Massoli, P.K. Quinn, D. Coffman, T.S. Bates, D.S. Covert, B. Sierau, T. Onasch, T. Baynard, E. Lovejoy, A.R. Ravishankara, and E.J. Williams (2008b), Particulate emissions from commercial shipping: optical, physical, and chemical properties, *in prep.*

Milestone 2:

Apply global chemistry/climate models to quantify the anthropogenic and biomass burning emissions for the 1860 to 2000 period, and their impact on ozone distributions.

Accomplishment: Since the end of the 1970s, biomass burning is known to be a major source of aerosols and gases in the atmosphere. The evolution of historical emissions due to biomass burning is essential for understanding the evolution of the distribution of tropospheric gases and aerosols during the past century. The evolution of fire emissions during the last century is however not well known, specially for the first decades.

An historical reconstruction of burned areas during the 20th century developed by Mouillot and Field (Global Change Biology, 2005) was used to calculate the emissions of atmospheric species for the 1900-



2007 period. The use of burned areas to determine the emissions of a species is not straightforward.

First, recent satellite observations of burned areas (i.e., the GBA-2000 product, Global Burned Area, a product from the Joint Research Center, Ispra, Italy), were used together with the ATSR World Fire Atlas (provided by the European Space Agency) which gives the location of active fires for the 1995–2007 period. The use of the distribution of vegetation provided by the Global Land Cover (GLC-2000, developed by JRC), together with information on the biomass density, burning efficiency, and emissions factors has allowed the construction of an inventory of biomass burning emissions for many atmospheric gases and aerosols during the 1997–2005 period.

To ensure consistency between historical and recent emissions, a scaling factor was then applied to the historical burnt areas dataset, for the different types of vegetation considered. Using this methodology, an inventory of biomass burning emissions was developed at a 1x1 degree resolution, on a decadal basis for the 1900–1990 period, and on a yearly basis for the 1997–2005 period.

An example of the evolution of the total emissions of CO₂ for each decade during the 1900–2000 period is shown in the figure above. Results are compared with the emissions provided by the RETRO inventory for the 1960–2000 period (Schultz et al., GBC, 2008). Most

modeling studies of the evolution of the composition of the troposphere performed during the past few years assumed that preindustrial biomass burning emissions were about 10 percent of the current emissions, with a rather similar spatial distribution. As shown on the figure, calculations show a very different evolution: global emissions due to biomass burning show a slight decrease from the 1900s to the 1960s. After that decade, a significant increase is obtained, which is due to the intense deforestation in the tropical areas of South America, Africa and South-East Asia.

These emissions are being inputted into the MOZART-4 chemistry-transport model. Simulations will be performed during the 1900–2007 period, and the evolution of the distribution of atmospheric gases and aerosols will be analyzed.

Product: These results have been presented at several international meetings and conferences. A publication will be submitted to *Atmospheric Environment*.

Milestone 3: *Employ high-resolution modeling, using MM5, of the dynamical processes around the subtropical jet stream; compare with observations, both statistically and in direct simulation.*

Accomplishment: The subtropical jet stream is an important feature of the upper troposphere and lower stratosphere, delimiting the width of the tropics and acting as a boundary between the stratosphere and troposphere. *In-situ* observations from aircraft platforms suggest that the subtropical jet stream can be a strong barrier to transport at times, and an active region of mixing at other times (e.g., Tuck et al. 2004, Ray et al. 2004). Initial simulations using the NCAR Mesoscale Model 5 (MM5) suggest that while the barrier aspect of the jet stream can be roughly reproduced by this model in certain cases, the mixing aspect of the jet stream is not accurately reproduced. Thus, this model is largely insensitive to observed small scale mixing in the region of the jet stream. The diffusive mixing scheme in MM5 is clearly not appropriate for examining small-scale transport near the jet stream. This essentially precludes the use of MM5 to assess whether small-scale mixing near the jet stream has a significant impact on climate modeling.

PSD-01 Modeling of Seasonal to Interannual Variability

Goal: Understand how much predictability, especially outside the tropics, exists on seasonal-to-interannual timescales beyond that associated with linear ENSO signals, and what additional useful predictive information can be extracted by making large ensembles of nonlinear General Circulation Model (GCM) integrations.

Milestone 1: *Continue 20th century reanalysis efforts in collaboration with NCEP, NCAR, NCDC, ECMWF, U. of East Anglia, Environment Canada, ETH-Zurich, and the UK Hadley Centre.*

Accomplishment: Production has begun of the reanalysis dataset spanning the late 19th century to present. Version 1 of the years 1908 to 1958 is now complete. About 18.6 million CPU hours for 2008 has been awarded from the DOE INCITE program to produce Version 2, spanning 1892–2008. Efforts at PSD/CDC,

NCEP, NCAR, NCDC, and international institutions are being coordinated for the International Surface Pressure Databank, the input database of surface pressure observations for the reanalysis.

Milestone 2:

Assess the importance of the global nonlinear impacts of central equatorial Pacific sea surface temperature changes.

Accomplishment: New atmospheric general circulation model integrations have been performed with identical prescribed warm and cold tropical sea surface temperature anomaly fields to further assess the nonlinear aspects of the response on extratropical stormtrack fields.

Milestone 3:

Assess the predictability of Northern American Summertime precipitation using a number of atmospheric general circulation models.

Accomplishment: The predictability of long-term precipitation trends over the Americas has been investigated by estimating the relative magnitudes of the trends associated with the ENSO-related unpredictable tropical SST trends and the ENSO-unrelated and potentially predictable tropical SST trends. This was done using the NCAR and NCEP atmospheric general circulation models. The unpredictable part was of the trend was found to be surprisingly large.

PSD-02 Understanding and Predicting Subseasonal Variations and their Implications for Longer Term Climate Variability

Goal: Investigate the variability and predictability of weekly averages of the atmospheric circulation through modeling and diagnosis of the observed statistics, and also through detailed analysis of numerical weather forecast ensembles for Week Two.

Milestone 1:

Use an empirical-dynamical coupled atmosphere-ocean model of tropical subseasonal variations to assess the impact of air-sea coupling on the variability and predictability of the Madden-Julian Oscillation (MJO).

Accomplishment: The impact of air-sea coupling on the predictability of weekly mean sea SST and atmospheric circulation and diabatic heating in the Tropics has been investigated in a coupled Linear Inverse Model (C-LIM). Predicted and observed lag-covariances and spectra were generally found to be in excellent agreement, even at much longer lags than that used to train the C-LIM. It was found that coupling SST to the atmosphere has a notable impact on interannual variability, but only a minor effect on intraseasonal (MJO) variability.

Milestone 2:

Investigate subseasonal atmospheric variability in the tropical Indian Ocean using AGCM experiments, with emphasis on the influences of the Indian Ocean SST dipole.

Accomplishment: A general circulation model study was conducted to determine the impact of air-

sea coupling in the Indian ocean on subseasonal atmospheric variability. The specific goal was to assess the importance of errors in atmospheric GCM forecasts introduced by prescribing SSTs in the region. Such errors were small, and not the likely source of the large Madden-Julian Oscillation simulation and prediction errors found in many GCMs.

Milestone 3:

Continue investigating the variability and predictability of extratropical subseasonal variations in all seasons of the year using a linear empirical-dynamical model that includes air-sea coupled tropical and stratospheric influences. Assess the predictability from deterministic as well as probabilistic perspectives, particularly in regard to the case-by-case and regime-dependent variations of predictability.

Accomplishment: Detailed analysis using the Linear Inverse Model showed that tropical diabatic heating greatly enhances persistent variability throughout the Pacific sector and over North America, while stratospheric effects are notable primarily over the polar region and Europe. A comprehensive paper describing the analysis technique and results was accepted for publication in the *Journal of Climate*.

GMD-04 Climate Forcing

Goal: Greenhouse gases: Conduct research to better understand the interactions of the atmosphere with the land and ocean. Aerosols: Characterize the means, variabilities, and trends of climate-forcing properties for different types of aerosols, and understand the factors that control these properties. Radiation: Research into broadband irradiance to improve benchmarks for climatic processes.

Milestone 1:

Incorporate models of ocean carbon, fire emissions, and fossil fuel emissions in GMD Ensemble Kalman Filter Carbon Data Assimilation system, and use to improve global and regional estimates of carbon flux.

Accomplishment: New ocean, fire, and fossil fuel

models have been developed for the CarbonTracker system. The ocean model now has 31 regions instead of 11. The fossil fuel model now takes advantage of country-based data to improve spatial resolution. The fire model is now kept up to date so that actual-year instead of climatological fire emissions are used in the data assimilation.

Product: W. Peters, A.R. Jacobson, C. Sweeney, A.E. Andrews, T.J. Conway, K. Masarie, J.B. Miller, L.M.P. Bruhwiler, G. Petron, A.I. Hirsch, D.E.J. Worthy, G.R. van der Werf, J.T. Randerson, P.O. Wennberg, M.C. Krol, and P.P. Tans (2007), An atmospheric perspective on North American carbon dioxide exchange: CarbonTracker, *Proc. Natl. Acad. Sci.*, 104 (48) : 18925–18930, issn: 0027–8424, ids: 239DK, doi: 10.1073/pnas.0708986104.

Milestone 2:

Use North American measurements of ¹⁴CO₂ and CO₂ to diagnose and improve representation of vertical transport within TM5 transport model.

Accomplishment: North American measurements of ¹⁴CO₂ and CO₂ have been used to diagnose and improve representation of vertical transport within TM5 transport model. Preliminary analysis of these data suggest that the TM5 model is generally accurate on an annual mean scale, but that significant seasonal transport deficiencies exist.

Milestone 3:

Use measurements of CO₂, CH₄, CO and N₂O from the Brazilian Amazon to evaluate process-based model estimates of emissions of these gases.

Accomplishment: Emissions estimates of CO₂ for the Brazilian Amazon have been compared with CO₂ measurements from aircraft. One preliminary conclusion is that there is much more variability in the real biosphere than as represented by the CarbonTracker model. Additionally, using a combination of SCIAMACHY satellite CH₄ data and aircraft observations, it has been shown that process-based models underestimate Amazonian methane emissions.

Product: Meirink, J. F., P. Bergamaschi, C. Frankenberg, M. T.S. D’Amelio, E. Dlugokencky, L. Gatti, S. Houweling, J.B. Miller, T. Rockmann, M.G. Villani, and M. Krol (2008), Four-dimensional Variational Data Assimilation for Inverse Modelling of Atmospheric Methane Emissions: Analysis of SCIAMACHY Observations, *Journal Geophys. Res.*, in press.

Miller, J.B., L.V. Gatti, M.T.S. d’Amelio, A.M. Crowell, E.J. Dlugokencky, P. Bakwin, P. Artaxo, and P. Tans (2007), Airborne measurements indicate large methane emissions from the eastern Amazon Basin. *Geophys. Res. Lett.*, 34 (10) : Art. No. L10809, issn: 0094–8276, ids: 173AM, doi: 10.1029/2006GL029213.

Milestone 4:

Implement representation of CH₄ within Ensemble Kalman Filter Carbon Data Assimilation system, to estimate fluxes of this greenhouse gas within for North America and globally.

Accomplishment: CH₄ has been implemented within the Ensemble Kalman Filter/CarbonTracker data assimilation system. No multi-year flux calculations have been made yet, but initial work suggests that the system operates as intended. Additionally, groundwork has been completed that simulates the ¹³C/¹²C ratio of methane with the CarbonTracker framework. This will

allow for the incorporation of ¹³C/¹²C within the data assimilation at a later time.

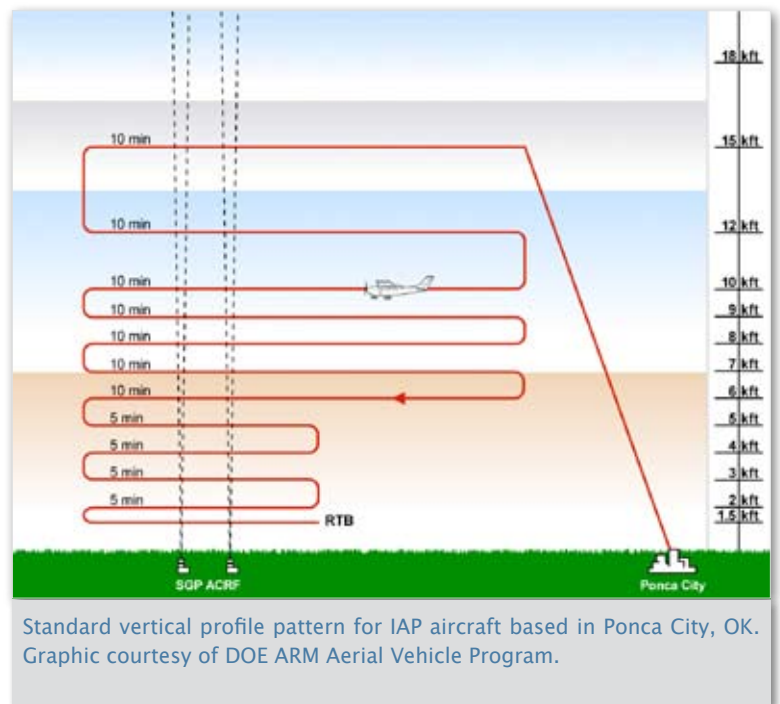
Milestone 5:

Develop tools to compare in-situ aerosol measurements from two NOAA-mentored airplane packages with measurements from ground-based sunphotometers and lidars. This work may improve retrievals of derived aerosol properties (e.g., size distribution) from remote sensing instruments and thus is applicable to remote sensing platforms both at the surface and in space (e.g., CALIPSO).

Accomplishment: Many remote sensing aerosol instruments (e.g., sunphotometers such as utilized by the AERONET network) measure/derive column average aerosol properties. To compare the *in-situ* measurements from the airplanes with co-located column average measurements, several corrections to the *in-situ* data must be made:

1. adjustments for the airplane inlet size cut,
2. adjustment to ambient conditions of relative humidity, and
3. assumptions about how to treat the aerosol between level flight legs and above the highest leg/below the lowest leg must be made.

Tools have been developed to allow these adjustments and the calculation of column averaged aerosol properties. In Andrews et al. (2004), comparisons of aerosol optical depth (AOD) (e.g., column average extinction), calculated from the *in-situ* aerosol profiles vertical profiles with other measurements of remote sensing measurements of AOD made from ground-based instruments showed fair correlation (R² ~0.8), although the aircraft AOD tends to have a consistent



offset of ~ -0.04 AOD units. Similar results were found by Ferrare et al. (2006). These scripts have also been used to make AOD comparisons between Airborne Aerosol Observatory (AAO) and an Aerosol RObotic NETwork (AERONET) sunphotometer based under the profile flights in Illinois (Sheridan et al. 2008).

Comparisons of column average properties obtained from different platforms provide a useful check on different techniques for deriving what might be termed bulk atmospheric conditions. However, in terms of climate forcing and aerosol transport it is often more useful to know the vertical distribution of the aerosol. Again, tools for adjusting the measurements made aboard IAP and AAO to ambient conditions allow comparison of the *in-situ* measurements with those made by instrumentation capable of measuring the vertical distribution of aerosol particles, e.g., lidar. Schmid et al. (2008) have shown good agreement between aerosol vertical distributions derived from micropulse lidar, an airborne sunphotometer, and the IAP vertical profiles obtained during 2003 and 2005 field campaigns in Oklahoma (figure previous page). Even more preliminary, comparisons of AAO vertical profiles with those obtained by CALIPSO's lidar show that the satellite is capable of reliably detecting layers of atmospheric aerosol when the scattering in the layer is greater than $\sim 25 \text{ Mm}^{-1}$ (Ogren et al. 2008).

The above accomplishments rely on adjusting measured *in-situ* aerosol optical properties based on surface measurements of aerosol properties such as hygroscopicity. This past year, funding allowed utilization of the AAO airplane to validate NASA Goddard Space Flight Center spectral lidar measurements and data inversion products. To accomplish this, additional tools will be developed to incorporate the large suite of measurements available on AAO, including aerosol size distribution and hygroscopicity.

Product: Ogren, J.A., Sheridan, P.J., Andrews, E., and Anderson, T.L. (2008), Comparison of aerosol vertical profiles from spaceborne lidar with *in-situ* measurements, NOAA Global Monitoring Annual Conference, Boulder, CO.

Sheridan, P.J., Andrews, E., Ogren, J.A., Albee, R., Wendell, J., and Unander, S. (2008), The NOAA/ESRL Airborne Aerosol Observatory the first two years of operation, NOAA Global Monitoring Annual Conference, Boulder, CO.

Schmid, B., Turner, D., Ferrare, R., Flynn, C., Newsom, R., Andrews, E., Ogren, J., Johnson, R., and Clayton, M. (2008), Routine measurements of aerosol extinction profiles by the ARM program and their validation, work in progress.

CSV-03 STRATOSPHERIC OZONE DEPLETION

CSD-04 Tropospheric and Stratospheric Transport and Chemical Transformation
GMD-05 Ozone Depletion

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CSD-04 Tropospheric and Stratospheric Transport and Chemical Transformation

Goal: Improve theoretical capabilities to predict the natural and human influences on the stratospheric ozone layer. Characterize the photochemical reactions relating to the human-induced loss of ozone in the stratosphere. Carry out *in-situ* studies of the photochemical and dynamical processes that influence the stratospheric ozone layer.

Milestone 1:

Examine what is necessary to improve the simulation of transport by three-dimensional numerical models of the atmosphere.

Accomplishment: Simulation of transport characteristics in the upper troposphere and lower stratosphere is important in order for global models to accurately forecast the climate. In particular, small-scale processes near the tropopause can have a significant impact on trace gas distributions and subsequently the chemical and radiative balance of the atmosphere. To aid in validation, flight-planning support was provided for two aircraft field missions designed to collect *in-situ* measurements of important trace gases in the upper troposphere and lower stratosphere. The first mission was the Tropical Composition Cloud and Climate Coupling (TC4) deployment based in San Jose, Costa Rica in July and August 2007. This mission included the WB-57, DC-8, and ER-2 aircraft and was

designed to investigate the structure, properties, and processes in the tropical Eastern Pacific. The second mission was the Stratosphere-Troposphere Analysis of Regional Transport (START08) deployment based in Boulder, CO in April and May 2008. This mission utilized the Gulfstream V aircraft to study the chemical, microphysical and transport characteristics of the extratropical upper troposphere and lower stratosphere.

Involvement consisted of providing local weather forecasts, analyzing tropospheric and stratospheric forecast conditions to help determine flight locations based on mission objectives, and the use of flight planning software Met Widget to help make flight plans. Met Widget is a unique IDL software package designed and maintained in the lab. This package allows drawing of flight plans on meteorological forecasts and easy communication of flight plans from the mission scientists to the flight crew.

GMD-05 Ozone Depletion

Goal: Stratospheric Ozone Measurements: Measure ozone declines during the past two decades at northern hemispheric midlatitudes and the tropics and to characterize dramatic ozone depletions over Antarctica. Ozone-Depleting Gases: Conduct research in the troposphere, stratosphere, oceans, polar snowpack, and terrestrial ecosystems in an effort to understand and predict the atmospheric behavior of these gases. Stratospheric Aerosols: Conduct experiments and measurements on aerosols to determine their impacts on solar insolation. Stratospheric Water Vapor: Conduct measurements to determine the change in water vapor and its coupling with aerosols.

Milestone 1:

The Ozone Depleting Gas Index will be updated and refined, as needed, with continued measurements of ozone depleting gases by NOAA and CIRES personnel.

Accomplishment: Air samples from multiple remote sites in both hemispheres were collected and analyzed to provide estimates of global surface concentrations of ozone-depleting gases throughout the period July 2007–Jun 2008. These results allowed update of the Ozone Depleting Gas Index (ODGI) through 2007.

Product: The ODGI shows that the overall atmospheric abundance of ozone-depleting gases continued to decrease through 2007 at a rate of 1–2 percent/yr. A paper describing the index and its changes through 2007 was submitted in May for publication in EOS. The web description of the index will be updated through 2007 by the end of September.

Milestone 2:

Utilize NASA aircraft and stratospheric balloon platforms to validate tropospheric and stratospheric measurements of ODSs (N₂O, CFC-

11, CFC-12) by space-borne instrumentation aboard the Aura satellite. These measurements, made as part of NASA-sponsored campaigns, also increase knowledge about upper atmospheric transport and chemistry, which in turn improve understanding of stratospheric ozone and its projected recovery.

Accomplishment: Thousands of *in-situ* measurements of ozone-depleting and climate-forcing gases were made aboard the NASA WB-57 aircraft during the Tropical Composition, Cloud and Climate Coupling (TC4) mission in July–August 2007 and aboard the NCAR/NSF Gulfstream-V aircraft during the Stratosphere–Troposphere Analyses of Regional Transport (START) mission in April–June 2008.

Product: These measurements provide important information about transport and chemistry in two important atmospheric regions; the tropical tropopause transition layer and the extra-tropical upper troposphere—lower stratosphere region. They also provide validation data for satellite-based sensors that map global trace gas distributions.

CSV-04 CLIMATE DYNAMICS

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PSD-06 Climate Dynamics

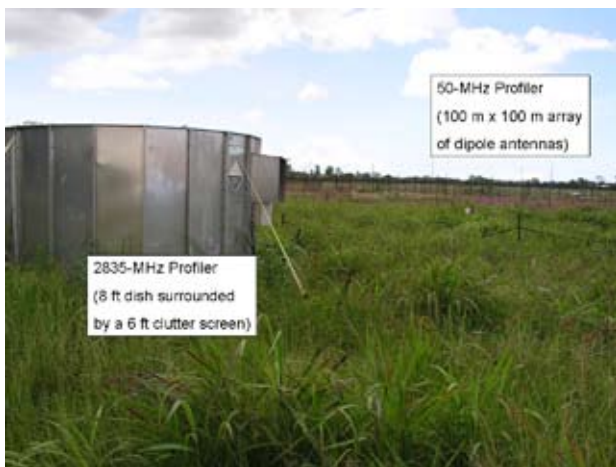
Goal: Conduct research to improve understanding of tropical Pacific Ocean dynamical processes related to the subseasonal atmospheric variability, the dynamics and the microphysics of precipitating cloud systems, and atmospheric circulation, convection, and moisture and heat budgets associated with the El Niño phenomenon.

Milestone 1:

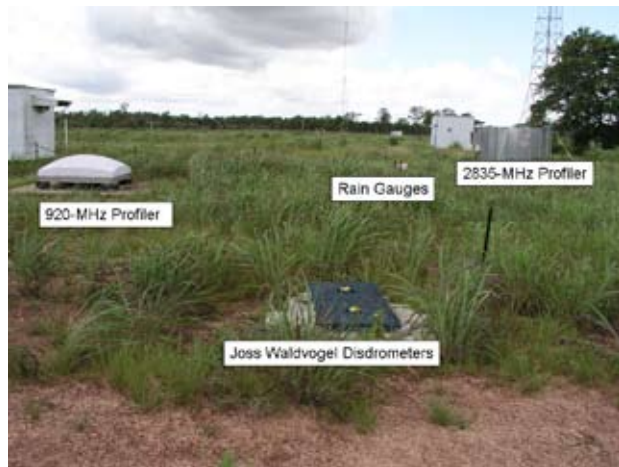
Determine the climatology of vertical air motions during precipitation events using the 17-year record of 50-MHz profiler radar observations collected at Darwin, Australia. The frequency distribution of vertical air motions during the ‘On Set’, ‘Monsoon’, and ‘Break’ periods are not well documented and are not well understood. This climatology of observed vertical air motions will be needed to validate the frequency distributions of vertical air motion simulated in numerical weather prediction and climate models.

Accomplishment: The 50-MHz profiling radar observations from Darwin, Australia, during the 2005–

2006 wet season have been processed during the On Set, Monsoon, and Break periods. Upward vertical air motions during the convective On Set period often exceeded 20 m/s. During the Monsoon period, the vertical air motions during the convective rain were typically 5 m/s upward. These vertical air motion observations have been provided to cloud modelers and work is ongoing to compare the frequency distributions of these observations and vertical air motions estimated by their models. Also, the 50-MHz profiler vertical air motions were used with the 920 MHz profiler observations to estimate the raindrop size distribution (DSD) as a function of height and then compared with DSDs estimated from a scanning polarimetric radar.



The NOAA/ESRL 2835-MHz profiler consists of an 8 ft circular dish surrounded by a 6-ft tall clutter screen. This antenna is very small compared to the 100 m by 100 m square array of dipole antennas of the 50-MHz wind profiler shown in the background.



NOAA/ESRL 2835-MHz precipitation profiler and CIRES Joss Waldvogel Disdrometers installed next to the permanently installed 920-MHz wind profiler (owned by CIRES) during TWP-ICE near Darwin, Australia (November 2005– April 2006).

In support of the Tropical Western Pacific—International Cloud Experiment (TWP-ICE), a NOAA/ESRL 2835-MHz vertically pointing precipitation radar and CIRES surface disdrometers were installed next to the permanently installed 920-MHz and 50-MHz wind profilers near Darwin, Australia. The NOAA/ESRL and CIRES instruments were installed for the wet season from November 2005 through April 2006. The 2835- and 50-MHz profilers are shown above (left).

The wind profiler site at Darwin, Australia, is operated and maintained by the Australian Bureau of Meteorology (BOM). Collaborations between BOM, NOAA/ESRL and CIRES enable instruments to be installed at the Darwin site and data to be freely exchanged between scientists in all three organizations.

Product: Williams, C.R., and P.T. May (2008), Uncertainties in profiler and polarimetric DSD estimates and their relation to rainfall uncertainties, *J. Atmos. and Oceanic Technol.*, in press.

Milestone 2:

Retrieve and analyze the raindrop size distribution (DSD) from multiple years of profiler observations producing tens-of-thousands of DSD profiles in different rain regimes that will lead to physically based DSD parameterizations needed to reduce the errors in current and future satellite based precipitation algorithms. These improved DSD parameterizations will also improve numerical weather prediction and climate model descriptions of precipitation. Data for this analysis will include profiler observations made in Darwin, Australia, and Estacion Obispo, Mexico.

Accomplishment: The raindrop size distribution (DSD) retrieved from profiler observations at Darwin, Australia, were analyzed to determine the DSD retrieval error using Ensemble Modeling. The same profiler observations were used as inputs into 42 different DSD retrieval models producing 42 different DSD estimates. The analysis indicates that the uncertainty of the retrieved mean raindrop diameter is about 0.1 mm and the uncertainty of the retrieved rain rate is about 8 percent, with the uncertainty increasing to 30 percent in

heavier precipitation. The 920- and 2835-MHz profiling radars used in this study are shown above (right), along with the surface rain gauges and disdrometers.

Product: Williams, C.R., and K.S. Gage (2008), Raindrop size distribution variability estimated using ensemble statistics, *Annales Geophysicae*, submitted.

Milestone 3:

Document the daily cycles of lower-tropospheric winds and surface fluxes at Estacion Obispo (Mexico) during the 2005 and 2006 North American Monsoon seasons, and evaluate the extent of interannual variability during 2004-2006.

Accomplishment: Summer-mean wind profiles and daily cycles from Estacion Obispo during 2005 and 2006 have been computed and compared with 2004 results and large-scale conditions. In the mean, the flow aloft was more northeasterly in 2005 compared with other years, and in 2006, the low-level southwesterlies backed with height instead of veering with height. The more northerly flow aloft in 2005 is consistent with the 700 hPa geopotential pattern found in the NCEP/NCAR Reanalyses. The driest year at Estacion Obispo was 2005, with five days having about 20–50 mm of rain and most of the others quite dry. More rain fell in 2004, in spite of the fact that the monsoon started fairly late. There were also distinct active and break periods. By far the wettest year was 2006, which had many fairly evenly spaced days with 20–50 mm of rain. In terms of the daily cycle, a sea breeze feature is evident in all three years, although directional constancy increases from year to year. Aloft, there were subdaily variations in southeasterlies at 3,000 m in 2004 and 2006, whereas in 2005 easterlies persisted throughout most of the day (with less directional constancy than during 2004 and 2006).

Product: Interannual Variability of the North American Monsoon: Large-Scale Conditions and Small-Scale Effects, oral presentation at the 28th Conference on Hurricanes and Tropical Meteorology, Orlando, FL.

CSD-06 Turbulent Meteorological Motions

Goal: Understand the mechanisms and effects by which turbulence influences atmospheric chemistry, composition, radiation, and transport on all scales, from that of molecular diffusion to that of the globe, some nine orders of magnitude. One milestone was met.

Milestone 1:

Explore methods of incorporating molecular-scale non-equilibrium statistical thermodynamics into the meteorological formulations of the Navier-Stokes equation for air flow.

Accomplishment: The nature of the atmosphere's vertical stratification is an outstanding problem in atmospheric science. Its characterization has been the subject of numerous theories of dynamical meteorology and its numerical modeling the subject of a series of problematic approximations. More than 200 state-of-the-art drop sonde atmospheric profiles were

used to test the predictions of cascade models of the atmosphere on the horizontal velocity, pressure, temperature, log potential temperature, log equivalent potential temperature, air density, humidity, and vertical sonde velocity. The study was motivated by the need to directly check the predictions of cascade models in the vertical direction. The predictions were accurately verified.

Product: Lovejoy, S., A.F. Tuck, S.J. Hovde, and D. Schertzer (2008), The vertical cascade structure of the atmosphere and multifractal dropsonde outages, *Journal of Geophysical Research*, accepted.

PSD-03 Empirical and Process Studies

Goal: Improve understanding of basic physical processes that contribute to climate variability across a broad spectrum of scales, with emphasis on moist atmospheric convection, radiative transfer in cloudy areas, and air-sea interaction.

Milestone 1:

Continue improving the representation of physical processes and the Madden-Julian Oscillation (MJO) in the NASA GEOS5 climate model.

Accomplishment: The tropical intraseasonal variability in the GEOS5 Test (Daedalus) Version was analyzed and compared with observations. The results show that the GEOS5 simulation of tropical intraseasonal variability is better than in 11 of the 14 IPCC Fourth Assessment Report GCMs analyzed by Lin et al. (2006). In particular, GEOS5 captures all the dominant intraseasonal modes in observation and reproduces the observed eastward propagation and spectral peak of the MJO over western Pacific. The remaining deficiencies include too-weak total intraseasonal variance and MJO variance over the Indian Ocean, which are common problems in almost all IPCC models.

Milestone 2:

Use three-dimensional cloud resolving model simulations of deep convection to explore how convection parameterizations may be linked to information about subgrid-scale variability. Focus on understanding how convection begins ("triggers") in a range of environments, and on the relationships between large- and small-scale variability and the initiation of convection.

Accomplishment: Multiscale convective wave disturbances with structures broadly resembling observed tropical waves were found to emerge spontaneously in a nonrotating, two-dimensional cloud model forced by uniform cooling. To articulate the dynamics of these waves, model outputs were objectively analyzed in a discrete truncated space consisting of three cloud types (shallow convective,

deep convective, and stratiform) and three dynamical vertical wavelength bands. Model experiments confirmed that diabatic processes in deep convective and stratiform regions are essential to the formation of multiscale convective wave patterns. Specifically, upper-level heating (together with low-level cooling) serves to preferentially excite discrete horizontally propagating wave packets which enhance the triggering of new deep convective cloud systems, via low-level destabilization. The new convection, in turn, causes additional heating over cooling, through delayed development of high-based deep convective cells with persistent stratiform anvils.

Milestone 3:

Develop empirical models of rapidly varying sea surface winds that accurately represent the local and global behavior of observed stochastic wind variability (on sub-daily timescale). Such models are critical for improving the understanding parameterization of sea surface fluxes that are at the heart of coupled climate system dynamics.

Accomplishment: The skewness and kurtosis of daily SST variations were found to be strongly linked at most locations around the globe in a new high-resolution observational dataset, and were analyzed in terms of a simple stochastically forced mixed layer ocean model. The predictions of the analytic theory were found to be in remarkably good agreement with observations, strongly suggesting that a univariate linear model of daily SST variations with a mixture of SST-independent (additive) and SST-dependent (multiplicative) noise forcing is sufficient to account for the skewness-kurtosis link. Such a model of non-Gaussian SST dynamics should be useful in predicting the likelihood of extreme events in climate, as many important

weather and climate phenomena, such as hurricanes, ENSO, and the North Atlantic Oscillation depend on a detailed knowledge of the underlying local SSTs.

Milestone 4:

Continue assessing stochastic influences on climate variability and predictability, through linear and nonlinear inverse modeling, and development and implementation of stochastic parameterizations in weather and climate models.

Accomplishment: Linear stochastically forced models have been found to be competitive with comprehensive nonlinear weather and climate models at representing many features of the observed covariance statistics and at predictions beyond a week. The stochastic noise in such linear models can be a mixture of state-independent (“additive”) and linearly state-dependent

(“multiplicative”) Gaussian white noises. In a major new study, it has been shown that such mixtures can produce not only symmetric but also skewed non-Gaussian probability distributions with power-law tails if the additive and multiplicative noises are correlated. A generic stochastically generated skewed (SGS) distribution can be analytically derived from the Fokker-Planck equation for a single-component system. In addition to skew, all such SGS distributions have a striking property that the (excess) kurtosis K is always greater than 1.5 times the square of the skew S . Remarkably, this K - S inequality is found to be satisfied by circulation variables even in the observed multi-component climate system. A principle of “Diagonal Dominance” in the multi-component moment equations can be invoked to understand this behavior.

PSD-15 Surface Processes

Goal: Develop and/or improve physical representations of atmosphere-surface interactions

Milestone 1:

Investigate problem of compatibility of boundary-layer models and surface layer boundary conditions.

Accomplishment: Bulk flux parameterization stability correction functions by Grachev et al. (2007) and Beljaars and Holtslag (1991, BH91) were evaluated for their ability to suppress turbulent fluxes during very stable conditions. Though ARCMIP mesoscale model schemes were unable to do this (Tjernstrom et al. 2007), both of these schemes were able. However, the results of these tests indicate that using the SHEBA stability functions provides a clear advantage over the BH91 functions for times with greater stability (e.g., when the 2-m surface temperature difference is $>2^{\circ}\text{C}$). For z_0 , it is recommended that either an equation incorporating the effects of drifting snow (Andreas et al 2003, 2004) or a constant value of $z_0 = 4 \times 10^{-4}$ m is used, the former when accurate stress calculations at high wind speeds are needed and the latter when accurate sensible heat fluxes are more important. For the thermal and moisture roughness lengths z_T and z_Q , constant $z_T = z_Q = 1 \times 10^{-4}$ m is recommended.

Product: Persson, O. (2008), Incorporating SHEBA Turbulence Parameterizations in a 1-D Model, Internal memo to NOAA/PSD3 surface flux group.

Milestone 2:

Further investigate the role of boundary-layer and synoptic-scale weather processes on surface chemical exchange in the polar regions.

Accomplishment: Organized session and presented two papers in AS2.04 Boundary-layer and Chemical Processes in High Latitudes: Observations and Modeling, at the Spring meeting of the European Sciences Union.

Recent investigations of atmospheric chemical

processes over the high Antarctic Plateau using ground-based and aircraft measurements carried out from 2003 through 2005 have revealed high concentrations of NO trapped near the surface as well as, on occasion, high levels aloft 500 to 1000m above the surface (together with high levels of HNO_3). Further work will examine various processes that can lead to redistribution of such constituents in the vertical, such as the diurnal cycle of mixing as well as synoptic effects associated with quasi-geostrophic vertical motions and frontal lifting interacting with katabatic winds.

The Antarctic Oscillation (alternatively, the Southern Annular Mode) has been identified as an indicator of climate change through the effects of stratospheric ozone depletion and/or increases in greenhouse gases. In its high index state it produces a stronger, more tightly confined polar vortex which, to the extent it is more centered over the high terrain of Antarctica, will result in lighter surface winds and stronger inversions. Such conditions have previously been identified with the occurrence of high concentrations of nitric oxide.

Product: Simpson, W. R., R. von Glasow, K. Riedel, P. Anderson, P. Ariya, J. Bottenheim, J. Burrows, L. J. Carpenter, U. Friess, M. E. Goodsite, D. Heard, M. Hutterli, H.-W. Jacobi, L. Kaleschke, W. Neff, J. Plane, U. Platt, A. Richter, H. Roscoe, R. Sander, P. Shepson, J. Sodeau, A. Steffen, T. Wagner, and E. Wolff (2007), Halogens and their role in polar boundary-layer ozone depletion, *Atmos. Chem. Phys.*, 7, 4375-4418.

Neff, W, D. Helmig, A. Grachev, and D. Davis (2008), A Study of Boundary-Layer Behavior Associated with High NO Concentrations at the South Pole using a Minisodar, Tethered Balloon, and Sonic Anemometer, *Atmospheric Environment*, 42(12), 2762-2779.

Anderson P. S. and W. D. Neff (2008), Boundary-layer physics over snow and ice, *Atmos. Chem. Phys.*, 8, 3563-3582.

Milestone 3:

Analysis of the polarimetric scanning radiometer measurements during the melt season in March 2003 to estimate feasibility of simultaneously observing soil moisture and snow water equivalent using remote sensors.

Accomplishment: A detailed analysis was completed of the airborne passive microwave remote sensing data collected at a broad range of microwave bands and at high spatial resolution during the 2002 and 2003 NASA Cold Lands Processes Experiment (CLPX). Accurate measurement of snowpack properties using passive microwave observations requires detailed knowledge of the relationship between snowpack geophysical parameters and the upwelling polarimetric brightness signature. The principle microwave instrument used for CLPX was the Polarimetric Scanning Radiometer (PSR), which provided ~100-m resolution maps of snow emissivity at all Advanced Microwave Scanning Radiometer for EOS (AMSR-E) bands during several intensive observation periods over the Colorado Rocky Mountains. Observed conditions included drought, normal snowpack, and spring snowmelt. The PSR and related ground-based observations of snowpack properties made during the 2002 and 2003 CLPX campaigns provide a comprehensive high-resolution passive microwave dataset.

Results show that the high-resolution PSR data exhibit emissivity modes similar to those observed in the historical datasets and that the empirical relationships between emissivity and the snow water equivalent (SWE), after the effects of macro-vegetation are removed, closely match those found in the past theoretical studies. Use of the 89 GHz channel in the empirical relationships provides improved accuracy under dry snow conditions and small SWE, but the variability of the SWE-emissivity relationships increases with increasing SWE. A summary of the observed relationships between the emissivity spectra of snow and snowpack properties is presented. Comparison of the total water content from the AMSR-E and the PSR observations shows that the satellite measurements underestimated the total volume of water storage from airborne observations on the average by a factor of five.

Product: Stankov, B. B., D. W. Cline, B. L. Weber, A. J. Gasiewski, and G. A. Wick, 2008, High-Resolution Airborne Polarimetric Microwave Imaging of Snow Cover During the NASA Cold Lands Processes Experiment (CLPX). *IEEE Transactions on Geosciences and Remote Sensing*, to appear.

Milestone 4:

Submit a paper on comparing the snow-level measured by radar profilers with the snow level on the ground surface (looking at surface heating affects and antecedent snowcover).

Accomplishment: The analysis was carried out by a CIRES post-doctoral researcher working with other CIRES scientists in the Water Cycle Branch. A paper has been published in the *Journal of Hydrometeorology*.

The elevation where precipitation transitions from contributing to snow water storage versus contributing to runoff is critical for hydrologic monitoring and forecasting in mountainous watersheds. Results demonstrate that in the Sierra Mountains of northern California, precipitation is equally as likely to fall as rain or snow when the surface temperature reaches 1.5°C. When the elevation along the slope where this temperature occurs is compared to the bright-band heights observed by wind profilers located in the Sierra foothills and along the California coast, there was an offset (bright-band heights higher than terrain) of 326 to 425m.

A statistically more robust analysis of the temperature at which precipitation is equally as likely to fall as rain or snow was carried out. Using optical disdrometer measurements, which simultaneously provide particle size and fall speed information, it was shown that this temperature is closer to 1.0°C. This novel approach and results will be presented at the 2008 Mountain Meteorology Conference.

Product: Kingsmill, D.E., A.B. White, D.J. Gattas, and P.J. Neiman (2008), Spatial variability of snow level across the northern California Sierra Nevada, 13th Conf. on Mountain Met., Whistler, B.C., and at the AMS meeting in Boston.

Lundquist, J.D., P.J. Neiman, B. Martner, A.B. White, D.J. Gattas, and F.M. Raloph (2008), Rain versus snow in the Sierra Nevada, California, Comparing Doppler profiling radar and surface observations of melting level. *J. Hydromet*, 9, 194-211.

Milestone 5:

Install high accuracy solar irradiance measurement capability and surface sensible and latent heat flux observing system in the North Fork of the American River for use in snow melt studies.

Accomplishment: This component of NOAA's Hydrometeorological Testbed research was not carried out because of a lack of funding.

CSV-05 CLIMATE RESEARCH DATABASE DEVELOPMENT

NSIDC-01 Digitizing Analog Cryospheric Data under the Climate Database Modernization Program	118
NSIDC-02 Observations for SEARCH—Data Integration for Arctic Reanalysis and Change Detection	118
NSIDC-03 World Data Center for Glaciology, Boulder—Current Programs	118

NSIDC-01 Digitizing Analog Cryospheric Data under the Climate Database Modernization Program

Goal: Scan and make available on line data from NSIDC's analogue collections so that it is more easily located, browsed, and obtained by users.

Milestone 1:

Pending funding, begin working with the CDMP contractor on scanning material related to the International Polar Year.

Accomplishment: This project was not funded.

NSIDC-02 Observations for SEARCH—Data Integration for Arctic Reanalysis and Change Detection

Goal: "Unaami," the changes in the Arctic that are the subject of the Study of Environmental Arctic Change (SEARCH) program, became apparent to researchers in the context of long-term and pan-Arctic observations. This work aims to assess what data are relevant to SEARCH reanalysis and change detection activities, collect these data from a wide variety of sources, and facilitate the SEARCH research community's access to the data. Another key element of the effort is to assess the Arctic performance of existing atmospheric reanalyses, with the aim of identifying shortcomings that will need to be addressed in developing a dedicated Arctic System Reanalysis. Note that this work is funded through Task III, rather than Task II.

Milestone 1:

Pending the availability of funding, finalize studies of the JRA-25 reanalysis, focusing on elements of the hydrologic cycle.

Accomplishment: Analysis of the JRA-25 data has been finalized

Milestone 2: *Pending the availability of funding, continue the collection of key datasets for change detection. With regard to applications for the Arctic System Reanalysis, efforts to obtain previously undigitized atmospheric sounding data may represent a viable focus area.*

Accomplishment: The Arctic System Reanalysis (ASR) has received support from the National Science Foundation. Data collection efforts in support of the ASR, which also have applications for change detection, are underway.

Milestone 3:

Adopt appropriate modifications to the land surface package to be used in the Arctic System Reanalysis. This effort is contingent on sufficient funding levels to perform the reanalysis itself. Leveraging from work supported under the present NOAA funding, a proposal to conduct a three-year reanalysis for the period of the International Polar Year was submitted to the National Science Foundation in spring 2006. If this activity is funded, additional support would be sought from NOAA and NASA.

Accomplishment: Under support from the National Science Foundation for the Arctic System Reanalysis, efforts are now ongoing with colleagues at the University of Colorado at Boulder and the Ohio State University to evaluate and improve the performance of the NoaH land surface package.

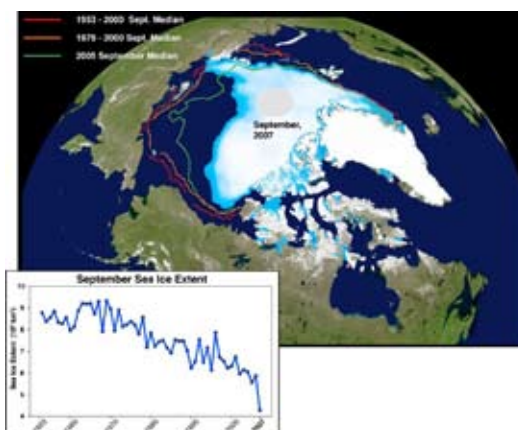
NSIDC-03 World Data Center for Glaciology, Boulder—Current Programs

Goal: Improve understanding of recent and unexpected changes in polar regions including lower sea-level atmospheric pressure, increased air temperature over most of the Arctic, lower temperatures over eastern North America and Greenland, reduced sea ice cover, thawing permafrost and changes in precipitation patterns.

Milestone 1:

Maintain and update existing research datasets (e.g., the Sea Ice Index). Publish new datasets (e.g., the Japan Meteorological Agency ice chart series.

Accomplishment: Sea Ice Index (http://nsidc.org/data/seaiice_index/). Sea Ice Index graphics and numbers figured prominently in coverage of the 2007 record sea ice extent minimum. The Index web site had more than 135,000 hits from more than 9,000 distinct users in September 2007. The data product currently averages more than 6,000 users each month.



Also in 2007, several magazines and news agencies used information from the Sea Ice Index web site. The Sea Ice Index viewed using Google Earth illustrated “Perspectives on the Arctic’s Shrinking Sea–Ice Cover,” which appeared in an article in Vol. 315 of *Science*. *Nature* used the Index for an article, “The New Face of the Arctic,” in the 8 March 2007 issue.

The NSIDC@NOAA team produced a browse image tool for the National Ice Center Arctic Sea Ice Charts and Climatologies in Gridded Format dataset (<http://nsidc.org/data/g02172.html>). Using a Browse Image Spreadsheet Tool (BIST), one can quickly compare different time periods and products visually. Sea ice animations are now available in the dataset catalog of NOAA’s Science on a Sphere (<http://sos.noaa.gov/>). Animations of sea ice concentration show the annual cycle and give some idea of its variability, while a series of September monthly means beginning in 1987 highlights the change in the annual Arctic minimum sea ice extent through time.

Product: The Sea Ice Charts of the Russian Arctic in Gridded Format, 1933–2006 dataset was released in November 2007. These newly published data, from the Arctic and Antarctic Research Institute in St. Petersburg, Russia, are an important new data source for those studying the role of sea ice in climate change. For more information, see the dataset documentation at <http://nsidc.org/data/g02176.html>.

The film from Good Days on the Trail, 1938–1942: Film Footage of the Rocky Mountains, Colorado dataset was shown as part of the University of Colorado at Boulder International Film Series. With color footage of university students on alpine hikes, the film provides a glimpse into the mountaineering lifestyle of an earlier time, along with shots of Arapaho Glacier and other Front Range glaciers. Scientists from NSIDC and the Institute of Arctic and Alpine Research narrated. The film is being preserved and digitized with support from NOAA NGDC and the Climate Database Modernization Program. For more information, see the dataset documentation at <http://nsidc.org/data/g02175.html>.

Milestone 2:

Make research information available through the NSIDC Information Center, acquire and catalog cryospheric materials in the NSIDC library, and maintain NSIDC’s analog datasets

Accomplishment: In 2007, The National Endowment for the Humanities awarded the Analog Archives collection a Preservation Assistance Grant for Smaller Institutions. This award will fund a contract with a preservation consultant to conduct a general preservation assessment of the collections. The Preservation Assistance Grant for Smaller Institutions will provide funding for NSIDC/WDC to contract with a consultant who will conduct a general preservation assessment of the collections of NSIDC’s archives. These collections are located in several office spaces, some shared, within the center. NSIDC is requesting assistance to



determine the overall condition of the collection and establish a plan to create a more cohesive, accessible, and well-preserved collection. The assessment will include

recommendations regarding proper housing for the materials, furniture requirements, security, and environmental controls within the archives, and archives policy creation. The consultant will provide the NSIDC archivist with a written report detailing findings and recommendations to form the basis of future preservation implementation efforts at NSIDC.

The Glacier Photograph Collection (<http://nsidc.org/data/g00472.html>) is an exceedingly popular part of NOAA@NSIDC’s data portfolio. Allaina Wallace’s role in developing this and other analog collections was recognized by CIRES with an Outstanding Service Award. NSIDC’s Analog Archives were featured at the Special Libraries Association conference. The conference, held in Denver, had a session on “Resources for the International Polar Year” at which Ruth Duerr spoke on Discovery and Access of Historic Literature from the IPYs. Duerr and NSIDC archivist and librarian Allaina Wallace lead the project, which is partially supported by the NOAA Climate Database Modernization Program. Wallace presented a paper on “Tracking Climate Change in the 21st Century: Supporting Research with Historic Photographs and Google Earth.” Former Vice President Al Gore opened the conference, highlighting importance of special libraries.

The World Glacier Inventory is a repository that contains information for more than 100,000 glaciers throughout the world. In 2007, more than 34,000 glaciers in China and more than 1,600 glaciers in the former Soviet Union were added to the inventory. Also, errors with 368 glacier IDs were identified and corrected. To access the inventory, please visit the World Glacier Inventory web site at http://nsidc.org/data/glacier_inventory/.

Product: The Glacier Photograph Collection is a very popular data product with the general public. Since its inception, thousands of photographs have been added to the online collection. The project is in its fifth year with the NOAA Climate Database Modernization Program (CDMP). In 2007, more than 1,200 glacier photographs were added, including glaciers in such areas as Greenland and Colorado, and spanning in 1890 to 1996. Also added to the collection were glacier photograph pairs in which glacier photographs are taken from the same vantage point but years apart in time. To access these photographs and other glacier photographs, please visit the Glacier Photograph Collection web site at http://nsidc.org/data/glacier_photo/.

PSD-10 Cloud and Aerosol Processes

Goal: Make observations of clouds, aerosols, and water vapor over a variety of ice, land, and sea surfaces using a multi-sensor, multi-platform approach to improve retrieval techniques useful for satellite validation studies.

Milestone 1:

Participate in VOCALS research cruises in October 2007; deploy cloud radar, radiometer, and flux systems to measure key surface marine boundary-layer parameters, low cloud macrophysical, microphysical, and radiative properties.

Accomplishment: The systems were deployed on the NOAA Ship Ronald H. Brown for three weeks in October 2007. All systems obtained data on the cruise. Data products are available at the ETL ftp site for this project ftp://ftp.etl.noaa.gov/et6/cruises/STRATUS_2007/RHB. Several papers on this work have been submitted/accepted:

Product: Fairall, C. W., J. E. Hare, T. Uttal, D. Hazen, M. Cronin, N.A. Bond, and D. Veron (2008), A seven-cruise sample of clouds, radiation, and surface forcing in the Equatorial Eastern Pacific, *J. Clim.*, 21, 655-673.

Wood, R., K.K. Comstock, C.S. Bretherton, C. Cornish, J. Tomlinson, D.R. Collins, and C.W. Fairall (2008), Open cellular structure in marine stratocumulus sheets, *J. Geophys. Res.*, to appear.

Serpetzoglou, T., B. A. Albrecht, P. Kollias, and C.W. Fairall (2008), Boundary layer, cloud, and drizzle variability in the southeast Pacific stratocumulus regime, *J. Clim.*, to appear.

Ghate, V., B.A. Albrecht, C.W. Fairall, and R.A. Weller (2008), Cloud fraction climatology and its indicators in South-East Pacific Ocean, *J. Clim.*, submitted.

De Szoeki, S.P., C.W. Fairall, and S. Pezoa (2008), Ship observations coasting South America in the tropical Pacific Ocean, *J. Clim.*, submitted.

Milestone 2:

Preliminary evaluation of data from ground-based cloud, aerosol, radiative, and surface meteorological instruments in Canada for SEARCH Arctic observations with an emphasis on regions with strong connections to the Arctic oscillation

Accomplishment: Cloud macrophysical properties datasets (including cloud occurrence, cloud boundaries, and cloud thickness) for three years at Eureka, six+ years at Barrow, six-plus years at Atkasuk, one year at SHEBA, one year at Summit Greenland, and four years at Ny'Alesund.

Cloud microphysical properties datasets (including cloud phase classification, particle size, and water

content) for one year at Barrow, one year at SHEBA, and one year at Eureka.

Product: Shupe, MD, 2007, A ground-based multisensor cloud phase classifier, *Geophys. Res. Lett.*, 34 (22) : Art. No. L22809, issn: 0094-8276, ids: 235TN, 22-Nov 2007.

Shupe, M.D., P. Kollias, M. Poellot, and E. Eloranta (2008), On deriving vertical air motions from cloud radar Doppler spectra, *J. Atmos. Ocean. Technol.*, 25, 547-557.

Shupe, M. D., P. Kollias, P.O.G. Persson, and G. M. McFarquhar (2008), Vertical motions in Arctic mixed-phase stratiform clouds, *J. Atmos. Sci.*, 65, 1304-1322.

Eloranta, E. W., T. Uttal, and M. Shupe (2007), Cloud particle size measurements in Arctic clouds using lidar and radar data, International Geoscience and Remote Sensing Symposium, IEEE, Barcelona.

Eloranta, E. W., T. Uttal, and M. Shupe (2007), A 2-year climatology of Arctic clouds for Eureka Canada prepared from High Spectral Resolution Lidar data, American Geophysical Union, San Francisco, CA.

Remillard, J., P. Kollias, M. Shupe, and E. Eloranta (2008), Cloud climatology and microphysics at Eureka using synergetic measurements from a cloud radar and a high spectral resolution lidar, Symposium On Recent Developments in Atmospheric Applications of Radar and Lidar, American Meteorological Society, New Orleans, LA.

Luke, E., P. Kollias, and M. Shupe (2008), High spectral resolution lidar emulation via Doppler cloud radar spectrum processing and its implications for cloud phase identification, Symposium on Recent Developments in Atmospheric Applications of Radar and Lidar, AMS, New Orleans.

Milestone 3:

Participate in planning for VOCALS intensive field program.

Accomplishment: C. Fairall and D. Wolfe attended the VOCALS planning meeting held in Boulder, 17-19 March 2008. They are currently working on the Cruise Instruction for the project.

Milestone 4:

Participate in MMA research cruises in June-July

2007; deploy cloud radar, radiometer, and flux systems to measure key surface marine boundary-layer parameters, low cloud macrophysical, microphysical, and radiative properties.

Accomplishment: The systems were deployed on the NOAA Ship Ronald H. Brown for three weeks in May 2008. All systems obtained data on the cruise. Data

products are available at the ETL ftp site for this project ftp://ftp.etl.noaa.gov/et6/cruises/AMMA_2008/RHB.

Product: A presentation on this project (“Observations of Air–sea Interaction in the Northeast Tropical Atlantic,” Fairall, Wolfe, Pezoa, and Bariteau) was made at the 2nd Int. AMMA Symposium in Karlsruhe, Germany (November 2007).

CSV-07 CLIMATE SERVICES

PSD-05 Experimental Regional Climate Services

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PSD-07 Experimental Climate Data and Web Services

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PSD-05 Experimental Regional Climate Services

Goal: Couple enhanced observations and research in regions of strong climate variability and societal impact with analysis of past data and improved modeling. Determine factors influencing the occurrence of extreme events. Improve the diagnosis, modeling, and prediction of the regional consequences of climate change and variability on timescales of days to decades, and on hydrological variables of relevance to society.

Milestone 1:

Survey Colorado temperature and precipitation trends during the last century in collaboration with the State Climatologist’ Office at CSU, and assess the importance of multidecadal variability (AMO, PDO) for the region.

Accomplishment: There are currently ~250 weather stations in Colorado reporting to the National Weather Service. These stations measure and report daily high and low temperatures, precipitation (rain and the melted water from snow and ice), snowfall and daily total snow depth. Average daily temperature is computed as the simple mean of the minimum and maximum temperatures. A smaller number of weather stations in the state report additional information such as wind, humidity, and cloudiness.

The varied climates within Colorado can be delineated by grouping observing stations together that vary in a similar manner from year-to-year. These clusters of observing stations form the basis for a new set of climate divisions that have been developed by the Western Water Assessment and the Colorado Climate Center (Wolter and Allured, 2007). Averaging selected stations with the cleanest observing records within each division helps to detect regional temperature trends by “averaging out” the peculiarities of each observing station. Sufficient data is available to construct time series of temperature for most of these new climate divisions back to the early 1930s.

Product: Wolter and Allured work has been featured in a Colorado Climate Center web page on Colorado Climate Trends that is currently under development <http://ccc.atmos.colostate.edu/~sean/> and has been incorporated into the first draft of the Climate Change Impacts Related to Water Resources in Colorado Report for the Colorado Water Conservation Board.

Milestone 2:

Continue monitoring daily, seasonal, and longer-term precipitation variability over the western United States. Continue downscaling NCEP Week Two ensemble forecasts for Colorado water resource managers. Continue developing seasonal forecast guidance tools for the United States based on the predictability of tropical SSTs several seasons in advance.

Accomplishment: Stronger collaborations between NOAA and the USBR/Lower Colorado office have led to the provision of near-real-time visualizations of easily accessed hydrometeorological data. Those data will help decision makers and other users incorporate climate information in decision processes.

Product: NOAA/ESRL/PSD Seasonal Forecast Guidance <http://www.cdc.noaa.gov/seasonalfcsts/ESRL>. Reforecast Analog probabilistic precipitation forecasts, Lower Colorado River regional view <http://www.cdc.noaa.gov/lowercolorado/>.

Milestone 3:

Continue programmatic development and impact assessments of climate, weather, and water services, especially in conjunction with the newly established National Integrated Drought Information Service (NIDIS).

Accomplishment: Conducted DRICOM-funded research leading to the submission of three, Simulating Multi-Season Past Droughts Abstracts to 33rd Climate Diagnostics and Prediction Workshop.

Early Warning Indicators for U.S. Drought by Martin Hoerling, Jon Eischeid and Xiao-Wei Quan

Abstract: To what extent is severe sustained

drought foreshadowed by global SST? Was the Dust Bowl potentially predictable, and is there early warning capability for the next Dust Bowl-like drought? Which patterns of severe sustained U.S. drought have the greatest prospects for early warning, and what are their oceanic predictors? Is there early warning of U.S. drought severity for the upcoming decade?

We present analyses of the relationship between leading patterns of U.S. drought and global SSTs during 1895–present. We include data from atmospheric models forced by observed SSTs and coupled ocean–atmosphere models forced by observed greenhouse gas, aerosol, and solar variability. The leading pattern of observed and simulated U.S. drought (diagnosed using the Palmer Drought Severity Index) is characterized by a nationwide pattern of drying, having maximum intensity in the central and northern Great Plains. Our diagnosis finds little evidence that such a drought has early warning capability based on SSTs alone. Neither empirical analyses, atmospheric model simulations, nor coupled model simulations indicate that the Dust-Bowl like drought pattern has strong SST precursors. In contrast, the ENSO phenomena is shown to provide a more viable early warning for U.S. drought, particularly over the southern United States. As concerns the next decade, we highlight the divergence between observed and greenhouse gas forced simulations of tropical SST change, and discuss implications for future U.S. drought.

Relationship between decadal precipitation anomalies in the Southwestern U. S. and global SSTs: Insights from the IPCC multi-model ensemble by Antonietta Capotondi.

Abstract: A subset of the climate model simulations performed in support of the Intergovernmental Panel for climate change (IPCC) Assessment Report 4 (AR4) has been analyzed to examine the relationship between the evolution of precipitation in the southwestern United States (SW) at decadal timescales and global sea surface temperature (SST) conditions. Previous studies, primarily based on observations and atmospheric model sensitivity experiments, have related precipitation deficit and drought conditions in the SW (e.g., the Dust Bowl in the 1930s) to cold tropical Pacific SSTs similar to those observed during La Niña events, while the influence of SST anomalies in other ocean basins is more uncertain. The large IPCC archive, including simulations of pre-industrial, present-day, and future climate scenarios offers a fantastic opportunity to revisit the relationship between SST anomalies in different ocean basins and precipitation anomalies in the SW across a multi-model ensemble. Long (300–500 yrs) pre-industrial control simulations are used in this study to more easily isolate natural variability from trends related to anthropogenic factors, and to increase the statistical significance of the results. The model

global patterns of SST and hydroclimate over the continents during long periods of precipitation deficit in the SW is consistent with evidence from the relatively-short and sparse observational record, and with paleoclimate reconstructions of past droughts. Correlations between decadal precipitation variations in the SW and global SSTs show a consistent pattern of significant correlations in the Pacific Ocean, which is similar to the observed pattern of Pacific decadal variability. In some models, the P–SST correlation pattern is very similar to the leading EOF of decadal SST, while in other models the leading mode of decadal SST anomalies has its dominant centers of action in the North Pacific, and significant loading in the tropical Pacific is found in the second and higher EOFs.

The impacts of tropical SSTs on the Regional Hydroclimate by Sang-ik Shin, Robert S. Webb, and Prashant D. Sardeshmukh.

Abstract: Changes in modern tropical SSTs are known to impact the regional hydroclimates. However, the areas of the tropical oceans that are most critical in controlling the regional hydroclimate still remain uncertain.

We addressed these issues by diagnosing the available observations and model simulations performed as part of the AMIP and CMIP3 projects, specifically 20th century climate simulations. We combined the near-surface air temperature and precipitation changes into a single hydroclimatic drought parameter—the Palmer Drought Severity Index (PDSI)—as distinct from a mere precipitation deficit or surplus. Then the constructed PDSI from the simulations and observations were correlated and regressed on to the tropical SSTs. Our results largely confirm previous studies that suggested dominant influence of the tropical SSTs on the regional hydroclimate. We further identified the SST patterns with the greatest influence on the regional PDSI by using the atmospheric general circulation model simulations with prescribed tropical SST anomalies. The PDSI responses were determined for an array of 43 localized SST anomaly patches over the Indian, Pacific, and Atlantic oceans. The identified “optimal SST patterns” for regional PDSI stress the importance of the tropical SST patterns in regional hydroclimate.

Reconciling Projections of Future Colorado River Streamflow. Within the Upper Colorado River Basin, projected reductions in naturalized streamflow by the mid 21st century tied to climate change range significantly based on findings from recent scientific literature. Projected reductions in streamflow range from ~45 percent by Hoerling and Eischeid (2007), 10 to 25 percent by Milly et al. (2005), ~18 percent by Christensen et al. (2004), and ~6 percent by Christensen and Lettenmaier (2007). In addition, the recent Seager et al. (2007) analysis of future P–E (a proxy for runoff) suggests an “imminent transition to a more arid climate in southwestern North America.” This wide range of future Colorado River streamflow

projections makes it difficult for decision makers and water managers to prepare and plan for potential future reductions in streamflow resulting from climate change. The goal of this project is to reconcile future Colorado River streamflow projections by evaluating the various methodologies and models being used in projections and to understand why different modeling approaches produce varying flow reduction amounts. The second component of this project entails identifying a common subset of appropriate climate scenarios and models in development of future projections of streamflow, and using these scenarios and models to generate a consistent suite of Colorado River streamflow projections by the mid to late 21st century. Results will

directly apply to the needs of water planners across the western United States, and similar mid-latitude continental regions where water resources are heavily dependent on snowmelt runoff from mountainous headwater areas.

The initial Meeting on Reconciling Colorado River Streamflow Projections was held in San Diego, CA, on 26 September 2007.

Product: PSD U.S. drought monitoring page, <http://www.cdc.noaa.gov/Drought/> and Reconciling Projections of Future Colorado River Streamflow http://www.colorado.edu/current_projects/rcn_strmflw_corvr.html

PSD-07 Experimental Climate Data and Web Services

Goal: Improve public access to climate information and forecast products to facilitate research, to inform public planning and policy decisions, and to assist any interested parties impacted by climate.

Milestone 1:

Continue updating the extensive publicly accessible climate data holdings on the CDC/PSD web site. Continue acquisition of new precipitation and soil moisture datasets.

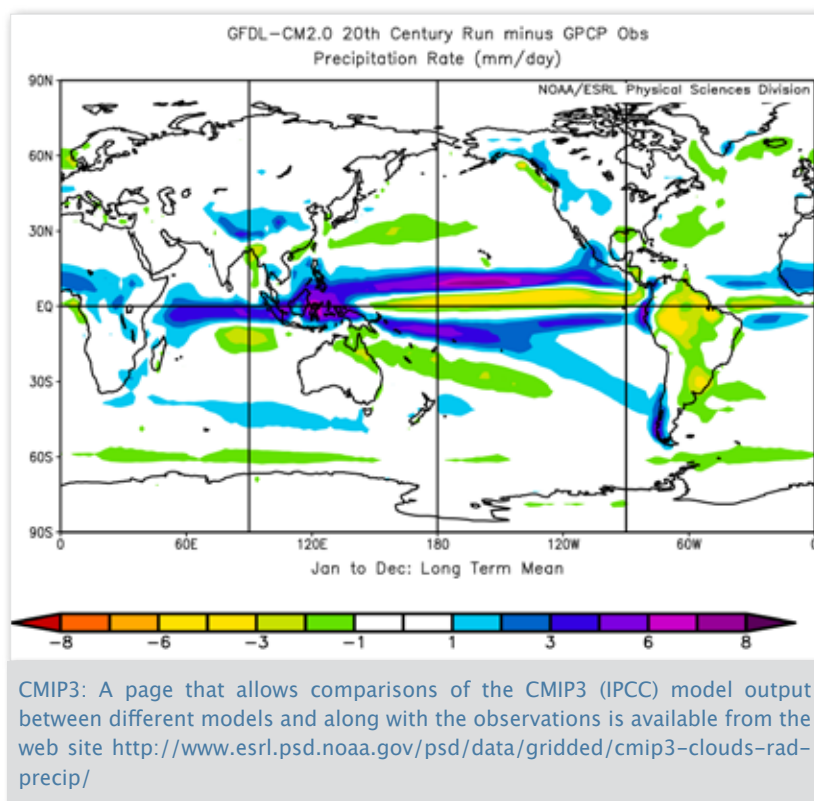
Accomplishment: ESRL/PSD has continued to add to existing datasets, including many that extend to the present. New data storage space has been acquired so that very large datasets (e.g., the North American Regional Reanalysis) can be continually updated. New datasets (e.g., the 20th Century Reanalysis and IPCC model output) that are continually being added have enabled researchers to look at climate change and at historic climate trends. Additions continue in the following datasets: cruise, profiler timeseries, Arctic station, radar, and other datasets that enable researchers to examine climate and weather processes.

Also being updated are various analysis datasets that have precipitation, as well as the North American Regional Reanalysis dataset where precipitation is assimilated. Updated versions of the Global Precipitation Climatology Centre and Global precipitation Climatology Project data are provided, and the University of Delaware precipitation dataset will soon be available beginning with 1900, instead of 1950—a doubling of data. Also under consideration are other precipitation datasets such as the Climatic Research Unit (now available in PSD) and the VIC soil moisture dataset (also in PSD).

Product: 20th Century Reanalysis: A subset of the 20th Century Reanalysis is available for download and viewing from the web site http://www.esrl.psd.noaa.gov/psd/data/gridded/data.20thC_Rean.html. An example of model output is shown in the figure at right.

Milestone 2:

Continue developing and maintaining the CIRES/NOAA web site dedicated to real-time predictions of tropical convection variations associated with the Madden-Julian Oscillation and their remote



impacts. Display various experimental and operational ensemble predictions in a uniform format to enable intercomparisons and skill evaluation.

Accomplishment: The Madden-Julian Oscillation web site continues to be maintained and is being transitioned to new web servers.

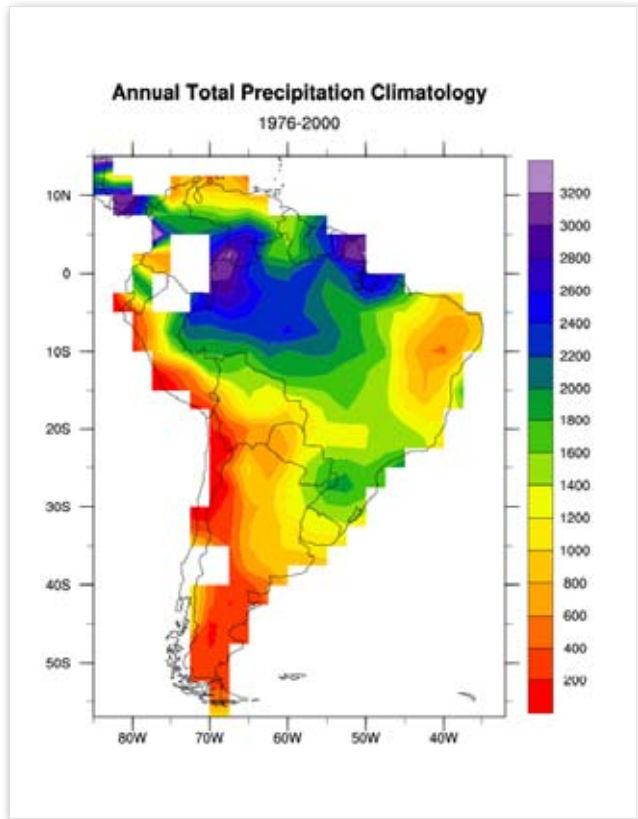
Milestone 3:

Continue with acquisition and major updating of special South and North American historical daily precipitation datasets.

Accomplishment: The U.S. daily precipitation dataset continues to be updated in real time for PSD users.

North American Regional Reanalysis, which includes assimilated precipitation is also being updated to the near present for PSD user and close to present for external users. A South American gridded precipitation has been created and is updated.

Product: A South American daily gridded precipitation dataset is available from http://www.cdc.noaa.gov/people/brant.liebmann/south_america_precip.html.



GEO: GEODYNAMICS

CIRES geodynamics research aims to characterize the internal processes of the planet, including the properties of the core-mantle boundary, convection within the Earth's mantle, and the effects of convection on the surface of the planet.

GEO-01: GEODYNAMICS

NGDC-05 Improved Integration and Modeling of Geophysical Data

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NGDC-05 Improved Integration and Modeling of Geophysical Data

Goal: Improve integration and modeling of geophysical data, further research into core-mantle processes, improve representation of magnetic fields at or near the Earth's surface, improve models of tsunami-threatened coastal regions, and improve understanding of past hazardous events and potential future impacts.

Milestone 1:

Produce the 2007/2008 CIRES/NGDC scientific geomagnetic field model, accounting for recent changes of the Earth's magnetic field.

Accomplishment: The 2007/2008 CIRES/NGDC scientific geomagnetic field model, accounting for recent changes of the Earth's magnetic field, was produced in June 2007 and made available on the Web at <http://geomag.org/models/pomme4.html>.

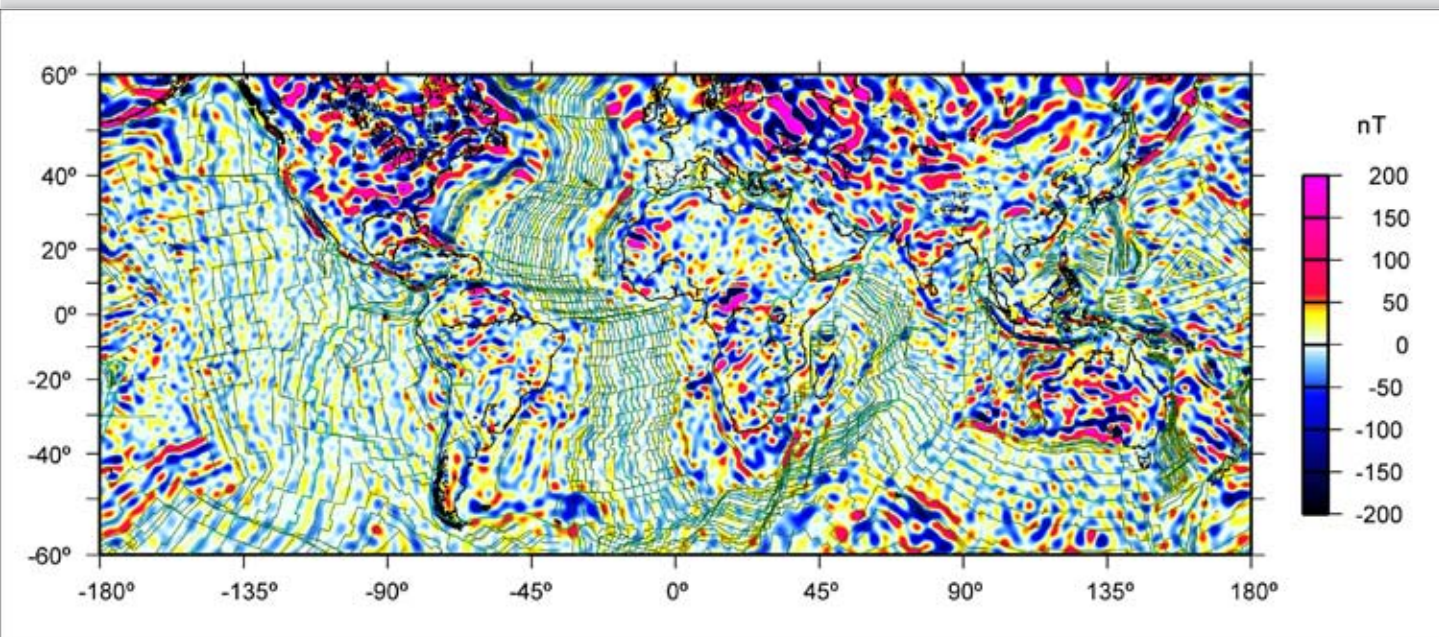
Subsequently, a significant breakthrough in magnetic field modeling was achieved in producing the model MF6, representing the static magnetic field caused by the magnetization of the Earth's crust. MF6 is the first satellite-based magnetic model to resolve the direction of oceanic magnetic lineations. The model was published in G-Cube (Maus et al. 2008) and is available on the Web at <http://geomag.org/models/MF6.html>. An example of the model output is shown in the figure below.

Milestone 2:

Establish links between satellite magnetic signatures of electrical currents in the low-latitude ionosphere and equatorial ionospheric instabilities impacting radio-wave communication and navigation.

Accomplishment: The equatorial ionospheric anomaly (EIA) is caused by a plasma fountain, which is driven by the day-side eastward electric field (EEF). The EIA has significant impact on radio communication and GPS. The day-side EEF is therefore one of the most important parameters of the equatorial ionosphere. The EEF is very weak (< 1 mV/m) and therefore difficult to measure directly using electric field instruments. Magnetic measurements from polar-orbiting LEO satellites are inverted to derive meridional profiles of the height-integrated, eastward current density in the equatorial region (Lühr, Maus, and Rother 2004). This inversion takes into account the satellite altitude and various geometrical effects that affect the magnetic signal

Vertical component of the MF6 crustal magnetic field at the Earth surface, overlain with the isochrons of an ocean-age model inferred from independent marine and aeromagnetic data by Muller et al. (2007) and plate boundaries by Bird (2003).

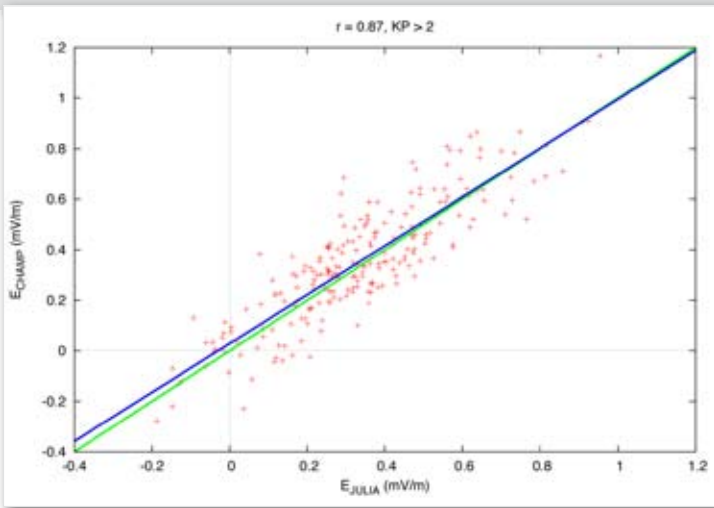


produced by the equatorial electrojet (EEJ). Except during sunrise, when the EEJ is usually reversed, the profiles typically show an eastward current at the dip equator, flanked by westward “return” currents. Using input models for various parameters of the ionosphere and thermosphere, including the horizontal winds, a method has been developed to invert the observed satellite-derived meridional current profiles for the EEJ (Maus, Alken, and Lühr 2007; Alken et al. 2008). The resulting electric field estimates have been validated using radar measurements (figure below, top). The method is very robust, even during magnetic storms. With an RMS difference of 0.1 mV/m to the radar measurements, the accuracy far exceeds the accuracy of satellite-based direct electric field measurements. In view of the significant importance of the EEJ for ionospheric specification, the magnetic-field-derived EEJ estimates provide a valuable new space-weather product from the present and upcoming satellite magnetic field missions.

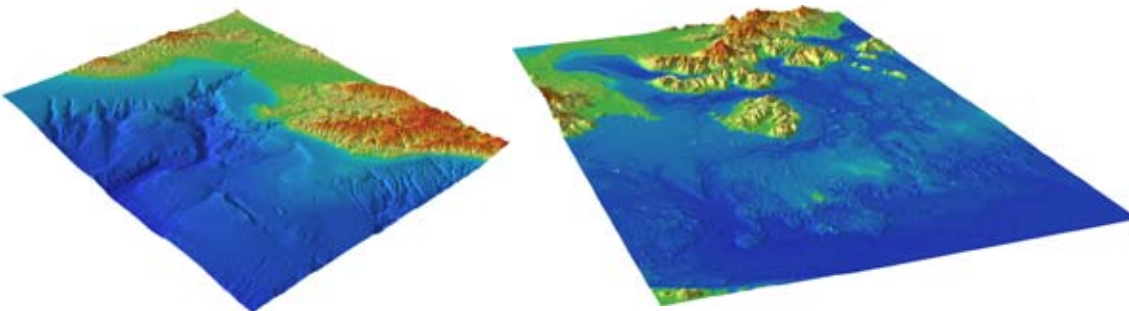
Milestone 3:

Produce bathymetric-topographic digital elevation models sufficient for tsunami propagation, run up, and inundation prediction for 14 priority regions, defined by the U.S. tsunami community.

Comparison of satellite-based electric field estimates with radar measurements at the Jicamarca Radio Observatory for direct overflights of the CHAMP satellite during periods of moderate to high ($K_p > 2$) geomagnetic activity. The regression line (blue) is very close to the ideal relation (green).



Accomplishment: CIRES/NOAA scientists built eight, high-resolution digital elevation models (DEMs) for select U.S. coastal regions. These combined bathymetric-topographic DEMs are used to support



tsunami forecasting and modeling efforts at the NOAA Center for Tsunami Research, Pacific Marine Environmental Laboratory (PMEL). The DEMs are part of the tsunami forecast system. Short-term Inundation Forecasting for Tsunamis and currently being developed by PMEL for the NOAA Tsunami Warning Centers, and are used in the Method of Splitting Tsunami model developed by PMEL to simulate tsunami generation, propagation, and inundation. More information, imagery, and DEMs are available at: <http://www.ngdc.noaa.gov/mgg/inundation/>

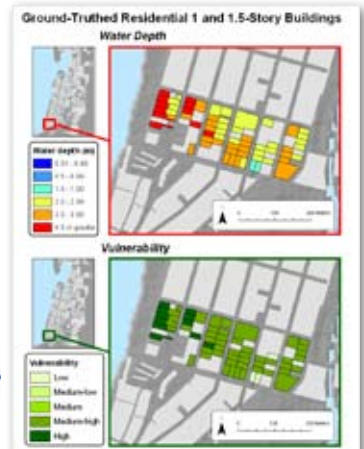
Product: High-resolution coastal DEM for each coastal inundation site. NOAA Technical Report for each DEM, and outreach material, including postcards for the DEM.

Milestone 4:

Produce a pilot study of the social and economic impacts of tsunamis on Seaside, Oregon.

Accomplishment: To determine the risk from tsunamis, it is first necessary to establish the hazard or probability that a tsunami of a particular magnitude will occur within a certain period of time. Tsunami inundation maps that provide 100-year and 500-year probabilistic tsunami wave height contours for the Seaside-Gearhart, Oregon, region were developed as part of an interagency Tsunami Pilot Study (figure below, left). These maps provided the probability of the tsunami hazard. The next step in determining risk is to determine the vulnerability or degree of loss resulting from the occurrence of tsunamis due to exposure and fragility. The tsunami vulnerability assessment methodology used in this study was developed by M. Papathoma and others (figure below, right). This model incorporates multiple factors (e.g., parameters related to the natural and built environments and socio-demographics) that contribute to tsunami vulnerability. Data provided with FEMA’s HAZUS loss estimation software and Clatsop County, Oregon, tax assessment data were used as input to the model. The results, presented within a geographic information system, reveal the percentage of buildings in need of reinforcement and the population density in different inundation depth zones. These results can be used for tsunami mitigation, local planning, and for determining post-tsunami disaster response by emergency services.

Product: Dominey-Howes, Dale, Paula Dunbar, and Jesse Varner (2008), Estimating probable maximum loss from a Cascadia tsunami, submitted to *Natural Hazards: Journal of the International Society for the Prevention and Mitigation of Natural Hazards*.



PM: PLANETARY METABOLISM

Planetary metabolism is the complex web of biochemical and ecological processes and their interaction with the lithosphere, atmosphere and hydrosphere. Both natural and anthropogenic disturbances drive the structure and dynamics of natural systems, and a thorough understanding of these complex processes is essential to protect the biosphere from the adverse effects of pollution, destruction of natural landscapes, and inadvertent alteration of climate.

PM-01: BIOSPHERE-ATMOSPHERE INTERACTIONS

CSD-07 Biosphere-Atmosphere Exchange

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CSD-07 Biosphere-Atmosphere Exchange

Goal: Gain an improved understanding of the role that the exchange of gases between the surface and the atmosphere plays in shaping regional climate and air quality.

Milestone 1:

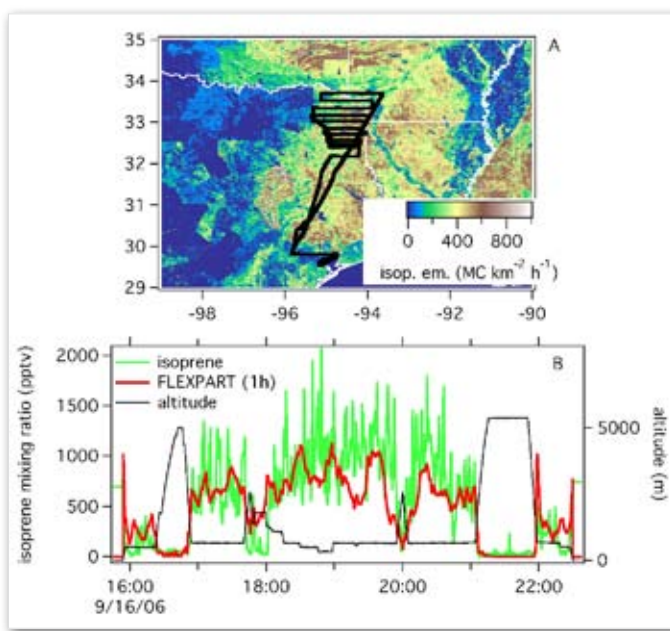
Analyze field observations from the International Consortium for Atmospheric Research on Transport and Transformation (ICARTT) field mission in 2004 and the TexAQS 2006 related to the natural sources of volatile organic compounds, such as isoprene, that could influence air quality.

Accomplishment: Isoprene is a volatile organic compound released from vegetation that can play an important role in the photochemical formation of ozone in the polluted atmosphere. In air quality models, isoprene emissions are calculated from inventories that combine land-cover data with parameterized emission models based on temperature, photoactive radiation (PAR), and other environmental parameters. Airborne measurements of isoprene were made during four different missions over the southeastern United States in 1999, the northeastern United States in 2004, and Texas in 2000 and 2006. The goal of this study was to evaluate different emission inventories for isoprene, using the available airborne data.

Two different methods were used in this study. First, isoprene emissions were estimated from the isoprene mixing ratios using measured boundary-layer heights, calculated levels of hydroxyl radicals, and the assumption that isoprene is uniformly mixed across the height of the boundary layer. The estimated emissions were then compared to the emissions from the inventory, extracted along the flight tracks using the temperature and PAR from the aircraft measurements. Second, isoprene emission inventories were incorporated into the Lagrangian transport model Flexpart, and compared to the measured isoprene mixing ratios along flight tracks. The figure at right shows the results of this analysis for one flight over northeastern Texas. Panel A shows the base emissions according to the BEISv3.12 inventory, as well as the flight track of the NOAA WP-3 research aircraft on September 16, 2006. Panel B shows the

comparison between the isoprene measured with a fast time response by proton-transfer reaction mass spectrometry (PTR-MS) and calculated using Flexpart. It is seen that model and measurement agree roughly within a factor of two, which was typically the case for data from the four missions and the different inventories investigated (BEISv3.12, BEISv3.13, MEGAN, and BEISv3.12 with the land-use data from Wiedinmyer et al. [2001]). Interannual differences between 2000 and 2006 were observed for Texas, which were only partially explained by the differences in temperature, cloud cover and leaf-area index.

Product: Warneke, C., et al. (2008), Determination of biogenic emissions in the eastern United States and Texas and comparison with biogenic emission inventories, *J. Geophys. Res.-Atmos.*, submitted.



NGDC-07 Anthropogenic Remote Sensing

Goal: Provide spatial and temporal depictions of human activities based on satellite detection and mapping of population centers, fires, gas flares, and heavily lit fishing boats.

Milestone 1: *Completion of annual time series of lighting from human settlements, gas flares, biomass burning and heavily lit fishing boats extending from 1992 through 2005.*

Accomplishment: An annual time series of lighting from human settlements, gas flares, biomass burning, and heavily lit fishing boats extending from 1992 through 2005 was completed.

Milestone 2: *Completion of an improved global map of poverty rates.*

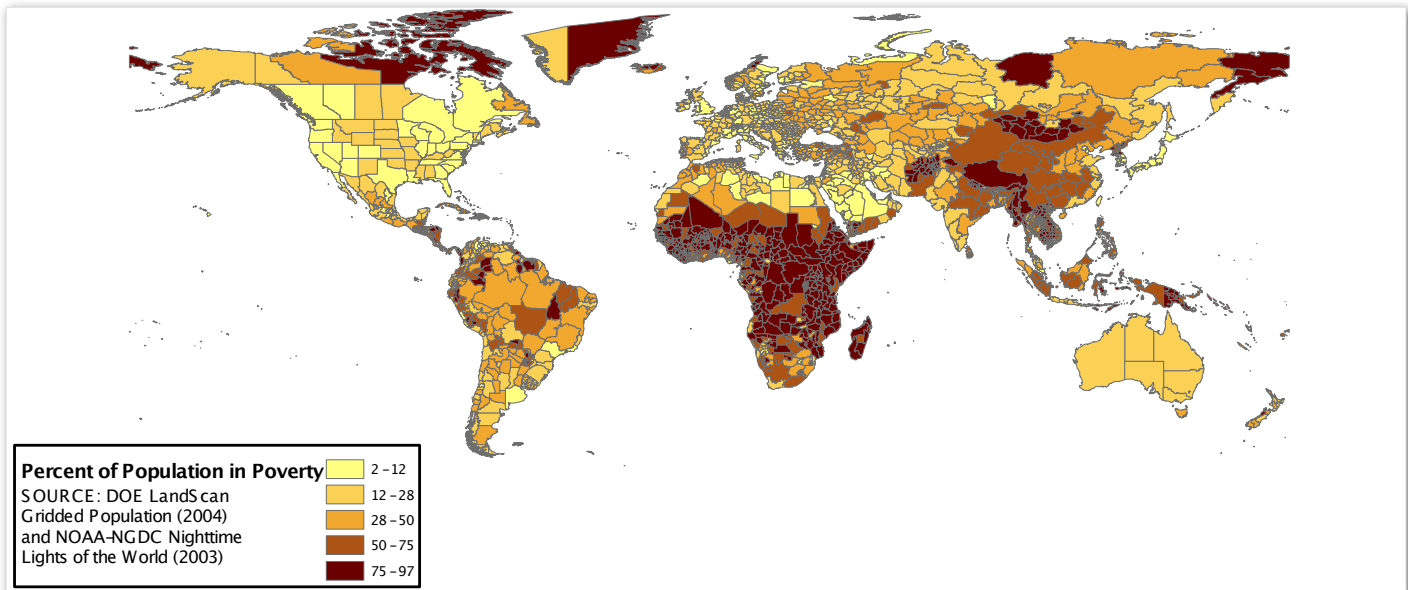
Accomplishment: An improved global map of poverty rates was completed (see below). The results will be published in a chapter invited to a book on urban remote sensing. The chapter is entitled, "Global Urban Mapping Based On Nighttime Lights."

Product: Global Poverty Map: http://www.ngdc.noaa.gov/dmsp/download_poverty.html.

Milestone 3: *Complete an analysis of global trends in gas flaring, urban growth, and heavily-lit fishing boat activity from 1992 through 2005.*

Accomplishment: Analysis of global trends in gas flaring activity from 1992 through 2005 completed. Cited in an article by Ofeibe Quist-Arcton for National Public Radio, "Gas Flaring Disrupts Life in Oil-Producing Niger Delta," <http://www.npr.org/templates/story/story.php?storyId=12175714>.

Product: http://www.ngdc.noaa.gov/dmsp/interest/gas_flares.html.



RP: REGIONAL PROCESSES

The effect of climate variability is often regionally focused, thus influencing very specific populations, economic systems, and ecosystems. Therefore, many research endeavors within CIRES and NOAA have a regional focus, addressing a particular set of geographies, demographics, or weather and climatic regimes.

RP-01: REGIONAL HYDROLOGICAL CYCLES IN WEATHER AND CLIMATE

PSD-11 Water Cycle

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PSD-11 Water Cycle

Goal: Improve weather and climate predictions through an increased knowledge of regional and global water cycle processes.

Milestone 1: *Plan and execute the 2008 Hydrometeorology Testbed-West (HMT-West) field campaign in the northern California American River Basin, located in the Sierra Nevada Mountains west of Lake Tahoe and east of Sacramento. The HMT-West 2008 effort will be conducted in coordination with the NSF-oriented Sierra Hydrometeorology and Atmospheric River Experiment (SHARE), where several NSF observing systems will be added to the HMT-West backbone of observations. CIRES investigators will be key participants and contributors to this activity.*

Accomplishment: The third year of full-scale field operations for HMT in the American River Basin (HMT-West 2008) was conducted from 3 December 2007 to 18 March 2008. A total of eight intensive operating periods (IOPs) were executed. Concentrated arrays of unattended instruments, including wind profilers, S-band precipitation profilers, various disdrometers, conventional and experimental precipitation and snow gauges, soil moisture sensors, stream level gauges, and surface meteorological stations monitored atmospheric and hydrologic conditions continuously for the entire field season. These observations were augmented during IOPs by manned operations of the ESRL PSD HYDROX gap-filling polarimetric Doppler radar and serial rawinsonde launches by local students managed by ESRL PSD. Supplemental rawinsondes were released from Oakland and Reno during six of the eight IOPs. Experimental, high-resolution (3 km) numerical weather prediction models were run daily by ESRL GSD and produced probabilistic forecasts of various precipitation amounts in the region. Forecasts, crew deployments, and storm debriefings were discussed on daily conference calls among the NWS and ESRL participants of HMT-West 2008. Observations and forecasts from the project were available via the Web (<http://www.esrl.noaa.gov/psd/programs/2008/hmt/>). Additionally, ALPS workstations were installed in the Sacramento, Reno and Monterey WFOs, and the Sacramento CNRFC in late February. A large fraction of the forecast

products along with some of the observational datasets were accessible on these workstations, which essentially mimic the AWIPS workstations used operationally.

The total precipitation accumulation during the season was just less than 50 inches at Huysink (2,011 m), just less than 40 inches at Blue Canyon (1,610 m), just less than 30 inches at Sugar Pine (1,171 m), and about 13 inches at CA State Sacramento (8 m). These precipitation accumulations were slightly larger than those observed during HMT-West 2007, but still far below the precipitation accumulations observed during HMT-West 2006. The number of IOPs executed during the three field seasons shows a similar trend. Streamflow was very low during HMT-West 2008, with a peak discharge of 2,000 ft³ s⁻¹. This is about a factor of four lower than the peak discharge observed during HMT-West 2007, and more than an order of magnitude lower than the peak discharge observed during HMT-West 2006. The low streamflow observed during HMT-West 2008 can be attributed to the exceptionally low snow levels that were associated with almost all of the storms that impacted the American River Basin. On average, snow levels were around 4,000 ft, but they occasionally descended down to below 1,000 ft. With the cold storms, snow piled up to very high levels. In late February, snow depths were about 7 ft at Blue Canyon (1,610 m), about 8 ft at Big Bend (1,739 m) and approaching 10 ft at Huysink (2,011 m).

The most noteworthy storm of HMT-West 2008 occurred during IOP-4 (3-7 January). This event was associated with an impressive offshore moisture plume displaying an atmospheric river signature and exceptionally strong winds. These factors combined to produce more than 7 inches of rain in the coastal mountains and 4 to 5 inches of liquid equivalent precipitation (about 2 ft of snow above 1,500 m) in the Sierra Nevada. The winds turned out to have the largest impact, with widespread power outages throughout northern California, including many HMT-West 2008 instrument sites.

Milestone 2:

Validating the Ka-band attenuation method by comparing Ka-band retrievals with results from longer wavelength precipitation radars.

Accomplishment: Rainfall rate (R) profiles retrieved from vertically-pointing 8-mm wavelength radar (MMCR) measurements using the attenuation-based method were compared to the R estimates from cm-wavelength precipitation radars. Comparisons were conducted at the ARM Tropical Western Pacific site, where MMCR retrievals were compared to the polarimetric estimates from the C-band polarimetric radar (C-Pol) located at a 26 km distance from the MMCR, and at the ARM Southern Great Plains site, where MMCR retrievals were compared to the estimates from

the WSR-88D radar (KVNK) at a distance of 60 km from the ARM site. It was shown that the mean relative standard deviations between MMCR and precipitating radar rainfall estimates (~40 percent) were within uncertainties of these estimates for both attenuation-based and traditional radar approaches. Overall, the attenuation-based method, as applied to Ka-band radars, was found to provide satisfactory retrievals for rainfalls in a range between about 1 and 15 mm/h for stratiform precipitation. Uncertainties of retrievals tend to increase for convective precipitation. The results of this research were presented at the ARM science team meetings, and at the International Atmospheric Radiation Conference.

RP-02: SURFACE/ATMOSPHERE EXCHANGE

PSD-12 Air-Sea Interaction

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PSD-12 Air-Sea Interaction

Goal: Perform cutting-edge micrometeorological and climatological research over the open ocean aboard research vessels, sea-based towers, and buoys.

Milestone 1:

Process Eastern Pacific Investigations of Climate (EPIC), the North American Monsoon Experiment (NAME), and the African Monsoon Multidisciplinary Analyses (AMMA) datasets, provide a detailed analysis of these air-sea interaction data products, and make the final dataset publicly available.

Accomplishment: In June 2008, ESRL/PSD released two synthesis datasets (<http://www.esrl.noaa.gov/psd/psd3/synthesis/>) containing observations of air-sea fluxes and cloud/radiative properties from nine years of cruises (1999-2007) in the Eastern Equatorial Pacific. The datasets are from Eastern Pacific Investigation of Climate (EPIC) Extended Monitoring cruises from fall 1999 through fall 2007. These observations were made as part of a joint ESRL, NOAA Pacific Marine Environmental Laboratory (PMEL), and Woods Hole Oceanographic Institution (WHOI) climate monitoring project funded by the Climate Prediction for the Americas (CPPA) program in NOAA's Climate Program Office. The project includes instrument enhancements of the Tropical Atmosphere Ocean (TAO) buoys at the 95 W and 110 W line, and ESRL's flux and cloud observations made during cruises to tend the TAO buoys and the WHOI climate reference buoy in the stratocumulus cloud region at 25 S 85 W. The equatorial database includes observations from nine TAO-buoy-tending cruises plus the EPIC2001 process study, held in the same region. The stratocumulus study contains data from annual cruises beginning in 2001. The Equatorial database is composed of time series of turbulent and radiative fluxes, low cloud properties, and column integrated water vapor and cloud liquid. The stratocumulus data have been further synthesized

to simplify comparisons with climate models. Besides the basic time series, diurnal and daily averages have been computed, and complete interpolated rawinsonde profiles are available.

Milestone 2:

Parameterization of sea spray will continue as part of the NOAA hurricane studies.

Accomplishment: The sea spray parameterization work was re-invigorated with a 2007 grant from the Joint Hurricane Testbed and funding from NOAA's Hurricane Forecast Improvement Project. A new version (Version8) was developed that uses, which inputs for kinetic energy lost to wave breaking, friction velocity, wave height, and wave period. This version was implemented and tested in the Hurricane Weather Research and Forecasting (HWRF) model. Collaborations have begun with the University of Rhode Island on a similar approach using the Feophysical Fluid Dynamics Laboratory wave model planned for the HWRF. In May, the stabilizing effect of droplet mass was incorporated into Version9, which is now undergoing testing in HWRF. A paper based on wind tunnel studies of spray production was submitted.

Product: Fairall, C.W., M. Banner, W. Peirson, R.P. Morison, and W. Asher (2008), Investigation of the physical scaling of sea spray spume droplet production. *J. Geophys. Res.*, submitted.

Milestone 3:

Further quantify the air-sea transfer of gases and use a detailed physical analysis of data obtained from the Post-GasEx and TexAQS surface processes experiments to evaluate and improve gas transfer parameterizations.

Accomplishment: Work continued with parameterizations for CO₂, ozone, and dimethyl sulfide. Ozone data from the TexAQS 2006 and Stratus 2007 cruises were used to evaluate the ozone parameterization and a paper is in preparation. Fairall and Bariteau attended workshops at the University of Hawaii (April 2008) and Boulder (July 2008) for processing of the GASEXIII flux observations. A paper on modeling of the global ozone budget was submitted.

Product: Ganzeveld, L., D. Helmig, C. Fairall, J.E. Hare, and A. Pozzer (2008), Biogeochemistry and water-side turbulence dependence of global atmosphere-ocean ozone exchange, *Global Biogeochemical Cycles*, submitted.

Milestone 4:

Develop, deploy, and test a robust ship-based system for routine ship-based CO₂ flux measurements.

Accomplishment: This project involves the repackaging of fast CO₂ sensors to permit continuous unattended deployment on the NOAA ship Ronald H. Brown. The goal is to obtain an extensive database of CO₂ flux and transfer velocity for a variety of verification and parameterization development objectives. The project has been underway for about two years. A prototype system was field tested on a Norwegian ship in the summer of 2006. The data were evaluated this year. An improved version of the sensor was deployed on the Stratus cruise in October 2007, and evaluation of that data led to refinements in the design. The latest version was deployed on Ronald H. Brown during the GASEXIII cruise (Feb-Mar 2008), and it is being evaluated compared to other sensors on that cruise.

Milestone 5:

Create a multi-year global oceanic dataset of near-surface temperature and humidity using a multi-sensor satellite retrieval method recently developed at the ESRL Physical Sciences Division.

Accomplishment: Refined multi-sensor satellite retrieval algorithms for the near-surface specific humidity and air temperature over the oceans were

developed through use of more diverse training data, incorporation of quadratic terms and logarithmic scaling in the retrieval equations, and development of a stability-based correction to reduce regional biases. The retrievals based on the Special Sensor Microwave/Imager (SSM/I), Special Sensor Microwave Temperature Sounder (SSM/T-2), and Advanced Microwave Sounding Unit (AMSU) provide improved accuracy over both single-sensor retrievals and preliminary multi-sensor retrieval algorithms. The algorithms were used to produce multi-year global datasets of near-surface specific humidity and air temperature at 0.5-degree and 3-hour resolution. Specific humidity and air temperature products based on SSM/I and AMSU were generated for 1999-2006, and an additional specific humidity product based on SSM/I and SSM/T-2 was created for 1993-2004. The SSM/I and AMSU products provide the best accuracy, but AMSU was first launched in 1998. Use of SSM/T-2 data allows extension of the specific humidity record back to 1993 at a slightly reduced accuracy level.

Product: All products are presently available through the Web at <http://www.esrl.noaa.gov/psd/psd2/coastal/satres/satflux.html> and have been supplied to collaborating scientists.

Milestone 6:

Study and parameterization of stable boundary layers as part of the NOAA/NSF Polar Programs.

Accomplishment: SHEBA data plots of non-dimensional gradients of wind speed and temperature using Ri (gradient Richardson number) replacing the traditional z/L stability parameter (Klipp and Mahrt 2004, and Sorbjan 2008) show a dramatic reduction in scatter of data, and data points collapse fairly well to a single curve in the very stable case. SHEBA data also show that non-dimensional variables should not include height z as a scaling parameter in this case.

Product: Grachev, A.A., E.L. Andreas, C.W. Fairall, S.P. Guest, and P.O. Persson (2008), Turbulent measurements in the stable atmospheric boundary layer during SHEBA: ten years after, *Acta Geophysica*, 56(1).

RP-03 REGIONAL AIR QUALITY

CSD-08 Regional Air Quality	131
GMD-06 Baseline Air Quality	136
PSD-13 Air Quality	137
GSD-02 Regional Air Quality Prediction	137

CSD-08 Regional Air Quality

Goal: Carry out laboratory measurements, atmospheric observations, and diagnostic analyses that characterize the chemical and meteorological processes involved in the formation of pollutant ozone and fine particles. Undertake research that contributes to the enhancement of air quality prediction and forecasting capabilities.

Milestone 1:

Present and publish results from TexAQS 2006 field study.

Accomplishment: Commercial marine vessels range in size from small fishing boats (20-30 meters in length) to extremely large container ships (>300 meters in length). These ships, almost without exception, use

Table 1. Summary of average marine vessel emission factors.

Engine type	NO _x	CO	SO ₂	H ₂ CO	LAC
Medium speed diesel (MSD)	60	8.7	9.1	0.17	0.41
Slow speed diesel (SSD)	74	6.6	28	0.20	1.16

All units are grams of species per kilogram fuel consumed.
Emission factors for CO are median data.

Table 2. Comparison of marine vessel and power plant emissions.

Emission source	NO _x /CO ₂	CO/CO ₂	SO ₂ /CO ₂
Commercial vessel, SSD	22	6.1	6.1
Commercial vessel, MSD	18	8.1	2.0
Electric power generating unit			
W. A. Parish	0.23	0.51	1.9
Welsh	0.88	1.4	1.8

All units are molecules of species per 1000 molecules of CO₂.

diesel engines for propulsion and auxiliary power generation. The larger ships, comprising bulk carriers, tankers, and container carriers, use diesel engines that produce power in the 10 MW to 100 MW range. These engines typically consume heavy fuel oils, which are high in sulfur content (1 to 4.5 percent by weight). These engines are also extremely efficient, converting essentially all of the carbon in the fuel to CO₂, but also emitting oxides of nitrogen (NO_x), carbon monoxide (CO), sulfur dioxide (SO₂), volatile organic compounds, and particulate matter.

During TexAQS 2006, measurements on board the NOAA/RV Ronald H. Brown, emissions from a large number of commercial marine vessels were characterized. From these data, mass-based emission factors were calculated for many of the compounds noted above. Table 1 presents the average derived NO_x emission factors for slow speed diesel (SSD) engines, which are those with maximum power greater than ~10 MW, and medium speed diesel (MSD) engines, which are of lower power. The NO_x values are within 20 percent of the average values reported in the Lloyd's (1995) study for both MSD and SSD engines, although the measured variability is large in both cases. These data are sufficient to provide emission factors classified by ship type (e.g., freighters, container ships, tankers, tugs, etc.). It is concluded that Lloyd's (1995) provides an accurate characterization of NO_x emissions from underway vessels in the Houston-Galveston-Brazoia (HGB) region.

The emission factors for CO are within 20 percent of the value reported in by Lloyd's (1995). There is no trend of increasing CO at lower vessel speeds (used as a surrogate for engine load), which was seen in the Lloyd's data. Measurements of formaldehyde (H₂CO) emissions from ships show little distinction between MSD and SSD engines; emission of H₂CO is less than 5 percent the emission of CO. Emission factors for SO₂ vary with fuel sulfur content. In the HGB region, the mean fuel S derived from the measurements is 0.46 percent for MSD engines and 1.4 percent for SSD engines. Measurements of light absorbing carbon (LAC; also known as black carbon) were also derived.

Given detailed activity data (e.g., marine fuel consumption) for ships in the HGB region, an emissions inventory for this source could be constructed. The 2007 report from Eastern Research Group (ERG) to TCEQ (Eastern Research Group 2007) has such data, but there appears to be a significant underestimate (factor of 2–8) of fuel consumption, when compared to an estimate from a more comprehensive model (Wang et al. 2007). The NO₂ emission factors used in the ERG report agree with CSD data to within 10 percent. Thus, for current ship emissions inventory modeling, there is less uncertainty contributed by emission factors than by activity data.

Table 2 gives emissions of NO_x, CO, and SO₂, relative to the emission of CO₂, from ships compared to similar emission ratios from electric power generating units (EGUs), from the 2004 point source emission inventory, updated to 2006 with CEMS data. Ships emit 10 to 100 times more NO_x (and somewhat more CO, and SO₂) per unit fuel burned (i.e., CO₂ emitted) than large stationary sources. Though the emissions from an individual vessel might be 10–100 times lower than from an EGU, the volume of ship traffic in the HGB region is sufficient that emissions from commercial shipping, in aggregate, cannot be neglected. Accurate fuel consumption or other ship activity data are needed to accurately quantify these emissions. Importantly, while emissions from stationary sources are a focus of ongoing control measures, emission controls on commercial shipping are not likely to be implemented, due to technical reasons and complications arising from international law.

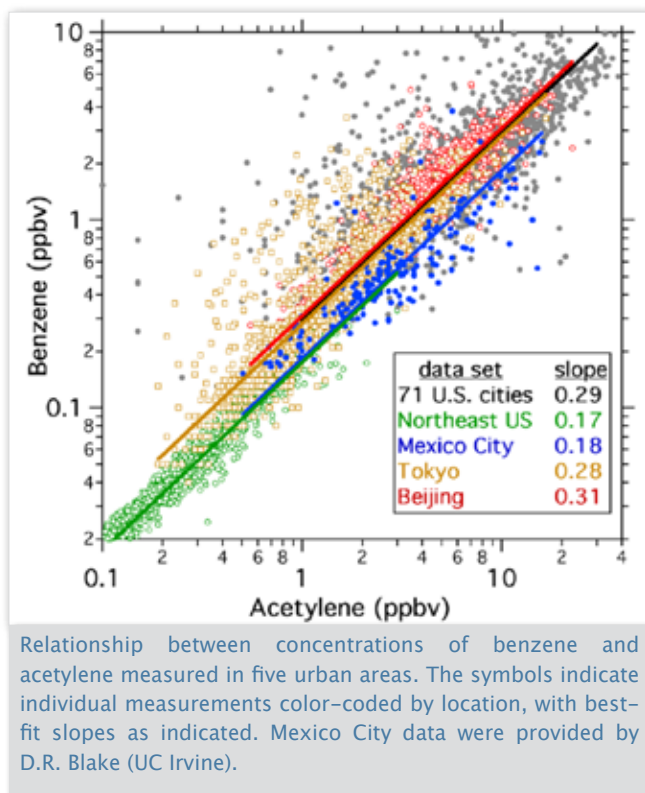
In addition, during the TexAQS/GoMACCS 2006 field campaign, the Ronald H. Brown often encountered small marine recreational craft while sailing close to the Texas coast, especially in Galveston Bay. Measurement of a suite of trace gases at high time resolution (1 Hz) allowed calculation of emission factors (EFs), relative to CO₂, for NO_x, SO₂, and CO for distinct exhaust plumes from these vessels. As previously observed along the New England coast, gasoline-powered craft showed significantly higher NO_x/CO₂ and lower CO/CO₂ EFs than current emissions inventories predict, although in agreement with the most recent published literature. These findings imply lower VOC emissions from these vessels, although this was not directly measured.

Product: Williams, E.J., B.M. Lerner, P.C. Murphy, S. Herndon, and M. Zahniser (2008), Gaseous emissions from commercial marine vessels in the Houston-Galveston region during TexAQS 2006, *manuscript in prep.*

Lerner, B.M., P.C. Murphy, and E.J. Williams (2008), In-situ measurements of small marine craft emission factors, *manuscript in prep.*

Milestone 2:
Characterize the volatile organic compounds (VOCs) in three mega-cities: New York City, Beijing, and Mexico City.

Accomplishment: VOCs are emitted from numerous different anthropogenic sources and play an important role in the formation of ozone and organic aerosol in urban areas. The impact of mega-cities on regional and global scales is currently under intense investigation, and will become even more important in the future



when a larger fraction of the world's population moves from rural to urban areas. There is currently very little information, however, on the VOC emissions from such large urban complexes, particularly those in lesser-developed countries. From 2004 through 2006, detailed measurements of VOCs were made in three of the world's largest mega-cities: New York City, Beijing, and Mexico City. The goal of this study is to investigate the similarities and differences.

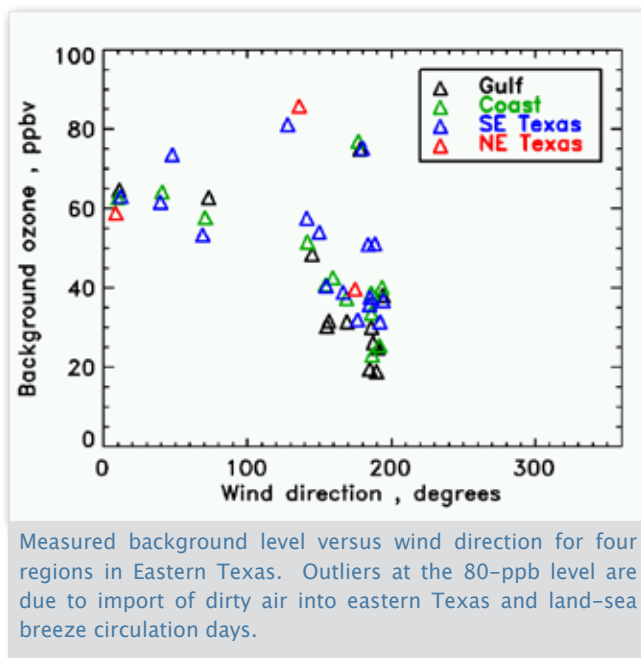
Initial results show striking similarities between the VOC composition of the three mega-cities investigated, suggesting that emissions from vehicles dominate the VOC emissions. As an example, the figure above, left, shows a scatter plot of benzene versus acetylene from Mexico City, Beijing, the northeastern United States (dominated by New York City and Boston) and some additional data from Tokyo and a study from 71 U.S. cities in the 1980s. The figure shows that the ratio between benzene and acetylene is remarkably similar in all these studies, a finding that extends to most other VOCs. Closer inspection of the data does reveal some systematic differences: For example, emission ratios of VOCs relative to CO from Mexico City were found to be higher on average than those from the United States, suggesting, not surprisingly, a difference in age and state of maintenance of the vehicle fleets. Comparison

between new data from the northeastern United States and the earlier data from the 1980s suggests that VOC emissions may have gone down. This important conclusion warrants further research.

Product: Newsletter: Comparison of air pollutant emissions among Mega-cities, D.D. Parrish, P.D. Goldan, J. de Gouw, M. Shao, Y. Kondo, T. Shirai, Y. Yokouchi, and M. Koike (2008), *IGACTivities* 38, 22-29.

Milestone 3:

Analyze data obtained during TexAQS 2006 study to investigate the role of meteorological processes in transport and mixing of pollutant species in the nighttime stable boundary layer in the Houston area, and publish findings in scientific journals.



Accomplishment: Ship-based lidar measurements were used to investigate the impacts of nocturnal boundary-layer processes on surface ozone measurements during TexAQS 2006. The lidar measurements focused on the relationship between the southerly nocturnal low-level jet and the surface ozone measured during the night and throughout the next day. Analysis of the measurements showed that strength and height of the low-level jet were inversely correlated with surface ozone concentrations measured on the ship (figure, above right). It is postulated, based on the observations, that a stronger low-level jet enhances turbulent mixing across the stable layer aloft, effectively entraining clean Gulf of Mexico air into the boundary layer and reducing ozone. Next day's peak ozone, as measured on the ship, was also observed to be inversely correlated with the strength and height of the low-level jet.

The airborne ozone lidar characterized background ozone levels in different regions around Texas. Highest background levels occurred in regions to the north and

west of Houston, and showed a strong dependence on wind direction—when winds were from the northeast to southeast, background ozone levels were highest during the experiment. The flux of ozone being transported into the state from the east was studied during two flights along the Texas–Louisiana border under easterly wind conditions. During the second flight, ozone levels at the border were above 80 ppb in a 2–km layer, indicating the very significant impact of imported ozone on background levels in east Texas.

Milestone 4:

Process and analyze lidar observations collected during TexAQS/GoMACCS 2006, present results at international conferences, and publish findings in scientific journals.

Accomplishment: An airborne ozone lidar and two shipborne lidars (a Doppler wind lidar and another ozone and aerosol profiling lidar) were deployed during TexAQS 2006. These three remote sensing systems produced extensive, multidimensional datasets of wind speed, wind direction, atmospheric turbulence, ozone concentration, aerosol backscatter and extinction, and mixed layer height. The analysis of these datasets has yielded results that address several important science questions related to the local buildup and regional transport of pollutants in eastern Texas.

The airborne lidar measurements provided mesoscale estimates of background ozone under different synoptic flow regimes. Background ozone levels in eastern Texas were significantly higher under easterly or northerly flow conditions when continental air was advected into Texas as compared to southerly flow that brought much cleaner, marine air into the state. In one case, after several days of easterly flow, the observed ozone background values exceeded the 8-hour National Ambient Air Quality Standard for Ozone, highlighting the potential impact of long-range transport of pollutants on local air quality.

To quantify the export of pollutants from strong localized sources to surrounding rural areas, airborne ozone lidar data from flight transects downwind of Houston and Dallas were used to compute horizontal ozone fluxes and ozone production rates. Based on several case studies of the Houston plume and one flight during which the Dallas plume was investigated, the horizontal ozone flux produced by the Houston metropolitan area was a factor of two to three times higher than the ozone flux emanating from the Dallas/Fort Worth area. As the Houston and Dallas pollution plumes disperse, they have the potential to significantly increase regional ozone background levels. Measurements indicate that ozone transported out of Houston during the course of a summer day may raise background ozone levels over a 10,000 square mile area by approximately 10 ppb.

The airborne lidar data were also used to investigate the relationship between boundary-layer depth and ozone concentration. Elevated ozone levels measured in the Houston plume downwind of the city showed no

correlation with mixed layer depth. However, ozone levels were inversely correlated with wind speed, indicating that horizontal dilution of the plume is an important process affecting ozone concentrations.

Data from the shipborne Doppler lidar were utilized to produce an extensive dataset of mixed layer heights over the Gulf of Mexico and Galveston Bay. A new composite method was employed to compute mixed layer height estimates from profiles of vertical velocity turbulence, wind speed, direction, and relative aerosol backscatter. It was found that in general the mixed layer over Galveston Bay and the Gulf of Mexico is several hundred meters deep and its height exhibits only slight diurnal variations. However, near-shore mixing heights can vary significantly, from approximately 150 meters at night during a low-level jet event to 2 km, when offshore flow advects a deep, well-mixed boundary layer over the water.

In addition, the lidar datasets gathered during the TexAQS 2006 study were used to investigate the relationship between wind speed and above-background ozone concentrations, the enhancement of mixing height associated with the urban heat island effect, and aerosol hygroscopic properties.

Thirteen conference papers highlighting these results have been presented at international conferences, a journal paper has been submitted, and several additional papers will be submitted to scientific journals by the end of September 2008.

Product: S. C. Tucker, W. A. Brewer, R. M. Banta, C. J. Senff, S. P. Sandberg, D. C. Law, A. M. Weickmann, and R. M. Hardesty (2008), Doppler Lidar Estimation of Mixing Height Using Turbulence, Shear, and Aerosol Profiles, Submitted to *Journal of Atmospheric and Oceanic Technology*.

Darby, L. S., C. Senff (2007), Comparison of the urban heat island signatures of two Texas cities: Dallas and Houston, 7th Symposium on the Urban Environment, San Diego, USA, 10–13 September.

Darby, L. S., C. J. Senff (2007), The Houston Urban Heat Island: Surface Temperature, Aerosol Mixing Layer Height, and Surface Wind Field Relationships, AGU Fall Meeting, San Francisco, California, USA, 10–14 December.

Senff, C. J., T. B. Ryerson, R. J. Alvarez II, R. M. Hardesty, R. M. Banta, L. S. Darby, A. M. Weickmann, S.P. Sandberg, D. C. Law, R. D. Marchbanks, W. A. Brewer, J. L. Machol, and D.D. Parrish (2007), Ozone Flux and Production Downwind of Houston and Dallas, AGU Fall Meeting, San Francisco, California, USA, 10–14 December.

Tucker, S. C., A. W. Brewer, C. Senff, S. Sandberg, D. Law, A. Weickmann, W. Angevine, R. M. Hardesty (2007), Ship-based Doppler lidar estimates of mixing layer heights during TexAQS 2006, AGU Fall Meeting, San Francisco, California, USA, 10–14 December.

McCarty, B. J., C. J. Senff, S. C. Tucker, W. L. Eberhard,

R. D. Marchbanks, J. Machol, and W.A. Brewer (2007), Vertical aerosol structure and aerosol mixed layer heights determined with scanning shipborne lidars during the TexAQS 2006 study, AGU Fall Meeting, San Francisco, California, USA, 10–14 December.

Hardesty, R.M., C.J. Senff, R.J. Alvarez, R.M. Banta, S.P. Sandberg, A.M. Weickmann, L.S. Darby (2007), Mixing Heights and Three-Dimensional Ozone Structure Observed by Airborne Lidar During the 2006 Texas Air Quality Study, AGU Fall Meeting, San Francisco, California, USA, 10–14 December.

R. M. Banta, C. J. Senff, J. W. Nielsen-Gammon, B. Lambeth, M.K. Trainer, R.J. Alvarez, R.M. Hardesty, T.B. Ryerson, G. J. Frost, L. S. Darby, and A.B. White (2007), Factors Controlling Peak Ozone Concentrations in the Houston Area: Wind Speed and Mixing Height, AGU Fall Meeting, San Francisco, California, USA, 10–14 December.

Tucker, S.C., W.A. Brewer, C.J. Senff, R.M. Banta, and W.M. Angevine (2008), Ship-based lidar measurements of nocturnal mean winds, mixing height and boundary-layer dynamics and correlation to Houston ozone measurements during TexAQS 2006, 15th Joint Conference on the Applications of Air Pollution Meteorology with the A&WMA, New Orleans, Louisiana, USA, 20–24 January 2008.

Alvarez II, R.J., W.A. Brewer, D.C. Law, J.L. Machol, R.D. Marchbanks, S.P. Sandberg, C.J. Senff, and A.M. Weickmann (2008), Development and Application of the TOPAZ Airborne Lidar System by the NOAA Earth System Research Laboratory, Proceedings of 24th International Laser Radar Conference, Boulder, Colorado, USA, 23–27 June 2008, 68–71.

S. C. Tucker, W. A. Brewer, S. P. Sandberg, A. M. Weickmann, D. C. Law, W. M. Angevine, J. B. Gilman, R. M. Banta, B.M Lerner, and E. J. Williams (2008), Coherent Doppler Lidar Applications to Air Quality: Focus on Houston, Proceedings of 24th International Laser Radar Conference, Boulder, Colorado, USA, 23–27 June 2008, 227–230.

J. L. Machol, G. Feingold, P. Massoli, P. K. Quinn, R. D. Marchbanks, B. J. McCarty, W. L. Eberhard, and C. J. Senff (2008), Aerosol Hygroscopic Properties Measured near Houston, Texas, Proceedings of 24th International Laser Radar Conference, Boulder, Colorado, USA, 23–27 June 2008, 468–470.

R. M. Hardesty, C. J. Senff, R.J. Alvarez II, R.M. Banta, and Y. Pichugina (2008), Observations of Mixed Layer Height and Ozone Levels in the Houston Region During TexAQS 2006, Proceedings of 24th International Laser Radar Conference, Boulder, Colorado, USA, 23–27 June 2008, 655–658.

C. J. Senff, R. J. Alvarez II, R. M. Hardesty, R.M. Banta, L.S. Darby, A.M. Weickmann, S.P. Sandberg, D.C. Law, R.D. Marchbanks, W.A. Brewer, D.A. Merritt, and J.L. Machol (2008), Airborne Lidar Measurements of Ozone Flux and Production Downwind of Houston and Dallas, Proceedings of 24th International Laser Radar

Conference, Boulder, Colorado, USA, 23–27 June 2008, 659–662.

Milestone 5: Analyze results from the measurement of the nocturnal nitrogen oxides, NO₃, and N₂O₅, during the TexAQS 2006.

Accomplishment: Analyze results from the measurement of the nocturnal nitrogen oxides, NO₃ and N₂O₅, during TexAQS 2006. Impact: Nocturnal formation and loss of NO₃ and N₂O₅ has a large effect on ozone formation and loss in polluted environments such as Houston, TX. Analysis of results from this campaign will assess the specific impact of these nighttime processes (e.g., NO_x and O₃ loss, VOC oxidation) on air quality in this region.

During the TexAQS 2006, measurements of the nocturnal nitrogen oxides, NO₃ and N₂O₅, were made from the NOAA WWP-3 aircraft. Analysis of these data during 2007–08 has quantified the influence of nocturnal nitrogen oxide reactions on regional air quality in the Houston area. The most important conclusions area as follows. First, aircraft transects of plumes from large NO_x point sources (e.g., coal-fired power plants) after dark, both in Houston and in north Texas, have shown the conversion of NO_x into N₂O₅, and have also shown that N₂O₅ acted as a stable reservoir rather than a reactive sink within these plumes. As a result, instead of undergoing conversion to and removal as soluble nitrate, NO_x could be transported overnight in the form of N₂O₅. At sunrise, this compound regenerates photochemically active NO_x that can participate in ozone production. Transport of N₂O₅ from the Parish power plant in Houston on one particular flight was predicted on the following day to release its NO_x over isoprene-rich areas of east-central Texas, where the ozone-forming potential of this NO_x would be large. Second, the inefficiency of N₂O₅ hydrolysis made the nitrate radical, NO₃, available as an oxidant for highly reactive VOC. In Houston, there are substantial emissions of alkenes from industrial sources within the Houston ship channel. Downwind transects of these sources showed VOC oxidation rates due to reaction with NO₃ in the range 0.2–2 ppbv hr⁻¹. Many of these VOC's were small alkenes, such as propoene, which are the most important for ozone formation during daytime. Finally, vertical profiling through the shallow, nocturnal urban boundary layer was achieved by missed approaches to low altitude over airfields around the Houston metropolitan area. These profiles showed that emissions of reactive VOC from urban sources were co-located with the strongest production rates for the NO₃ oxidant within the nocturnal boundary layer, but that this chemistry occurred within shallow layers less than 400 m above ground level.

Product: These results have been presented in both oral presentations and posters at the 2007 fall AGU meeting. Manuscripts are currently in preparation for the *Journal of Geophysical Research*, with publication expected in 2009.

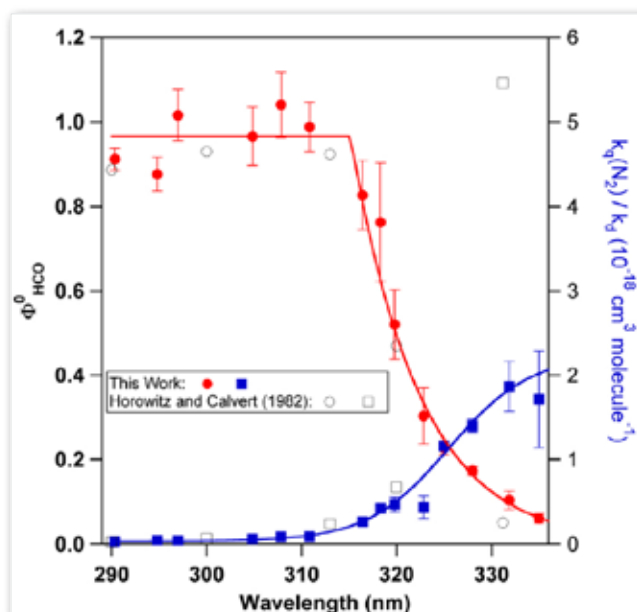
Milestone 6:

Make direct measurement of quantum yields for formyl radical, HCO, production in the photolysis of aldehydes, RC(O)H.

Accomplishment: Quantum yields of the formyl radical (HCO) in the UV photodissociation of acetaldehyde and propanal were measured at 298 K as a function of pressure (50–550 Torr N₂) and wavelength (290–341 nm). Quantum yields were measured by combining pulsed laser photolysis with cavity ring-down detection of HCO. The pressure dependence of the HCO yield is well-represented at all wavelengths by a Stern-Volmer relationship, (see figure at right). The Stern-Volmer analysis yielded accurate values for the ratio of the rate constant for collisional quenching of the excited electronic state (k_q) to the rate constant for dissociation, k_d . The results from these studies provide input to atmospheric models and will improve the accuracy of calculated photolysis rates as a function of solar zenith angle and altitude.

Product: Flad, J.E., S.S. Brown, J.B. Burkholder, and A.R. Ravishankara (2008), Wavelength and pressure dependence of the HCO radical yield from acetaldehyde UV photolysis, *manuscript in prep.*

Flad, J.E., S.S. Brown, J.B. Burkholder, and A.R. Ravishankara (2008), Wavelength and pressure dependence of the HCO radical yield from propanal UV photolysis, *manuscript in prep.*



Zero pressure HCO quantum yields and k_q/k_r values (Stern-Volmer analysis) for acetaldehyde obtained in this work compared with previously reported values obtained by measurement of stable end-product yields (Horowitz and Calvert, *J. Phys. Chem.* 86, 3105, 1982).

GMD-06 Baseline Air Quality

Goal: Study intercontinental transport events to improve understanding of their importance in affecting overall air quality and impacts on public health.

Milestone 1:

As part of the Global Atmospheric Watch Network of monitoring sites, the ESRL/GMD Aerosol Group will build and deploy to Taiwan an instrument package to measure aerosol radiative properties.

Accomplishment: The aerosol instrumentation has been fully tested and is waiting to be deployed to Taiwan, pending travel arrangements and site preparation by the Taiwan EPA.

Product: Aerosol instrumentation system, which includes a nephelometer, particle soot absorption photometer, condensation nuclei counter, data

acquisition hardware and software, regulated power supply, and a vacuum system with pumps, blowers, and monitors.

Milestone 2:

As part of the International Geophysical Year and also 50th anniversary of the NOAA Mauna Loa Observatory, there will be a field campaign at Mauna Loa to calibrate the Dobson ozone instruments from around the world.

Accomplishment: The world standard Dobson ozone spectrometer was calibrated.

PSD-13 Air Quality

Goal: Gather and analyze atmospheric observations to characterize meteorological processes that contribute to high-pollution episodes. Compare these measurements with air-quality forecasting model predictions to assess and improve research model performance.

Milestone 1:

CIRES investigators will participate in the planning and execution of the NOAA Health of the Atmosphere Program field study, tentatively planned for the winter of 2008.

Accomplishment: A regional wintertime air quality study in the continental United States was abandoned in favor of conducting an Arctic air quality cruise led by PMEL in support of the International Polar Year.

Milestone 2:

Further quantify the air-sea transfer of gases and use a detailed physical analysis of data obtained from the TexAQS 2006 surface processes experiments to evaluate and improve gas transfer parameterizations.

Accomplishment: The air-sea surface flux measurements taken during the TexAQS 2006 have been analyzed to evaluate and improve gas transfer parameterizations. Direct covariance, inertial-dissipation, and bulk turbulent fluxes have been produced at 10-min and hourly averages, including momentum, sensible and latent heat, and CO₂ fluxes. Ozone fluxes are still under analysis, but preliminary fluxes have been produced. Fluxes can be accessed on the NOAA ftp site at: ftp://ftp.etl.noaa.gov/et6/cruises/TexAQS_2006/RHB/Scientific_analysis/Flux. The results from the analysis are compared with the model simulations along with mixing heights derived from Doppler-lidar-measured turbulence profiles.

The systems were deployed on the NOAA Ship Ronald H. Brown for five weeks in July–August 2006, as part of the TexAQS 2006 project. All systems obtained data on the cruise. Ozone fluxes were obtained over the Gulf of Mexico and over ‘land’ when the ship went up rivers and channels. Extensive processing techniques have been developed to deal with sample tube time delay and attenuation of correlations. Good ozone fluxes were obtained, and ozone deposition velocity over the

open water was slightly smaller than typical published parameterizations.

Product: L. Bariteau, J. Hueber, K. Lang, D. Helmig, C.W. Fairall, and J.E. Hare, 2008, Ozone deposition velocity by ship-based eddy correlation flux measurements, *J. Atmos. Oceanic Tech.*, in prep.

Grachev, A.A., J. Ludovic, J. Bariteau, K. Hueber, D. Lang, D. Helmig, C.W. Fairall, and J.E. Hare, 2008, Near-surface Ozone fluxes from ship-based eddy correlation measurements during TexAQS 2006, *J. Geophys. Res.*, in prep.

W.M. Angevine, M. Žagar, S.C. Tucker, C. Fairall, L. Bariteau, D.E. Wolfe, and W.A. Brewer (2008), Modeling the boundary layer over Galveston Bay and the Gulf of Mexico for air pollution studies, Submitted to *JGR Atmospheres*.

Milestone 3:

Process data from measurements of air-sea fluxes and gas transfer in the New England experiment on the Ronald H. Brown in August 2006.

Accomplishment: Processing is complete and three papers were published, one during the current fiscal year. These papers detailed the unique observations of fluxes and boundary-layer properties obtained during the cruise, used the observations to illustrate the unexpected effects of the shallow coastal boundary layer, and demonstrated the difficulty of simulating the conditions with conventional mesoscale models used for air pollution forecasts.

Product: Wolfe, D. E., C.W. Fairall, D.C. Welsh, M. Ratterree, A.W. Brewer, J.M. Intrieri, C.J. Senff, B.J. McCarty, S. Tucker, D.C. Law, A.B. White, and D.E. White (2007), Shipboard multi-sensor merged wind profilers from NEAQS 2004: Radar wind profiler, high-resolution Doppler lidar, GPS rawinsonde, *J. Geophys. Res.*, 112.

GSD-02 Regional Air Quality Prediction

Goal: Design and evaluate new approaches for improving air-quality prediction.

Milestone 1:

Use data from real-time weather and air-quality forecasts during the Houston 2006 field experiment for further evaluation and improvements of the coupled modeling system Weather Research and Forecast Model, WRF/Chem.

Accomplishment: A chemical data assimilation method was implemented and evaluated for WRF/Chem and the Grid Point Statistical Interpolation (GSI) system. Chemical assimilation was applied for ozone and

particulate matter. Results were evaluated with the TexAQS 2006 dataset.

Smoke from wildfires was included in the modeling system through inclusion of a sophisticated plumerise model within WRF/Chem. Initial data came from satellite observations (WF-ABBA from Wisconsin). Results were evaluated with data from Alaska, and are also running in real time.

A simple approach for aerosols was included into the model. This approach considers total mass of black

carbon, organic carbon, sulfate, and a few other species. These modules came from NASA's Goddard Chemistry Aerosol Radiation and Transport (GOCART) model. Results were evaluated with the TexAQS 2006 dataset.

Product: Results are displayed at <http://www-frd.fsl.noaa.gov/qaq/wrf/>

Milestone 2:

Prepare documentation and tutorials to support WRF/Chem as a community model

Product: WRF/Chem Users Guide http://ruc.fsl.noaa.gov/wrf/WG11/Users_guide_22july08.pdf.

RP: REGIONAL PROCESSES

CSD-05 Tropospheric and Stratospheric Transport and Chemical Transformation

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CSD-05 Tropospheric and Stratospheric Transport and Chemical Transformation

Goal: Carry out modeling studies and airborne and surface measurements of chemical species in order to elucidate the processes involved in the intercontinental transport of photochemical pollution.

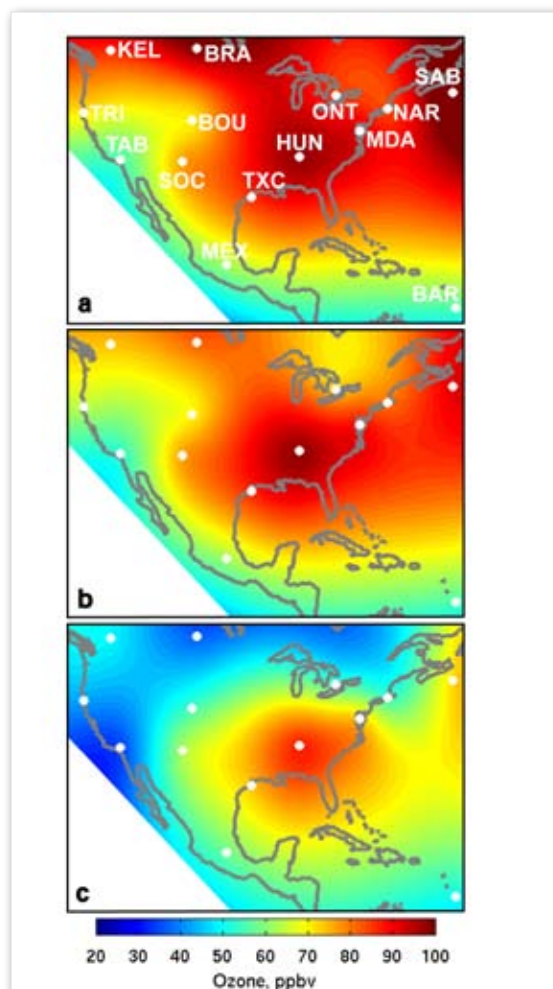
Milestone 1:

Examine the influence of transport pathways on the ozone profile measurements across North America during the TexAQS 2006 Study/Gulf of Mexico Atmospheric Composition and Climate Study experiment, as measured by ozone sondes, research aircraft, and commercial MOZAIC aircraft.

Accomplishment: Ozone is a key trace gas for both the chemistry and radiative balance of the troposphere, and because it is the principal pollutant associated with photochemical smog, its presence in the lower troposphere has large implications for air quality. In the past, quantifying the North American ozone budget has been difficult due to the limited number of profiling sites across the continent. This lack of information was partly rectified by the 2004 INTEX Ozone Sonde Network Study (IONS), which revealed an upper tropospheric ozone enhancement above Texas during summer. Measurements of pollution in conjunction with modeling work indicated that much of this enhancement was due to photochemical ozone production involving lightning NO_x emissions. However, large regions of North America were not covered by the IONS network and the spatial extent of the ozone enhancement is still not known. Also unknown is whether it was an annually recurring event.

To further improve knowledge of upper troposphere ozone above North America, a consortium of U.S. and Canadian government laboratories and several universities organized a second IONS experiment in August, 2006, but this time with much better spatial coverage across all of mid-latitude North America (figure at right, panel a). Daily ozonesondes (balloon borne instruments that measure ozone) were launched from 14 sites, carefully selected to monitor ozone transport influenced by the North American summer monsoon. The data reveal a distinct upper tropospheric ozone maximum above eastern North America, centered over the southeastern United States (see figure at right, panel b). Recurring each year, the location and strength of the ozone maximum is influenced by

the summertime upper tropospheric anticyclone that traps convectively lofted ozone, ozone precursors, and lightning NO_x above the southeastern United States. The North American summer monsoon that flows northwards along the Rocky Mountains is embedded within the western side of the anticyclone and also marks the westernmost extent of the ozone maximum.



Median ozone mixing ratios during August 2006, a) all 14 measurements regardless of location in the troposphere or stratosphere b) measurements only within the troposphere ($\text{PV} < 1$ pvu), and c) measurements only within the troposphere less the calculated quantity of ozone from the stratosphere.

Removing the influence from stratospheric intrusions (figure opposite, panel c), median ozone mixing ratios (78 ppbv) in the upper troposphere (> 6 km) above Alabama, near the center of the anticyclone, were nearly twice the level above the U.S. West Coast. Simulations by an atmospheric chemistry general circulation model indicate lightning NO_x emissions led to the production of 25–30 ppbv of ozone at 250 hPa above the southern United States during the study period.

Product: Cooper, O.R., M. Trainer, A.M. Thompson,

S.J. Oltmans, D.W. Tarasick, J.C. Witte, A. Stohl, S. Eckhardt, J. Lelieveld, M.J. Newchurch, B.J. Johnson, R.W. Portmann, L. Kalnajs, M.K. Dubey, T. Leblanc, I.S. McDermid, G. Forbes, D. Wolfe, T. Carey-Smith, G.A. Morris, B. Lefer, B. Rappenglück, E. Joseph, F. Schmidlin, J. Meagher, F.C. Fehsenfeld, T.J. Keating, R.A. Van Curen, and K. Minschwaner (2007), Evidence for a recurring eastern North America upper tropospheric ozone maximum during summer, *J. Geophys. Res.*, 112, D23304, doi:10.1029/2007JD008710.

RP-05 AEROSOL CHEMISTRY AND CLIMATE IMPLICATIONS

CSD-09 Aerosol Formation, Chemical Composition, and Radiative Properties

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CSD-09 Aerosol Formation, Chemical Composition, and Radiative Properties

Goal: Carry out airborne and ground-based experiments that characterize the chemical composition of radiatively important aerosols in the upper troposphere and at the Earth's surface.

Milestone 1: *Add airborne data to those from the R/V Ronald H. Brown to examine the role of organic molecules in aerosols, particularly during cloud formation. Consider the implications for the role of the biosphere and human activity in climate.*

Accomplishment: Data on the composition of the aerosol organic mass fraction—acquired aboard R/V Ronald H. Brown during the TexAQS/GoMACCS 2006 campaign using the recently developed Aerosol Observation System (AOS) Proton Transfer Reaction (PTR) Ion Transfer Mass Spectrometry (ITMS) instrument—have been analyzed, and a manuscript describing the instrument and results from the field campaign has been prepared for publication.

Milestone 2: *Analyze data acquired during the Gulf of Mexico Atmospheric Composition and Climate (GoMACCS), focusing on measurements and modeling of the radiative forcing of clouds in the Houston area.*

Accomplishment: During the past year, two major studies were completed on aerosol–cloud interactions during GoMACCS field deployment in 2006. The first summarized aerosol and cloud observations made from the Center for Interdisciplinary Remotely-Piloted Aircraft Studies (CIRPAS) Twin Otter, addressing aerosol effects on cloud albedo and the initiation of precipitation. It included a detailed analysis of the effects of entrainment on cloud optical properties, and showed that cloud optical property response to aerosol perturbations can be strongly over-estimated if entrainment is not considered.

The second study was a model–observation comparison study. Data collection from the CIRPAS aircraft during GoMACCS was designed for statistical comparison

between observations and modeling. A series of large eddy simulations of cumulus cloud fields were performed for five different case studies. The model output was statistically sampled, much as if it had been sampled by the aircraft, and comparison was made between modeled and observed cloud/dynamical fields. Results showed good agreement between model and observations, both in terms of broad sample statistics and cloud profiles.

A followup study, currently in progress, is further quantifying this agreement in terms of the cloud radiative response. In this study, observed radiation fields that were being compared with radiation fields calculated based on the cloud fields generated by large eddy simulations. This is a very rigorous test of the ability of a model to simulate aerosol indirect effects—e.g., the effect of aerosol on cloud radiative forcing—because it requires that the model simulate both the macroscale cloud properties (cloud fraction, cloud depths, water content) and the microscale properties (cloud drop size distributions). To date, results show that good agreement between model and observations is obtained, provided the aerosol residing between the clouds is also included in the calculations. This result was somewhat unexpected and points to the importance of cloud-enhanced scattering by aerosol residing between clouds. Results have been reported in a conference proceedings paper and a journal article is in preparation.

Product: Jiang, H., G. Feingold, H. Jonsson, M.-L. Lu, P.Y. Chuang R.C. Flagan, and J.H. Seinfeld (2008), Statistical comparison of properties of simulated and observed cumulus clouds in the vicinity of Houston during the Gulf of Mexico Atmospheric Composition and Climate Study (GoMACCS), *J. Geophys. Res.*, 113, D13205, doi:10.1029/2007JD009304.

Lu, M.-L., G. Feingold, H.H. Jonsson, P.Y. Chuang, H. Gates, R.C. Flagan, and J.H. Seinfeld (2008), Aerosol-cloud relationships in continental shallow cumulus, *J. Geophys. Res.*, 113, D15201, doi:10.1029/2007JD009354.

Feingold, G., J. Small, P.Y. Chuang, H. Jiang, S. Krueger, and H. Jonsson (2008), Assessment of Aerosol and Entrainment-Mixing Processes on Drop Size distributions in Warm Cumulus, 15th International Conference on Clouds and Precipitation (ICCP), Cancun, MX.

Schmidt, K. S., G. Feingold, P. Pilewskie, and H. Jiang (2007), Impact of aerosol and clouds on 3D irradiance fields during the GoMACCS experiment, AGU 2007 Fall meeting.

Feingold, G., K. S. Schmidt, H. Jiang, H. Jonsson, N. Nussbaum, C. Mazzoleni, M. Dubey, S. Murphy, A. Sorooshian, H. Gates, R. Flagan, J. Seinfeld (2007), Vertical Redistribution of Aerosol by Shallow Cumulus Clouds: Observations and Modeling, AGU 2007 Fall meeting.

Schmidt, K. S., P. Pilewskie, G. Feingold, H. Jiang, S. Platnick, G. Wind (2008), The shortwave properties of cloud fields during GOMACCS AND TC4, 15th International Conference on Clouds and Precipitation (ICCP), Cancun, MX.

Milestone 3:

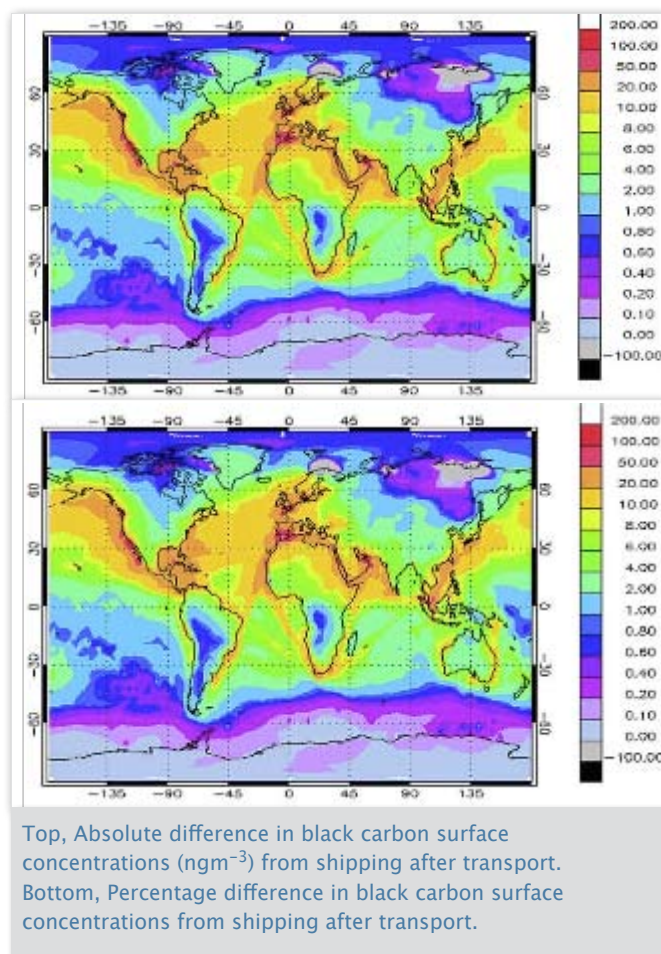
Analyze the aerosol optical property data from instruments (e.g., cavity ring-down aerosol extinction spectrometer and photo-acoustic aerosol absorption spectrometer) fielded in FY 2006, aboard the NOAA WP-3 aircraft and NOAA R/V Ronald H. Brown during TexAQS/GoMACCS 2006, to evaluate the role of atmospheric aerosol on climate and regional air quality.

Accomplishment: During the summer of 2006, a cavity ring-down aerosol extinction spectrometer and a photo-acoustic aerosol absorption spectrometer were deployed aboard the NOAA Research Vessel, Ronald H Brown. This deployment was part of TexAQS/GoMACCS 2006. During 2007 and 2008, extensive data analysis of the 2006 TexAQS/GoMACCS study dataset was conducted. The results of this analysis have appeared in a recent publication and will be published in at least three further manuscripts by the end of 2008. These publications will provide a more detailed understanding

of a) the quantity, composition and optical properties of aerosols from commercial shipping, b) the mechanisms of severe biases in traditional aerosol absorption instrumentation, and c) the aerosol optical properties of multiple aerosol sources within the Texas region.

The most recent publication from this dataset was focused on the emissions of black carbon from commercial shipping (see figure below). Surprisingly, current inventories are underestimating this source by at least a factor of two. Further analysis showed that tugboats, which operate exclusively in ports, emit the most black carbon of any vessels. This indicates that tugboats make a larger contribution to degraded air quality in port region than previously estimated.

Product: Lack, D., B. Lerner, C. Granier, T. Baynard, E. Lovejoy, P. Massoli, A. R. Ravishankara, and E. Williams (2008), Light absorbing carbon emissions from commercial shipping, *Geophys. Res. Lett.*, 35, L13815, doi:10.1029/2008GL03906.



IA: INTEGRATING ACTIVITIES

CIRES engages in a wide range of integrating activities in research, education, and outreach that encompass each of the Institute's research themes and contribute to CIRES' science mission to society. CIRES' integrating activities include K-16 interdisciplinary education and outreach, graduate and post-graduate education, scientific assessments, interdisciplinary research, and science and technology policy research.

IA-01 SCIENCE AND SOCIETY

CSD-10 Scientific Assessments for Decision Makers	141
POLICY-01 Science Policy Lecture Series	141

CSD-10 Scientific Assessments for Decision Makers

Goal: Plan, lead, prepare, and disseminate assessments for the decision-making communities associated with ozone-layer depletion, greenhouse warming, and regional air quality.

Milestone 1:

Contribute to the coordination and preparation of the synthesis and assessment product of the U.S. Climate Change Science Program (CCSP) product 2.4, on chemistry related to the stratospheric ozone layer.

Accomplishment: A series of 21 "synthesis and assessment products" are being produced by the U.S. CCSP, to provide a synthesis of the cumulative knowledge on climate, and to evaluate the implications for scientific research and policy formulation. A key component of the CCSP Strategic Plan (released July

2003), is the integration of research results focused on important science issues and questions frequently raised by decisionmakers. Synthesis and Assessment Product 2.4 is on "Trends in Emissions of Ozone-Depleting Substances, Ozone Layer Recovery, and Implications for Ultraviolet Radiation Exposure." The report provides a synthesis and integration of the current knowledge of the stratospheric ozone layer, ozone-depleting substances, and ultraviolet radiation reaching the Earth's surface. A draft of SAP 2.4 was reviewed by the National Research Council and then revised for public review. The final report is expected to be published in FY 2009.

POLICY-01 Science Policy Lecture Series

Goal: Provide useful information that will help improve the relationship between societal needs and science and technology policies

Milestone 1: *Implement the second science policy lecture series, most likely a series of debates over relevant science policy and energy-related topics.*

Accomplishment: A lecture/panel discussion series

has been planned for fall 2008 to coincide with the presidential campaign. Three events have been planned: two panel discussions addressing different aspects of the energy/climate challenge, and a keynote address before the 2nd CU-Boulder Energy Initiative Research Symposium.

IA-02 WESTERN WATER ASSESSMENT

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WWA-03 Climate and Water Affairs	143
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WWA-01 Scientific Assessments

Goal: Using models, analyses, surveys, written reports, and presentations, acquire and disseminate information about the relationship between Rocky Mountain climate and water resources.

Milestone 1:

Front Range water needs to 2040. Colorado's Front Range is one of the most rapidly growing areas in the West. This ongoing model-based

study, the South Platte Regional Assessment Tool (SPRAT), will investigate the region's ability to meet new water needs through proposed projects, conservation, and groundwater. This portion of

the project will involve helping transfer the model to a larger regional water provider.

Accomplishment: This project was put on hold due to staffing issues at the water provider.

Milestone 2:

Colorado River Climate Change Analysis. Use the U.S. Bureau of Reclamation's Colorado River Simulation System model to investigate the vulnerability of the basin to flow changes based on IPCC Fourth Assessment Report model runs.

Accomplishment: This project, jointly funded with the Bureau of Reclamation, was delayed and will begin again next year when a qualified graduate student can assist with the modeling tasks.

Milestone 3:

Dust on Snow Studies. Investigate impacts of dust storms on Southwest Colorado snowpack.

Accomplishment: It was established that the mountain snowpack in southwest Colorado melts out approximately one month earlier due to the presence of dust deposited from largely disturbed lands of the desert southwest United States (Painter et al. 2007). Subsequently, analysis of alpine lake cores showed that dust deposition to these mountains is now 500 percent greater than during the megadrought of 900 to 1300 AD, and before the railroad-facilitated expansion of cattle and sheep into the western United States (Neff et al. 2008).

For water managers, the most compelling question is "how great is the interannual variability in dust deposition and effect on snowmelt runoff?" Intensive measurements of dust deposition and point melt forcing began in 2005, so there is little capacity to infer the interannual variability. The remote sensing record from the NASA instrument Moderate Resolution Imaging Spectroradiometer (MODIS) and the NOAA Advanced Very High Resolution Radiometer (AVHRR) have the capacity to infer the presence of dust in mountain snow cover. For MODIS data, an algorithm was developed to give instantaneous measures of enhanced absorption from dust across the Colorado Rockies (Painter et al. *in prep.* 2008a). Such information will be bridged into the 1980s through intercalibration of the MODIS and AVHRR records. From these remotely sensed data, a modern record of interannual variability of dust forcing in snow cover and, in turn, its effect on melt and runoff will be established.

Dust in Snow reports were delivered to water managers concerned with Colorado water. In spring 2008, a Colorado-wide sampling network was established, coincident with Snow Telemetry (SNOTEL) sites from the southwest to north central mountains. Measurements indicated substantial dust deposition across the state in April and May but with varying mass flux and

optical properties (changes in absorption capacity). The synoptic scale events of April 2008 were captured during surveys and will result in publication of the statewide changes in dust forcing (Painter et al. *in prep.* 2008b).

Product: Neff, J. C., A.P. Ballantyne, G.L. Farmer, N.M. Mahowald, J. Conroy, C.C Landry, J. Overpeck, T. H Painter, C.R Lawrence, and R. Reynolds (2008), Recent Increases in Eolian Dust Deposition due to Human Activity in the Western United States, *Nature Geosciences*, doi: 10.1038/ngeo133.

Painter, T. H., A. P. Barrett, C. Landry, J. Neff, M. P. Cassidy, C. Lawrence, K. E. McBride, and G. L. Farmer (2007), Impact of disturbed desert soils on duration of mountain snow cover, *Geophysical Research Letters*, 34, L12502, doi:10.1029/2007GL030284.

T.H. Painter, M. P. Cassidy, and A. Guess (2008a), Remotely Sensed Analysis of Dust Concentration, Snow Grain Size, and Broadband Albedo of Alpine Snowcover, *Remote Sensing of Environment*, *in prep.*

Painter, T. H., C. Landry, P. McNeally, A. Guess, G. Hallar, I. McCubbin, J. Belnap, and J. Steenburgh (2008b), Synoptic scale dust deposition event to the Colorado Rocky Mountains, *in prep.*

Meetings: Myriad presentations at the at the following meetings: International Union of Geodesy and Geophysics, American Geophysical Union, Ecological Society of America, and many others.

Coordination meeting with water managers from Upper Rio Grande, Tri-County, Colorado River, Gunnison River on dust in snow feedbacks on snowmelt runoff and timing, February 2008.

International media coverage of snow pollution research, including:

- KCPW Radio, Salt Lake City public radio, Midday Metro interview with Lara Jones, <http://www.kcpw.org/article/5128>, 2008.
- KSL-5, Salt Lake City, The Grayest Snow on Earth? Story features Painter group research on impurities in snow, 16 January, 2008.
- Salt Lake Tribune, U. Professor Explores the Part Pollution Plays in Melting Snow, http://www.sltrib.com/ci_796421614, January 2008.
- Science, Trouble in Them Thar Hills, <http://sciencenow.sciencemag.org/cgi/content/full/2007/1212/3>, 12 December 2007.
- AGU Press Conference, Climate change in high elevation mountains, San Francisco, fall 2007.
- Forest Magazine, High Peaks, Dirty Snow, article on Painter group's dust in snow research, <http://www.fsee.org/index.html?page=http%3A//www.fsee.org/forestmag/>, Winter 2008.

WWA-02 Climate Products

Goal: Develop information, products, and processes to assist water resource decision makers throughout the Intermountain West.

Milestone 1:

Monthly Intermountain Climate Summary (ICS). Climate information is widely scattered on the Web and other locations. Water managers and other climate sensitive sectors have requested a single monthly summary of climate information, including precipitation, temperature, snow water equivalent, long-lead temperature, and precipitation outlooks, reservoir levels and streamflow forecasts.

Accomplishment: The ICS was produced eight times during the last year. This is a flagship product of the Western Water Assessment (WWA) and contains information used by water managers throughout the Intermountain West. Although designed for water managers, it appears to be read by a much wider audience. For example, a *Science* article this year cited an ICS article that reviewed and synthesized scholarly publications on the changing climate of the West.

Product: Intermountain Climate Summaries http://wwa.colorado.edu/forecasts_and_outlooks/intmntn_clim_smry.html.

Milestone 2:

Web-based seasonal guidance for Water Managers, Climate Prediction Center (CPC). Improve ability of federal, state, and local water managers to plan water operations during drought. Provide input to CPC seasonal outlooks.

Accomplishment: WWA produces experimental seasonal guidance for water managers approximately eight times a year. This web-based product features an ENSO status update, a look at regional conditions, and the most recent CPC forecasts.

Product: <http://www.cdc.noaa.gov/people/klaus.wolter/SWcasts/>.

Milestone 3:

National Integrated Drought Information System (NIDIS). As necessary, WWA will provide support activities for NIDIS implementation efforts.

Accomplishment: WWA works closely with NIDIS personnel on a variety of activities. WWA provided both administrative support and technical help with two NIDIS workshops held in 2008. The first workshop on remote sensing was held in Boulder in February, and the second workshop on the status of the Drought Early Warning System was held in Kansas City in April 2008. WWA personnel also attended and contributed to the NIDIS Southeast Drought Workshop in April 2008.

Milestone 4:

Lee's Ferry Reconstructions web site. Enhance existing site on Colorado River streamflow.

Accomplishment: The WWA's web site was revamped, with substantial additional content on the Assessment's Colorado River streamflow reconstructions. In addition to the new material on the Colorado River, the web site also contains information on stakeholder workshops held during 2007–2008, and an extensive list of current publications. A variety of tutorials are now online as well.

Product: <http://wwa.colorado.edu/treeflow/>.

Milestone 5: *Colorado River Climate, Management, Law and Policy web site. Enhance and update existing site on matters of interest to Colorado River water managers. Add discussion of useful existing climate products and new climate product needs by water managers.*

Accomplishment: WWA added substantial new content to this critical portion of the web site.

Product: http://wwa.colorado.edu/colorado_river/.

WWA-03 Climate and Water Affairs

Goal: Increase decision makers' level of knowledge about climate science so they can become better consumers and demanders of climate products and assessments, and help WWA set its research agenda.

Milestone 1:

Climate Change For Water Resource Managers Working Group. Convene a group of Front Range water managers to discuss and implement helpful research and synthesis products for water managers.

Accomplishment: WWA organized a group of Front Range Water Providers (Denver, Aurora, Colorado Springs, Northern, and Boulder) to participate in preparing a joint climate change and hydrology study for the Front Range. This group applied for and received an American Water Works Association Research Foundation grant to perform the work. WWA

has provided technical assistance and in-kind efforts, including a global change seminar to facilitate the study. WWA will continue this work into 2008–2009. This is an unusual effort because it is a scientific enterprise led by water providers.

Milestone 2:

Southwest Colorado Workshop. Convene a group of stakeholders in southwest Colorado to discuss regional needs with respect to research on climate variability and change. Jointly hosted with the Climate Assessment for the Southwest (CLIMAS) and the Center for Snow and Avalanche Studies.

Accomplishment: WWA held a stakeholder workshop in 2006 in Durango to investigate stakeholder interest in joint research ventures. WWA's Dust on Snow efforts are, in part, an outcome of this workshop. In addition, WWA held a follow-on workshop in 2007–2008 on paleoclimatology techniques.

Product: The workshop report, <http://wwa.colorado.edu/treeflow/durango2008.html>.

Milestone 3:

Water Availability Task Force. Provide technical support for the Governor's drought task force as needed.

Accomplishment: WWA regularly attends and presents at the quarterly meetings of the drought task force organized by the Colorado Water Conservation Board for the Governor of Colorado. On occasion, WWA hosts the workshop. WWA interacts with the state climatologist and the National Weather Service to provide forecasts and a statewide analysis of drought conditions.

Milestone 4:

Speakers for Interested Organizations and Public Events. From time to time, WWA is invited to speak on the interaction of climate and water at public events or to various organizations.

Accomplishment: WWA was frequently invited to speak at events in the Intermountain West. During 2007–2008, there were more than 30 of these events, including: the annual science retreat for U.S. Forest Service scientists, a meeting of the Water Utility Climate Alliance (which included the general managers of Seattle, Portland, San Francisco, Los Angeles, San Diego, Las Vegas, Denver and New York City), the Water Education Foundation bi-annual meeting on the Colorado River Compact, the CIRES Science Retreat, the South Platte Forum, the U.S. Fish and Wildlife Service, a Continuing Legal Education Forum on the Rio Grande River, the Western States Water Council, and the Western Governor's Association Annual Meeting.

WWA-04 Management

Goal: Provide overall guidance to WWA projects, and day-to-day management.

Milestone 1:

General Management Activities. Hold biweekly team meetings. Prepare annual budget. Interact with Regional Integrated Sciences and Assessment (RISA) program managers. Interact with CIRES and NOAA administrative staff. Establish strategic activities.

Accomplishment: The WWA management team meets regularly to provide guidance for the project, and the entire team meets regularly during the academic year. WWA provides overall leadership for the eight RISA teams located around the country.

Milestone 2:

Western Water Assessment web site. Provide a portal into all Western Water activities for researchers, water providers, and the public.

Accomplishment: The WWA web site was entirely revamped during the period of this report. In addition to a new interface, the web site has substantial additional content on climate change, Colorado River research and related hydrology and policy material, paleo reconstructions of streamflow, and water law and policy. The web site is now in a format which will allow easier updating by WWA staff.

Product: <http://wwa.colorado.edu>

Milestone 3:

Inform NOAA about Climate Services Needs. An important part of the WWA mission is to keep NOAA's NWS and OAR informed of new and evolving user needs, existing product limitations, and general lessons from the water management community.

Accomplishment: A report on uses of climate information and needs of Front Range municipal water managers was presented at the NOAA Climate Prediction Assessment Workshop in March 2008; a paper is in preparation on this work. WWA maintains a collaboration with the NOAA Climate Prediction Center (CPC) and Climate Testbed including providing user feedback to enhance CPC products, in particular drought-related products. WWA and CPC have designated liaisons to work together. WWA submitted an abstract to the 2008 NOAA Climate Diagnostics and Prediction Workshop based on this effort. WWA investigators regularly participate in NOAA fora to provide feedback on user needs and product lines, including the CPASW, CDPW, AMS, and NIDIS Drought Monitor Users Meeting.

IA-03 RESOURCE DEVELOPMENT FOR EDUCATORS AND DECISION MAKERS

POLICY-02 Outreach to Decision Makers through the Internet
POLICY-03 Outreach to Decision Makers through Newsletters

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POLICY-02 Outreach to Decision Makers through the Internet

Goal: Provide useful information that will help improve the relationship between societal needs and science and technology policies.

Milestone 1:

Continue to maintain and upgrade the Center's web site in terms of appearance, quality, and quantity of content, reliability, and ease of maintenance.

Accomplishment: A new web server was purchased last summer to increase the reliability of the Center's web site, which continues to be updated and maintained.



POLICY-03 Outreach to Decision Makers through Newsletters

Goal: Provide useful information that will help improve the relationship between societal needs and science and technology policies.

Milestone 1:

Continue to improve content of newsletter to make it of greater interest to the science and technology policy community and decision makers. Increase number of subscribers and distribute newsletter more widely. Continue to expand and upgrade the Center's science policy briefings.

Accomplishment: The Policy Center has attempted to make the newsletter interesting and relevant to the science and technology policy community by including opinion pieces on topics such as communicating the urgency of climate change. The next issue will include an exchange by leading voices in the climate change community on the usefulness of climate models. The science policy briefing is currently distributed to more than 3,500 science policy decision makers.



MEASURES OF ACHIEVEMENT: CALENDAR YEAR 2007



CIRES scientists and faculty published 435 peer-reviewed papers in 2007, commanding attention from the scientific community and the news media. International awards and a strong record of service reflect institutional excellence.

Publications by the Numbers

CIRES scientists and faculty published 435 peer-reviewed papers during 2007. The table below tabulates publications by affiliation of first author. CIRES scientists and faculty published an additional 150 non-refereed publications in 2007, with NOAA scientists as lead authors on 38 of those, CIRES on 64, and others on the remaining 48.

These publication counts are only one measure of CIRES' impact. Additional information on how CIRES research is pushing the boundaries of scientific knowledge is summarized in the Executive Summary, and also detailed throughout this report.

Refereed Publications

	2002	2003	2004	2005	2006	2007
CIRES Lead Author	112	177	165	188	141	118
NOAA Lead Author	60	31	56	20	81	67
Other Lead Author	110	183	134	145	289	250
Total	282	391	355	353	511	435

Refereed publications, 2007

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Honors and Awards, 2007

2007 Nobel Peace Prize

When the United Nations' Intergovernmental Panel on Climate Change (IPCC) won the 2007 Nobel Peace Prize with former Vice President Al Gore, several dozen Boulder experts shared the honor. Honorees included scientists from NOAA, NCAR, and CIRES.

CIRES Fellow Susan Solomon co-chaired Working Group 1 of the IPCC. Tingjun Zhang, a research associate with CIRES' National Snow and Ice Data Center (NSIDC), served as lead author of the chapter "Observations: Changes in Snow, Ice and Frozen Ground." NSIDC researchers Richard Armstrong, Roger Barry, Oliver Frauenfeld, James McCreight, Bruce Raup, Mark Serreze, Andrew Slater, and Walt Meier also contributed to portions of the report. So did CIRES Director Konrad Steffen and other CIRES Fellows David Fahey, Steve Nerem, and Carol Wessman, and other CIRES staff, including Kristen Averyt and Melinda Marquis.



Araujo-Pradere, Eduardo

Career track promotion to Research Scientist III

Auerbach, Nancy

Customer Service Award National Geophysical Data Center, for outstanding service to customers of the National Geophysical Data Center

Barry, Roger

Association of American Geographers, Cryosphere Specialty Group, Francois Emile Matthes Award

Founder's Medal, Royal Geographical Society, London

Nobel Peace Prize, shared by Vice President Gore and the IPCC, review editor for Working Group 1, The Cryosphere, and Working Group 2, The Polar Regions

Atmospheric Science Librarians International (ASLI) Choice Award—Honourable Mention, Scientific and Technical Category

Buhr, Susan

Colorado Math, Engineering and Science Achievement (MESA) Program of Excellence award

Cooper, Owen

2006 Editors' Citation for Excellence in Refereeing, *JGR-Atmospheres*

Outstanding Scientific Paper Award, NOAA's Office of Oceanic and Atmospheric Research

de Gouw, Joost

CIRES Outstanding Performance Award for Science

Diaz, Henry

Fellow of the American Meteorological Society

Dutton, Geoffrey

Stratospheric Ozone Protection Award, U.S. Environmental Protection Agency

Fedrick, Kelvin

CIRES Outstanding Performance Award for Science

Frauenfeld, Oliver

Nobel Peace Prize, shared by Vice President Gore and the IPCC, contributing author, IPCC Working Group 1, Fourth Assessment Report, Chapter 4: Observations: Changes in Snow, Ice, and Frozen Ground

Frost, Gregory

Career track promotion to Research Scientist III

Froyd, Karl

Outstanding Presentation, Boulder NOAA Laboratories Postdoctoral Symposium

Howard, Alliana

CIRES Outstanding Performance Award for Service

Jimenez, Jose

Provost's Faculty Achievement Award, University of Colorado at Boulder

Jones, Craig

Fellow, Geological Society of America

Kofler, Jonathan

CIRES Outstanding Performance Award for Science

Lu, Lixin

International Scholar of the Year, University of Colorado at Boulder

Appointed adjunct professor at the Institute of Remote Sensing Application, Chinese Academy of Sciences

Maurer, John

CIRES Outstanding Performance Award for Service

Maus, Heinrich

National Geophysical Data Center 2007 Director's Award, for enhancing the reputation of the NGDC

Miller, Roy

Nobel Peace Prize, shared by Vice President Gore and the IPCC

Career track promotion to Associate Scientist III

Ostashev, Vladimir

Fellow of the Acoustical Society of America

Parsons, Mark

Co-Chairmanship IPY Data Policy and Management Subcommittee, ICSU/WMO Joint Committee for IPY

Rajagopalan, Balaji

Awarded tenure and promoted to Associate Professor, CU-Boulder

Raup, Bruce

Nobel Peace Prize, shared by Vice President Gore and the IPCC, contributing author, Chapter 4 of the Assessment Report of Working Group 1.

Ray, Eric

CIRES Bronze Medal, in recognition of contributions to the Unmanned Aerial Vehicles demonstration project using the Altair

Sheehan, Anne

CU-Boulder Faculty Fellowship

Incorporated Research Institutions for Seismology/Seismological Society of America (IRIS/SSA) Distinguished Lecturer

Green Scholar, Institute for Geophysics and Planetary Physics, University of California, San Diego

Smith, Lesley

Champion of Education, Thorne Ecological Institute

Solomon, Amy

Associate Editor, *Journal of Geophysical Research-Atmospheres*

Stark, Harald

Career track promotion to Research Scientist II

Steffen, Konrad

Nobel Peace Prize, shared by Vice President Gore and the IPCC, contributor, IPCC Working Group 1, Fourth Assessment Report, Chapter 4: Observations: Changes in Snow, Ice, and Frozen Ground

Stone, David

CIRES Outstanding Performance Award for Science

Tolbert, Margaret

Hazel Barnes Prize, CU-Boulder, for excellence in teaching, research, and scholarship

Commencement Speaker, University of Colorado at Boulder, Winter 2007

Doctor of Science, honoris causa, Grinnell College, 2007

Tuttle, Benjamin

Rocky Mountain Region 2007-2008 Scholarship, American Society of Photogrammetry and Remote Sensing

Udall, Bradley

Climate Science Service Award, California Department of Water Resources

Vaida, Veronica

Sigma Xi distinguished lecturer, 2007–2008

Wang, Xuguang

Career track promotion to Research Scientist II

Washenfelder, Rebecca

National Research Council Postdoctoral Fellowship

Best Presentation in the Chemical Sciences category, Boulder Postdoctoral Poster Symposium, 2007

Williams, Christopher

Elected to Senior Member of IEEE

Zhang, Tingjun

Nobel Peace Prize shared by Vice President Gore and the IPCC, lead author, IPCC Working Group 1, Fourth Assessment Report, Chapter 4: Observations: Changes in Snow, Ice, and Frozen Ground

Atmospheric Science Librarians International Choice Award, Scientific and Technical category

Service, 2007

Conference Organizer/Convener

Aerodyne Aerosol Mass Spectrometer 8th Users' Meeting
American Geographers' special session, Snow Cover Observations and Variability
American Meteorological Society's 16th Conference on Applied Climatology
AMS Polar Meteorology and Oceanography meeting
AMS special session, Precipitation and Drought
Annual Conference of the American Association for Aerosol Research special symposium on Advances in Aerosol Instrumentation: Development, Application, and Use in Model Evaluation
Antarctic Meteorologic Observation, Modeling, and Forecasting, second workshop
Arctic-CHAMP (Community-wide Hydrologic Analysis and Monitoring Program) Scientific Steering Committee
Association of American Geographers' special session, Regional-Scale Changes in Cryospheric Variables
Atmosphere Observation Panel for Climate
CEDAR Lidar Technology Workshop at the NSF 2007 CEDAR workshop
Consortium of Resonance and Rayleigh Lidars 2007 Meeting
Front Range Aerosol Program
Global Climate Observing System
Group for the Global Digital Sea Ice Data Bank 3rd steering session
Intergovernmental Panel on Climate Change Working Group
International Permafrost Association, 9th International Conference on Permafrost
IUGG's International Association of Hydrological Sciences Symposium on Climate-Permafrost-Hydrology Interactions
JCOMM Expert Team on Sea Ice
NAS Space Studies Board: Committee on NASA Astronomy Science Centers
Ocean Observation Panel for Climate
Standing Committee for Data, Information and Communications
Terrestrial Observation Panel for Climate of the Global Terrestrial Observing System
WCRP/Global Climate Observing System
World Climate Research Programme

Editorial Service

Journal of the Acoustical Society of America
Aerosol Science and Technology
American Society of Civil Engineers
Annals of Glaciology
Annals of Glaciology, Associate Editor
Journal of Atmospheric Chemistry
Atmospheric Environment
Bulletin of the American Meteorological Society
Chinese Academy of Sciences
Climate Research
Darwin
Department of Energy
Earth Surface Processes and Landforms
Earth, Moon, and Planets
Encyclopedia of Inland Waters
Environmental Hazards
Environmental Science and Policy
Geological Society of America
Journal of Geophysical Research
Journal of Geophysical Research-Atmospheres
Journal of Geophysical Research-Earth Surface
GeoSphere
Global Environmental Change
International Association for Mathematical Geology
Limnology and Oceanography Methods
Mathematical Geology
Monthly Weather Review
Natural Hazards Review
Oecologia
Plant Biology
Plant Biosystems
Polar Geography
Policy Sciences
Scientific Online Letters on the Atmosphere
Journal of Soil Biology & Biochemistry
Journal of System Science, India
Trees
Water Resources Research
Zeitschrift fuer Gletscherkunde und Glazialgeologie

Paper/Proposal Reviewer

Journal of the Acoustical Society of America
Journal of Advances in Space Research
Advances in Water Resources
Journal of Aerosol Science and Technology
Agriculture and Forest Meteorology

Journal of Agriculture Systems
American Geophysical Union
American Journal of Physics
American Meteorological Society
Annales Geophysicae
Applied and Environmental Microbiology
Applied Microbial and Biotechnology
Journal of Applied Meteorology and
Climatology
Arctic Natural Sciences
ASCE Journal of Hydraulic Engineering
Journal of Atmospheric Chemistry and Physics
Atmospheric Environment
Journal of Atmospheric and Oceanic
Technology
Journal of the Atmospheric Sciences
Australian Antarctic Division
Australian Government's Commonwealth
Environmental Research Facilities
Biochemistry
Biogeochemistry
Journal of Boreal Environmental Research
Journal of Climate
Climate and Large-Scale Dynamics
Climate Dynamics
Climate of the Past
Colorado Water Resources Research Institute
Journal of Computational Acoustics
Journal of Computational Physics
Computers and Geosciences
Computing in Science and Engineering
Department of Energy
Dutch National Science Foundation
Earth Surface Processes and Landforms
Journal of Earth System Science
Ecological Applications
Ecology
Ecosystems
Ecotropicos
Encyclopedia of Inland Waters
Environmental Chemistry
Enzyme and Microbial Technology
European Geophysical Unions Journal
French National Agency of Research
Freshwater Biology
Geochemistry, Geophysics, and Geosystems
Geologica Acta
Geological Society of America
Geology
Journal of Geophysical Research
Journal of Geophysical Research-Atmospheres
Geophysical Research Letters

Journal of Geophysical Research-Solid Earth
Global and Planetary Change
Global Biogeochemical Cycles
Global Change Biology
GSA Today
Journal of Hydrology
Journal of Hydrometeorology
IEEE Transactions on Aerospace and Electronic
Systems
IEEE Transactions on Geoscience and Remote
Sensing
International Foundation for Science (IFS)
International Geology Review
International Glaciological Society
International Journal of Climatology
International Journal of Mass Spectrometry
Limnology
Limnology and Oceanography
Mineralogy and Geochemistry
Molecular Biology and Evolution
Monthly Weather Review
National Aeronautical and Space Administration
National Institute of Water Resources
National Research Council
National Science Foundation
Nature
NOAA Climate Test Bed
Oecologia
Optical Engineering
Permafrost and Periglacial Processes
Journal of Physical Oceanography
Proceedings of the National Academy of
Sciences
Protein Science
Quaternary Science Reviews
Radio Science
Journal of Respiratory Physiology and
Neurobiology
Science
Science of the Total Environment
Soil Biology & Biochemistry
Journal of Sound and Vibration
Terra Nova
U.S. Geological Survey
Water Resources Research
Wave Motion
Weather and Forecast Journal

Professional Memberships

Acoustical Society of America
American Association for the Advancement of
Science
American Association of Pharmaceutical

Scientists
American Association of State Climatologists
American Geophysical Union
American Indian Science and Engineering
Society
American Meteorological Society
American Water Works Association
Colorado Association of Libraries United States
Colorado Water Congress
Engineers Without Borders
Geological Society of America Member
Geophysical Journal International
Geophysical Research Letters
Goldschmidt Award Committee for the
Geochemical Society
Icarus
Incorporated Institutions for Seismology
International Association for Mathematical
Physics
International Association of Geodesy
International Society for Limnology
International Society on General Relativity and
Gravitation
Journal of Geophysical Research
Journal of Geophysical Research–Oceans
Morris K. Udall Foundation
National Association of Science Writers
Science Communications and Marine Public
Information Network
Sigma Xi Scientific Research Society
Society of American Archivists
Special Libraries Association
U.S. Permafrost Association
WCRP/Global Climate Observing System

APPENDICES



Governance and Management

CIRES Leadership

Konrad Steffen, Director

William M. Lewis, Jr., Associate Director

Jon Rush, Associate Director for Administration

Suzanne van Drunick, Assistant Director for Science

CIRES Divisions

Atmospheric and Climate Dynamics: Michael Hardesty, Associate Director

Cryospheric and Polar Processes: Richard Armstrong, Associate Director

Ecosystem Sciences: Carol Wessman, Associate Director

Environmental Chemistry and Biology: Fred Fehsenfeld and Maggie Tolbert, Associate Directors

Solid Earth Sciences: Roger Bilham, Associate Director

Weather and Climate Dynamics: Randall Dole, Associate Director

Fellows Committees

The Council of Fellows constitutes the “Board of Directors” and chief governing body of CIRES. It is comprised of individuals with an outstanding record of achievement and ability in diverse areas of environmental sciences. They are primarily university faculty, senior research scientists, or government scientists who form the core leadership of the Institute. Their responsibilities are to (1) provide leadership at all levels in environmental science, (2) maintain an active scientific research/education program, (3) support the CIRES infrastructure through indirect cost recovery and in-kind contributions, (4) participate in CIRES management, and (5) contribute interdisciplinary expertise and participate in collaborative work. As a group, they personify the concept of collaboration that is the founding principle of the NOAA Cooperative Institutes Program. Ex-officio individuals include representatives of the Members’ Council and CIRES administration. Fellows meetings are held monthly during the academic year.

The Council of Fellows met eight times during FY08: August 30, September 20, October 18, November 15, January 25, February 22, March 22, and April 19.

Council of Fellows

Susan Avery (Former CIRES Director; Former Professor of Electrical and Computer Engineering)

Richard Armstrong (Senior Research Scientist; Acting Director, National Snow and Ice Data Center)

Ben Balsley (Research Professor, CIRES)

Roger Barry (Distinguished Professor of Geography; Former Director, National Snow and Ice Data Center)

Roger Bilham (Professor of Geological Sciences)

John Cassano (Assistant Professor of Atmospheric and Oceanic Sciences)

Thomas Chase (Associate Professor of Civil, Environmental and Architectural Engineering)

Xinzhao Chu (Associate Professor of Aerospace Engineering)

Shelley Copley (Professor of Molecular, Cellular and Developmental Biology)

Joost de Gouw (Research Physicist, ESRL CSD)

Lisa Dilling (Assistant Professor of Environmental Studies)

Randall Dole (Deputy Director for Science, ESRL)

David Fahey (Research Physicist, ESRL CSD)

Christopher Fairall (Chief, Weather and Climate Physics Branch, ESRL PSD)
G. Lang Farmer (Professor of Geological Sciences)
Fred Fehsenfeld (Senior Research Scientist, ESRL CSD)
Graham Feingold (Research Scientist, ESRL CSD)
Noah Fierer (Assistant Professor of Ecology and Evolutionary Biology)
Baylor Fox-Kemper (Assistant Professor of Atmospheric and Oceanic Sciences)
Timothy Fuller-Rowell (Senior Research Scientist, CIRES/NOAA Space Weather Prediction Center)
Vijay Gupta (Professor of Civil, Environmental and Architectural Engineering)
R. Michael Hardesty (Program Lead, Atmospheric Remote Sensing, ESRL CSD)
José-Luis Jiménez (Associate Professor of Chemistry and Biochemistry)
Craig Jones (Associate Professor of Geological Sciences)
William Lewis, Jr. (Professor of Ecology and Evolutionary Biology; Director, Center for Limnology; Associate Director, CIRES)
Peter Molnar (Professor of Geological Sciences)
Russell Monson (Professor of Ecology and Evolutionary Biology)
William Neff (Director, ESRL PSD)
Steven Nerem (Professor of Aerospace Engineering)
David Noone (Assistant Professor of Atmospheric and Oceanic Sciences)
Roger Pielke, Jr. (Professor of Environmental Studies; Former Director, Center for Science and Technology Policy Research)
Balaji Rajagopalan (Associate Professor of Civil, Environmental and Architectural Engineering)
Prashant Sardeshmukh (Senior Research Scientist, ESRL PSD; Director, Climate Diagnostics Center)
Mark Serreze (Research Professor of Geography; Senior Research Scientist, National Snow and Ice Data Center)
Anne Sheehan (Professor of Geological Sciences)
Robert Sievers (Professor of Chemistry and Biochemistry)
Susan Solomon (Senior Scientist, ESRL CSD)
Konrad Steffen (Professor of Geography; Director, CIRES)
Margaret Tolbert (Professor of Chemistry and Biochemistry)
Greg Tucker (Associate Professor of Geological Sciences)
Veronica Vaida (Professor of Chemistry and Biochemistry)
John Wahr (Professor of Physics)
Carol Wessman (Professor of Ecology and Evolutionary Biology)
Tingjun Zhang (Senior Research Scientist, National Snow and Ice Data Center)

Emeritus Fellows

Carl Kisslinger (Professor Emeritus of Geological Sciences)
George Reid (Research Scientist Emeritus, CIRES/ESRL CSD)
Doug Robertson (Retired NOAA National Ocean Service, National Geodetic Survey)
Hartmut Spetzler (Professor Emeritus of Geological Sciences)

Fellows Affiliates

Ray Fall (Professor of Chemistry and Biochemistry)

Executive Committee

The Executive Committee assists and advises the Director in matters regarding day-to-day management of the Institute, and makes important decisions and policies affecting CIRES. Members of the Executive Committee include the Associate Directors of the six administrative units for CIRES, two Fellows elected at-large for two-year terms (renewable for one term), and two voting members that are the Members' Council representatives. The Assistant Director for Science, the Associate Director for Administration, and the Senior Finance Officer are ex-officio members of the committee.

Career Track Committee

This committee is charged with consideration of all nominations for promotion within the CIRES career tracks of Research Scientist, Associate Scientist, and Administrative Associate. Nominations are made once yearly, and the committee's recommendations are forwarded to the Director for consideration and action. A special committee, organized in early 2005, reviewed and revised the career track descriptions, and clarified the promotion process.

Computing Advisory Committee

The purpose of the CIRES Computing Advisory Committee (CAC) is to provide expert counsel and recommendations on technical issues, user support, resource allocations, and the establishment of computing policies. That advice is available to anyone in CIRES, however, the primary CAC advisees are the Director and Council of Fellows and the CIRES Computing Facility (CCF) Manager. CIRES staff or the CCF manager submit questions, issues, and recommendations through CAC members, or via a web suggestion page to the CAC chairperson for committee consideration. CAC also serves as the last-resort mediator of disputes between users and the CCF. The CAC membership includes people with the diverse expertise that is required to understand and contribute to the CIRES computing decision-making process, and people representing the user groups that are supported by the CIRES Computing Facility. The Director of CIRES appoints the chairperson of the committee and selects one other Fellow to be a member. Additional members are nominated and selected by the CAC. All members serve a 3-year term.

Distinguished Lectureship Series Committee

This lecture series was created to bring in outstanding scientists and innovative thinkers who have given serious consideration to environmental and Earth system science issues. Coordinators are given the task of putting together this program and hosting the scientists' visits.

External Awards Committee

This group identifies and prepares nominations of CIRES employees for awards offered by the university, professional societies, federal agencies, national academies, and other organizations.

Fellows Appointment/Reappointment Committee

All CIRES Fellows are subject to periodic review. First-term Fellows are reviewed after two years, and continuing-term Fellows generally every five years thereafter. This committee considers the package of reappointment submitted by the Fellow, which includes a cover letter outlining reasons for continuing as a Fellow and a *curriculum vita*. The committee prepares its recommendations, which are submitted to the full Council of Fellows for consideration and final vote. This committee is also charged with considering the identification and nomination packages of possible new Fellows within the community of scientists at the University of Colorado at Boulder and NOAA. Nominations for new Fellows are considered once yearly.

Graduate Student Research Fellowship Committees

These groups serve as the review and selection committees for the CIRES Graduate Student Research Fellowships and the ESRL-CIRES Fellowships. The fellowships are competitively awarded to new or existing CIRES-affiliated graduate students each year.

Innovative Research Program Committee

This program is designed to stimulate a creative research environment within CIRES and encourage synergy between disciplines and research colleagues. The intent is to provide an uncomplicated mechanism for supporting small research efforts that can quickly provide concept viability. The number of awards each year depends upon the funds available and funds requested, but averages about six.

New Fellows Committee

This committee is charged with considering the identification and nomination packages of possible new Fellows within the community of scientists at the University of Colorado at Boulder and NOAA. Nominations for new Fellows are considered once yearly.

Space Committee

A continuing problem for CIRES is the limited office and laboratory space for employees. This committee provides advice on the best use and distribution of existing space, provides ideas on improvement of space through renovation, and develops options for planning future space.

Visiting Fellows Committee

This committee is responsible for the review of all applications for CIRES Visiting Fellowships. In the process of this review, the committee makes the decision regarding those best qualified for a fellowship in any given year, and submits that slate to the Fellows Council for final discussion and selection.

Sabbatical Leave and Bridge Funding Committee

This committee is charged with developing guidelines, procedures and selection criteria for a program through which CIRES Research Scientists may apply for bridge funding for support between funded projects, and sabbatical leave to promote interactions with other research groups, to advance their professional development and build new collaborations.

Special Committees

Additional special committees are appointed as needed by the Director. These include Faculty Search committees, the university Program Review Committee, and others. They are created as a need arises, exist to accomplish a specific task, and are then disbanded.

Members' Council

The CIRES Members' Council (CMC) was created in 1997 to act as an information and policy conduit between CIRES leadership and the Institute members (Associate Scientists, Research Scientists, and Administrative Associates). To accomplish this in the most effective manner, the CIRES membership was divided geographically into six groups of approximately equal size. Each group is represented by two people, preferably from two different classifications in the CIRES career track. From this council of twelve, two representatives to the CIRES Council of Fellows and Executive Committee are elected (one PRA representative and one RA representative). The two representatives to the Fellows' Council/Executive Committee serve as the liaison between the Council of Fellows/Executive Committee and the Members' Council. The Members' Council, which meets monthly, then serves as a direct line of communication to the Member population at large.

Personnel Demographics

CIRES Personnel Breakdown 2007-2008

Category	Total CIRES Personnel	NOAA-supported CIRES Personnel	Highest Degree Earned by NOAA-supported personnel		
			B.S.	M.S.	Ph.D.
Research Scientist	173	118			118
Visiting Scientist	35	3			3
Post Doc	5	2			2
Associate Scientist	211	123	46	65	12
Administrative	32	23	19	2	2
Total > 50% NOAA support		269	65	67	137
Undergraduate Students	54	18			
Graduate Students	127	13	13		
Received < 50% NOAA support	??	19	3	1	15
TOTAL	637				

CIRES Personnel in NOAA Boulder Laboratories

OAR	203
Chemical Sciences Division	66
Global Monitoring Division	49
Global Systems Division	24
Physical Sciences Division	64

NGDC/NESDIS	32
NWS/SWPC	25
TOTAL NOAA	260
Obtained NOAA employment within the last year	7

Acronyms and Abbreviations

AAO	Airborne Aerosol Observatory
ADE	Advection–Diffusion Equation
AERONET	Aerosol Robotic Network
AGDC	Antarctic Glaciological Data Center
AFWA	Air Force Weather Agency
AGU	American Geophysical Union
AIRS	Aerometric Information Retrieval System
AMIE	Assimilative Mapping of Ionospheric Electrodynamics
AMISA	Arctic Mechanisms of Interaction between the Surface and Atmosphere
AMMA	African Monsoon Multidisciplinary Analyses
AMO	Atlantic Multidecadal Oscillation
AMOS	Advanced Modeling and Observing Systems (CIRES scientific theme)
AMSR–E	Advanced Microwave Scanning Radiometer–Earth Observing System
AMSU	Advanced Microwave Sounding Unit
AQCC	Air Quality Control Commission
AOD	Aerosol Optical Depth
ARW	Advanced Research WRF
ARCSS	Arctic System Science
ASTER	Aerosol Scattering–to–Extinction Ratio
ATOC	Atmospheric and Oceanic Sciences Department (university department)
AVHRR	Advanced Very High Resolution Radiometer
BAMEX	Bow Echo and MCV Experiment
CAFS	CCD Actinic Flux Spectrometer
CCSM	Community Climate System Model
CDC	Climate Diagnostics Center
CDMP	Climate Database Modernization Program
CFC	Chlorofluorocarbon
CH ₃ Br	Methyl Bromide
CH ₃ Cl	Methyl Chloride
CHAMP	Challenging Minisatellite Payload
CIMS	Chemical Ionization Mass Spectrometry
CLASS	Comprehensive Large Array Stewardship System
C–LIM	Coupled Linear Inverse Model
CLIMAS	Climate Assessment Project for the Southwest
CLM	Community Land Model
CLPX	Cold Lands Processes Experiment
CME	Coronal Mass Ejection
CO	Carbon Monoxide
CO ₂	Carbon Dioxide
COMEDS	Continental U.S. Meteorological Data System
CONUS	Continental United States
COSMIC	Constellation Observing System for Meteorology, Ionosphere and Climate
CPCP	Cross Polar Cap Potential
CRD	Cavity Ring–Down
CRDS	Cavity Ring–Down Spectroscopy
CSD	ESRL Chemical Science Division

CSES	Center for the Study of Earth from Space (CIRES center)
CSTPR	Center for Science and Technology Policy Research (CIRES center)
CSV	Climate System Variability (CIRES scientific theme)
CTIPe	Coupled Thermosphere–Ionosphere–Plasmasphere–electrodynamical
CU	University of Colorado at Boulder
CUCF	Central UV Calibration Center
CZO	Critical Zone Observatory
DAAC	Distributed Archive Data Center
DEM	Digital Elevation Model
DFI	Digital Filter Initialization
DOD	Department of Defense
DOE	Department of Energy
DSD	Drop Size Distribution
ECMWF	European Center for Medium–Range Weather Forecasting
EEF	Eastward Electric Field
EEJ	Equatorial Electrojet
EGRID	Emissions and Generation Resource Integrated Database
EIA	Equatorial Ionosphere Anomaly
EIT	Extreme Ultraviolet Imaging Telescope
ENS–DA	Ensemble–Based Data Assimilation
ENSO	El Niño–Southern Oscillation
ENVS	Environmental Studies (university department)
EOF	Empirical Orthogonal Function
EOS	Earth Observing System
EPA	Environmental Protection Agency
ESRL	Earth System Research Laboratory
FAC	Field–Aligned Currents
FGDC	Frozen Ground Data Center
FIM	Flow–Following Finite–Volume Icosahedral Model (FIM)
GAIM	Global Assimilation of Ionospheric Measurements
GasEx	Gas Exchange Experiment
GCM	General Circulation Model
GC–Net	Greenland Climate Network
GEFS	Global Ensemble Forecast System
GEO	Geodynamics (CIRES scientific theme)
GFDL	Geophysical Fluid Dynamics Laboratory
GFS	Global Forecast System, NCEP Model
GHG	Greenhouse Gas
GIS	Geographic Information System
GLDAS	Global Land Data Assimilation System
GLIMS	Global Land Ice Measurements from Space
GMD	ESRL Global Monitoring Division
GOES	Geostationary Operational Environmental Satellite
GoMACCS	Gulf of Mexico Atmospheric Chemistry and Climate Study
GPS	Global Positioning System
GRACE	Gravity Recovery and Climate Experiment
GSD	ESRL Global Systems Division
GSI	Gridpoint Statistical Interpolation

H ₂	Hydrogen
HFC	Hydrofluorocarbons
HIRS	High-Resolution Radiation Sounder
HMT	Hydrometeorological Testbed
HNO ₃	Nitric Acid
HRDL	High-Resolution Doppler Lidar
IA	Integrating Activities (CIRES scientific theme)
ICARTT	International Consortium for Research on Transport and Transformation
ICEALOT	International Chemistry Experiment in the Arctic Lower Troposphere
IDEA	Integrated Dynamics through Earth's Atmosphere
IMPACT	In-Situ Measurements of Particles and CME Transients
INCITE	Innovative and Novel Computational Impact on Theory and Experiment
IPCC	Intergovernmental Panel on Climate Change
IPY	International Polar Year
IRP	Innovative Research Program
ITCT	Intercontinental Transport and Chemical Transformation
LAI	Leaf Area Index
LASP	Laboratory for Atmospheric and Space Physics
LES	Large Eddy Simulations
Lidar	Light Detection and Ranging
LIM	Linear Inverse Model
MF6	Magnetic Field Model
MJO	Madden-Julian Oscillation
MM5	Mesoscale Model 5
MMS	Mesoscale Model
MOZART	Model of Ozone And Related Tracers
N ₂ O ₅	Dinitrogen Pentoxide
NAME	North American Monsoon Experiment
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
NCDC	National Climatic Data Center
NCEP	National Centers for Environmental Prediction
NEAQS	New England Air Quality Study
NESDIS	National Environmental Satellite Data and Information Center
NEPA	National Environmental Policy Act
NetCDF	Network Common Data Form
NEUBrew	NOAA/EPAUV Network
NGDC	National Geophysical Data Center
NIDIS	National Integrated Drought Information Service
NIST	National Institute of Standards and Technology
NO ₂	Nitrogen Dioxide
NO ₃	Nitrate ion
NO _x	Nitrogen Oxides
NSF	National Science Foundation
NSIDC	National Snow and Ice Data Center
NWP	Numerical Weather Prediction
NWS	National Weather Service
O ₃	Ozone

OA	Organic Aerosol
OAR	NOAA Office of Oceanic and Atmospheric Research
ODGI	Ozone-Depleting Gas Index
ODS	Ozone-Depleting Substance
OLR	Outgoing Longwave Radiation
OMI	Ozone Monitoring Instrument
OSSE	Observation System Simulation Experiment
PAR	Photoactive Radiation
PDO	Pacific Decadal Oscillation
PDSI	Palmer Drought Severity Index
PM	Particulate Matter or Planetary Metabolism (CIRES scientific theme)
PMEL	Pacific Marine Environmental Lab, NOAA
POA	Primary Organic Aerosol
POES	Polar Orbiting Operational Environmental Satellite
PSD	ESRL Physical Science Division
PSR	Polarimetric Scanning Radar
RCM	Rice University Inner Magnetosphere Convection Model
RET	Riparian Evapotranspiration
R/V	Research Vessel
RISA	Regional Integrated Sciences and Assessments
RP	Regional Processes (CIRES scientific theme)
RR	Rapid Refresh
RTVS	Real-Time Verification System
RUC	Rapid Update Cycle
SEARCH	Study of Environmental Arctic Change
SIMM	Simple Inner Magnetosphere Model
SOARS	Significant Opportunities in Atmospheric Research and Sciences
SST	Sea Surface Temperature
STEREO	Solar Terrestrial Relations Observatory
SWE	Snow Water Equivalent
SXI	Solar X-ray Imager
TAO	Tropical Atmosphere Ocean
TCEQ	Texas Environmental Quality
TEC	Total Electron Count
TexAQS	Texas Air Quality Study
TRI	Toxics Release Inventory, EPA
TTL	Tropical Troposphere Level
UAS	Unmanned Aircraft System(s)
UCAR	University Corporation for Atmospheric Research
USBR	United States Bureau of Reclamation
VIRBO	Virtual Radiation Belt Observatory
VOC	Volatile Organic Compound
VOCALS	VAMOS Ocean-Cloud-Atmosphere-Land Study
WHOI	Woods Hole Oceanographic Institution
WMO	World Meteorological Organization
WSA	Wang-Sheeley-Arge Model
WRF	Weather Research and Forecasting Model
z0	Momentum surface roughness length