

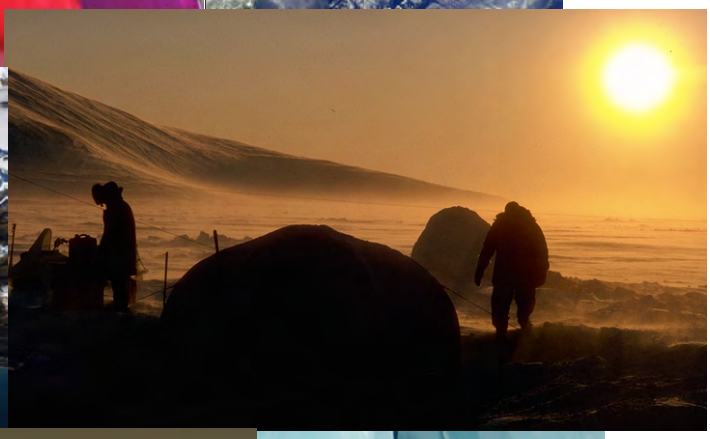



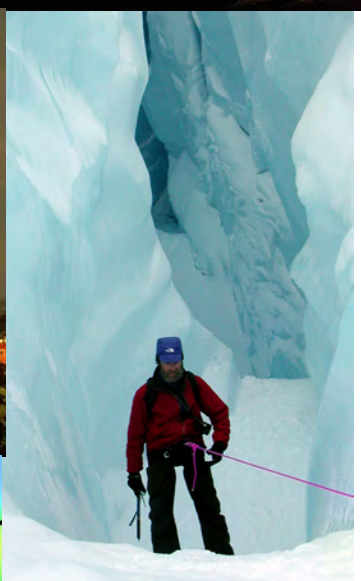
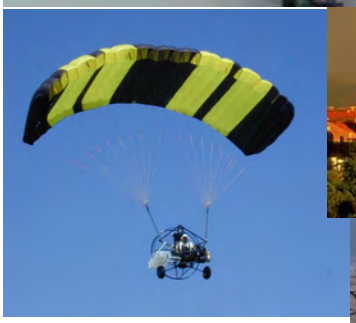

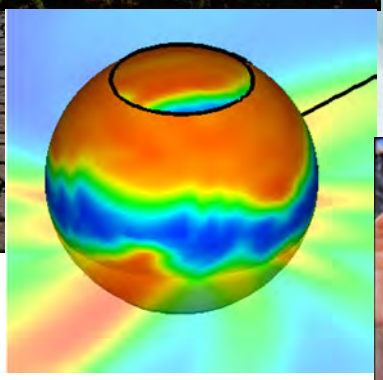


Annual Report 2005-06

CIRES

FY 2006 Annual Report

NOAA Cooperative Agreement #NA17RJ1229

September 30, 2006

Konrad Steffen, Director
William M. Lewis, Jr., Associate Director

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Letter from the Director

Director's Welcome

This past year had been marked by a number of important changes. The creation of the Earth System Research Laboratory (ESRL) has been finalized bringing together a number of labs under one common umbrella and leadership. We welcome Dr. Sandy McDonald, Deputy Assistant Administrator for NOAA Research Laboratories and Cooperative Institutes and Director of ESRL in this new position and wish him well.

Also CIRES reorganized its division structure to pay tribute to the emerging expertise in biology, modeling and forecasting. We added two new divisions in Environmental Biology, and in Environmental Observations, Modeling and Forecasting. Some of the remaining CIRES divisions have been realigned to concur with the new ESRL division structure and are now called Environmental Chemistry, Weather and Climate Dynamics, Solid Earth Sciences, and Cryospheric and Polar Processes.

A new Center for Environmental Technology (CET) in the College of Engineering has been established which is also affiliated with CIRES. CET projects include airborne hydrometeorological imaging, satellite imager and sounder development and UAV sensor development. The expertise and personnel for CET came from the Boulder NOAA labs and CIRES and were transferred to the University of Colorado. Other CIRES centers are the Climate Diagnostic Center, the Center for Limnology, The Center for Science and Technology Policy Research, the Center for the Study of Earth from Space, and the National Snow and Ice Data Center. The CIRES centers focus our research and bring together scientists within CIRES, CU, and NOAA, as well as outside the University.

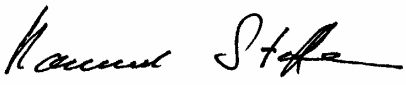
The first CIRES "Science Day" was organized by the Members' Council in spring. This highly successful endeavor devoted a full day to science presentations and discussions across all disciplines, engaging over 300 scientists, students, and staff. We will institutionalize the science day as an annual event.

CIRES continues to be the world leader in environmental sciences as we are committed to identifying and pursuing innovative research in Earth System Science and to fostering public awareness of this research. Our research budget continues to grow and has reached over $46 M, supporting a total of 550 employees, including graduate and undergraduate students. We have published over 340 papers in peer-reviewed science journals, participated in a number of news conferences, briefings on Capital Hill, and outreach activities. The outcome and findings of our research is important in forming policies that are crucial for future generations.

We welcome two new CIRES tenure track faculty researchers: Dr. Xinzhao Chu, assistant professor in the Department of Aerospace Engineering Sciences with expertise in experimental Lidar application and technology, and Dr. Noah Fierer, assistant professor in the Department of Ecology and Evolutionary Biology with expertise in carbon cycling. Further, we were authorized by the University to add three more faculty lines to CIRES in remote sensing applications, physical oceanography, and policy research.

Our Assistant Director for Science, Mr. Paul Sperry has left CIRES after eight years to spend time as a researcher in an off-shore diving project. He was instrumental in implementing the new annual CIRES workplan and the Innovative Research Program.

This 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 contribution of Associate Director Dr. Bill Lewis who was instrumental in coordinating this effort. Enjoy your reading!



Executive Summary and Research Highlights

The Cooperative Institute for Research in Environmental Sciences (CIRES), which was founded in 1967, is an organized research unit of the University of Colorado. The institute is based on a research collaboration between NOAA and the University of Colorado at Boulder. In 2005-2006, CIRES employed approximately 500 scientists and support staff with a NOAA Cooperative Institute budget of $22,000,000 and an overall extramural research budget of $43,000,000. CIRES research, supported through its cooperative agreement with NOAA, is organized according to themes that include modeling and observing systems, climate system variability, planetary metabolism, and regional processes. During 2005-2006, under guidance from Director Konrad Steffen, the institute constructed a new strategic plan that includes creation of a new research center (Center for Polar Studies), restructuring of an existing center (Center for the Study of Earth from Space), five new faculty hires in areas of emerging importance, creation of mechanisms for improved internal communication and communication with federal scientists in NOAA, and improved efficiency of infrastructure. During 2005-2006, CIRES supported over 50 graduate students, 13 post doctoral associates, and 55 undergraduate students in support of research. CIRES continued development of its highly successful outreach program, which serves the needs of federal research support agencies in making science accessible to meet public needs. During 2006, CIRES passed through program review with the University of Colorado and was judged to be a vigorous research unit with high productivity and excellent leadership.The following highlights illustrate accomplishments that emerged from the CIRES-NOAA-University of Colorado partnership during the previous year.

Advanced Modeling and Observing Systems

This theme includes the optimization of modeling and observing systems for disciplines such as atmospheric chemistry, physical atmospheric and oceanic processes, cryospheric processes, space weather, nonlinear systems applications, data centers, and data management. Research ranges from local to regional and global scales.

- We successfully developed a white-light optical particle counter (OPC) designed to measure coarse-particle-size distributions from 0.6 to 8.0 μm in diameter, and a variable condensation particle sizer to measure ultra-fine particle-size distributions from 0.005 to 0.05 μm in diameter.
- We continued development of a laboratory-based instrument for the measurement of single-scattering albedos of single aerosol particles. The system consists of a diode laser locked to an external cavity containing an aerosol scattering cell. The scattering cell collects the total scattered light along with the forward and backward scattered light in separate channels as individual particles traverse the cavity beam.
- We used SO_2 total column measurements to verify emissions from point sources that will allow the scientific community to better understand the role of these compounds in acid rain, photochemical smog, and radiative forcing of the climate system in the New England region.
- We completed development of a new, compact airborne lidar for measuring profiles of ozone and aerosols. The new lidar system was integrated and tested on a NOAA Twin Otter aircraft in May and June of 2006. Its first deployment will occur during the TexAQS II air quality study in the Houston, TX area in August/September 2006. The lidar transmitter is based on a solid-state laser which emits tunable ultraviolet light.
- We developed an attenuation-based method to retrieve vertical profiles of rainfall rate from vertically pointing measurements of 8-mm wavelength ARM radars has been developed. The method was applied to a wide variety of rainfall events observed at different ARM testbed sites. It was demonstrated that this method can successfully retrieve rainfall rates in a range from 5 to more than 100 mm/hr.
- The MultiBeam Bathymetric Data Base (MBBDB) continued to grow as a worldwide, comprehensive, bathymetric data base. The present data volume is over 500 Gigabytes of data with over 800 surveys, all available for download.
- We used airborne measurements to quantify emission ratios of sulfur dioxide to nitrogen oxides from power plants in the Eastern US. We then compared our observations with measured emissions reported by these plants. We updated nitrogen oxide emission inventories to correspond with observed levels. The impact of these emission reductions on ozone levels was simulated with an air quality model.
- In collaboration with the NOAA/NCEP Environmental Modeling Center (EMC), we developed a new vertical structure for the GFS general circulation model (GCM) and implemented it on EMC supercomputers. The new IDEA-GFS model has been extended from the standard altitude of about 60 km up to over 600 km with an unprecedented vertical resolution of 150 layers.

Climate-System Variability

Climate variability affects virtually all natural systems and human activities. Climate directly influences agriculture, water quantity and quality, and human health. Understanding and potentially predicting climate change is critical to the public interest, as well as to a broad array of decision makers within federal and state government, industry, resources management, and hazard mitigation.

- We identified the sea-surface-temperature (SST) patterns with the greatest influence on the global mean climate and found very different, and often opposing, sensitivities to SST changes in the tropical Indian and West Pacific Oceans. Our work stresses the need to reduce climate model biases in these sensitive regions, as they not only affect the regional climates of the nearby densely populated continents, but also have a disproportionately large effect on the global climate.
- We concluded from observations and GCM simulations of the last 50 years that the four-year average precipitation anomaly pattern during the 1998-2002 drought was mostly caused by the persistent La Niña forcing. Although the four-yr average tropical SST anomaly pattern was indeed to a first approximation a La Niña pattern plus a spatially uniform "global warming" trend, and the latter made a substantial contribution to the extratropical surface temperature anomalies, it was much less important in causing the precipitation anomalies. This conclusion is further supported by the fact that after 2002, the hemispheric pattern of annual-average precipitation anomalies changed radically, but that of the surface temperature anomalies has not.
- We collaborated with FRAMES, the Fire Research And Management Exchange System, to provide data on fire history and past climate to the interdisciplinary fire history community. We became the content managers for the fire history subject area of the FRAMES project. These efforts will improve assessments of the natural frequency of forest fires throughout the western United States.
- We gathered tropical cyclone positions and intensities from the Joint Typhoon Warning Center and the Hurricane Research Center best track data sets for the different ocean basins. For each year and ocean basin region we compiled average water vapor and cloud properties in the upper troposphere during intense tropical storms (category 4 hurricane or larger).
- Collaboration between CIRES and the NOAA ESRL CSD has led to the development of a new technique for deriving the path-integrated liquid water path (PLWP) and ice water path (PIWP), both climatically important parameters, from the spectral measurements. This method measures cloud properties very simply, using scattered light in the near-infrared.
- Ozone (O_3) and ozone-depleting substances (ODSs) were measured *in situ* from the Altair unmanned aerial vehicle (UAV) during the 2005 NOAA UAV Demonstration flights conducted near Palmdale, CA. The two-channel UAV Chromatograph for Atmospheric Trace Species (UCATS), built by the NOAA/ESRL Global Monitoring Division, measured ozone-depleting nitrous oxide (N_2O), chlorofluorocarbons (CFCs) -11 (CCl_3F) and -12 (CCl_2F_2), and Halon-1211 ($CBrClF_2$) every 70 seconds during flights. UCATS also measured the potent greenhouse gas sulfur hexafluoride (SF_6) at 70-s intervals.
- A report to be completed in October 2006 describes formats and knowledge transfer mechanisms needed in support of the National Integrated Drought Information System (jointly with RISA Programs and especially the Southwestern Climate Assessment). These include development of a "Drought Portal" "one-stop shopping" for drought information and consistent formats, terms, and scales of information, compatible with the standards of the reservoir management community.

Geodynamics

The goal of geodynamics is to characterize the internal processes of the planet, including the properties of the core-mantle boundary, convection within the Earth's mantle, and effects of convection on the surface of the planet.

- We updated and reviewed quality of all US Coastal tsunami event data.
- We developed a new tsunami vulnerability assessment methodology.
- We implemented Windows desk-top version of Tsunami Travel Time software (P. Wessel) and provided TTT map products for the Pacific Region Tsunami Exercise (spring 2006).

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 the overall mission of the Institute, NOAA, and the University of Colorado. The primary focus is on five overlapping categories that include 1) K-16 Interdisciplinary Education and

Outreach, 2) Graduate and Post-Graduate Education, 3) Scientific Assessments, 4) Interdisciplinary Research, and 5) Science and Technology Policy Research.

- We contributed to the 2002 Assessment as required by Article 6 of the United Nations Montreal Protocol on Substances that Deplete the Ozone Layer.
- We have identified water user needs for climate products (information and forecasts), matched these needs to WWA and NOAA climate research and continued dialog between water managers and WWA researchers.
- Using the PRISM precipitation and temperature data set, CIRES researchers investigated how temperature and precipitation have changed during the last 50 years in the Upper Colorado River Basin. Annual precipitation increased during the entire 50-year period both in winter and summer. Temperatures, both minimum and maximum, have increased over the last 50 years, with minimums showing larger increases.

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 adverse effects due to pollution, destruction of natural landscapes, and inadvertent alteration of climate.

- During the New England Air Quality Study, CIRES researchers measured isoprene with a fast time response using PTR-MS onboard the NOAA WP-3D aircraft. In the polluted portions of the atmosphere, isoprene is an important precursor of ozone and aerosol, which are both important factors in determining regional air quality and climate. Accurate emissions inventories will help to improve the (forecast) models describing ozone and aerosol, and thus illuminate their importance in the atmosphere.

Regional Processes

Many of the research endeavors within CIRES and NOAA have a regional focus because they address a particular confluence of geography, demographics, or weather and climatic regimes. The effect of climate variability is often regionally focused, thus influencing very specific populations, economies, and ecosystems.

- CIRES investigators completed their participation in the North American Monsoon Experiment. The CIRES project deployed an S-band precipitation profiler, a 449-MHz Doppler wind profiler, and a raindrop disdrometer at Estacion Obispo, Mexico for a two-month period during the summer of 2004.
- The1-D Kepert-Fairall-Bao explicit sea-spray model was used to investigate thermodynamic feedback effects of sea-spray in the droplet evaporation layer under hurricane conditions. The PSD sea-spray parameterization scheme was implemented into the MM5 model, the WRF-ARW model and an operational hurricane model (i.e., NCEP's operational hurricane model). Numerical experiments using the operational model were carried out for several historical hurricane cases to assess the impact of the PSD sea-spray parameterization scheme on operational hurricane intensity forecasts.
- The first season of full-scale HMT operations took place in California’s American River Basin (ARB) from December 2005 through March 2006. Water supplies from this basin are immensely important to California’s economy and natural habitats, and the threat of catastrophic floods to the downstream Sacramento area is extremely serious. The instruments contribute to a comprehensive view of weather in and approaching the ARB.
- A new instrumented aircraft (Cessna 206) for long-term monitoring of vertical profiles of aerosol chemical, radiative, and microphysical properties has been deployed over the central United States (near Champaign, IL). The aircraft has been making vertical profiling measurements of aerosol chemical, optical and physical properties over a surface site several times a week since June 2006.
- CIRES researchers showed that ozone-related pollutants can survive longer in the atmosphere when they are transported in layers above the ocean. Consequently, urban areas can affect air quality far from the source and even over remote regions of the Earth.

CIRES in 2005-2006

Overview

The Cooperative Institute for Research in Environmental Sciences (CIRES) is a joint institute established in 1967 between the University of Colorado and the National Oceanic and Atmospheric Administration (NOAA). The purpose of CIRES is to maintain an interdisciplinary environment for research on the geosphere, biosphere, atmosphere, hydrosphere and cryosphere. CIRES conducts basic research in support of NOAA's goals for application of environmental science to advance the public welfare. CIRES strengthens the scientific foundation upon which NOAA's many services depend. CIRES' connections with NOAA's Office of Oceanic and Atmospheric Research (OAR) and sister Cooperative Institutes also provide an avenue for coordinated studies on a scale that could not be addressed by university research units on their own.

Interdisciplinary science at CIRES is fostered through centers that cross traditional boundaries, and these include the Center for the Study of Earth from Space, the Center for Limnology, the National Snow and Ice Data Center, the Science and Technology Policy Research Center, and the Climate Diagnostics Center. CIRES' campus affiliation provides NOAA a breadth of connections in 11 university departments (Figure 1).

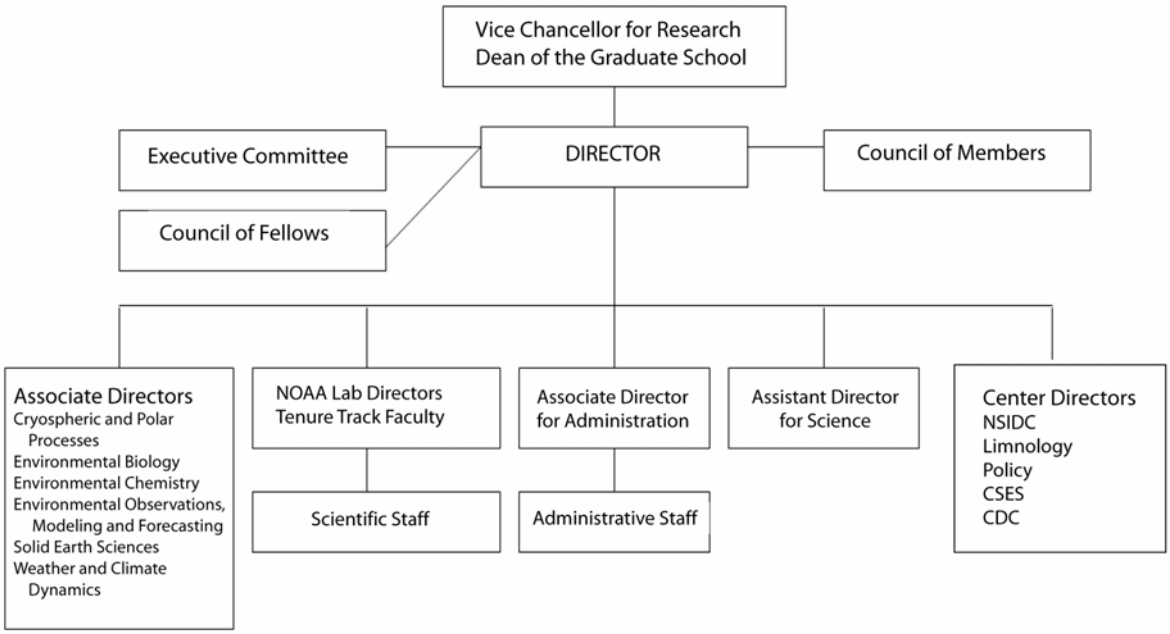
Mission Statement

CIRES is dedicated to fundamental and interdisciplinary research targeted at all aspects of *Earth System Science* and is communicating these findings to the global scientific community, to decision-makers, and to the public.

Vision

As a world leader in Environmental Sciences CIRES is committed to identifying and pursuing innovative research in *Earth System Science* and to foster public awareness of these processes to ensure a sustainable future environment.

CIRES' direction is provided through its Council of Fellows, its executive committee, and committees working on focused objectives such as maintaining excellence in computing facilities. Communication is facilitated through a members' council, scientific retreats, regular town meetings, and outreach. 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 a graduate research fellowship program, a visiting faculty and postdoctoral program, and innovative research program, and a distinguished lecture series. Advanced research tools are provided through an instru-ment design group, machine shop, glassblowing, numerical climate models, and access to remote sensing and analytical instrumentation.



Research support for CIRES increased in 2005-2006 (Figure 2), reflecting high research productivity both through the agreement (Figure 3) and other extramural funding. During 2005-2006, CIRES created a new strategic plan designed to maintain this productivity of the institute.

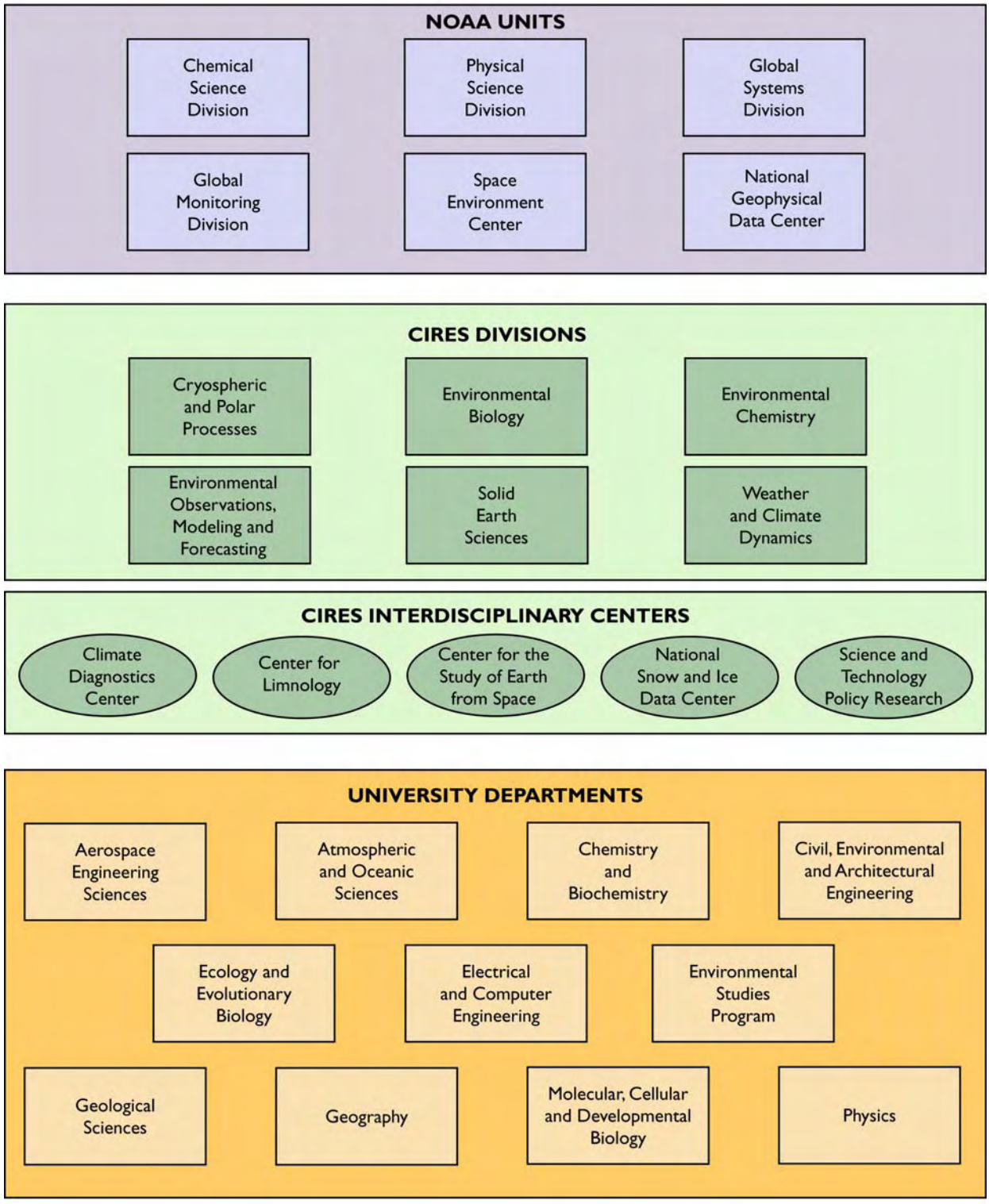


Figure 1. CIRES Divisions, Centers and cognate departments

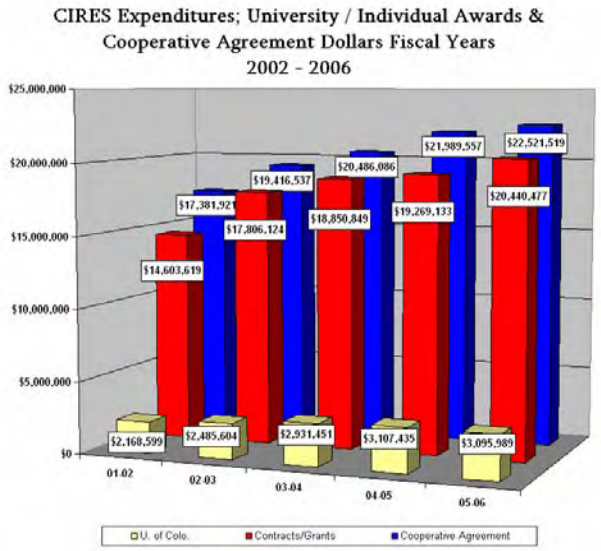
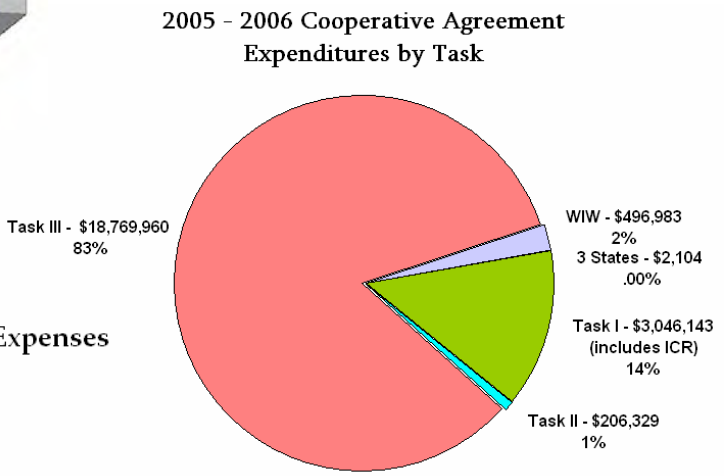
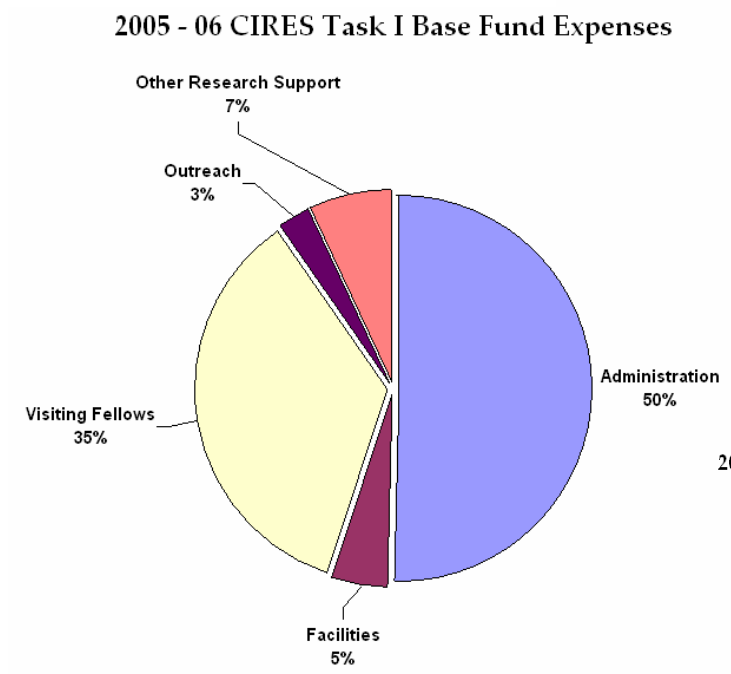


Figure 2 (left). CIRES expenditures over the last five years.





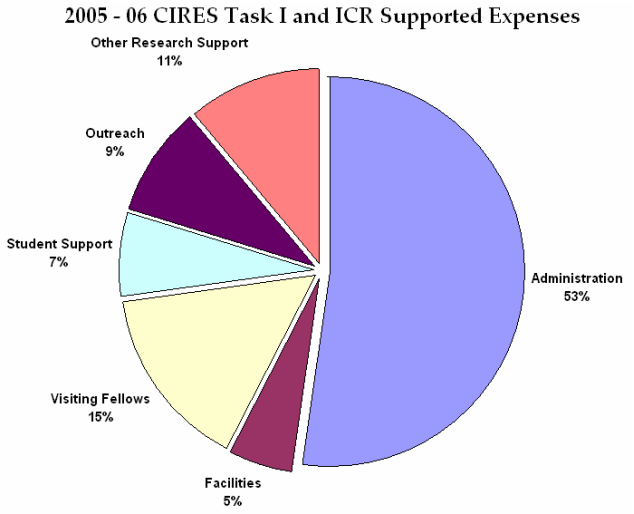


Figure 3. Division of support under the CIRES-NOAA Cooperative Agreement

Contributions to NOAA's Strategic Vision

Research within CIRES is strongly aligned with NOAA's strategic plan and 20-year vision, as embodied in the current five-year plan for NOAA research. NOAA's research vision statement accurately describes the research goals of CIRES: "Through research, we discover and improve our knowledge of the Earth's oceans, coasts, and atmosphere."

> *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 through research on observing systems and extreme events. Ecosystem management as conceived by NOAA is based upon the concept of building resilient communities. Resilience involves continuous collection and interpretation of environmental data at regional scales. CIRES constantly advances the state of the art in regional observations of air quality, atmospheric moisture, and atmospheric dynamics. Instrumentation and models developed by CIRES are ready for efficient implementation as functioning observing systems through the partnership between CIRES and NOAA.

Resilience of human communities also requires advance knowledge and probability forecasts for extreme events, for which communities must be preadapted. CIRES is a leading research contributor to the basic knowledge of factors that lead to the formation, intensification, and tracking of severe storms that are of constant concern in U.S. coastal areas. CIRES is also developing new tools for the prediction of tsunamis. Research products are directly applicable to the coastal zone aspects of NOAA's ecosystem mission goal.

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

CIRES has a well-established reputation for advancing climate science in areas relevant to NOAA's climate mission goal. Basic research in climate mechanisms within CIRES covers a range of time and spatial scales. CIRES researchers contribute to the state of the art in understanding climate variability as a means of anticipating future climate conditions. CIRES develops and uses constantly improved instrumentation to detect key climate variables such as global ice cover and sea level. CIRES researchers probe the mechanisms of climate change through data collection in the field as well as modeling.

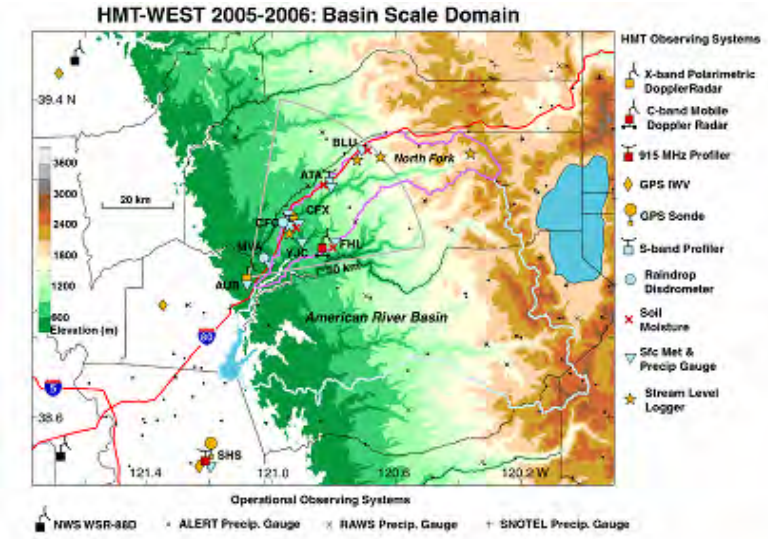
CIRES researchers have contributed substantially toward the ability of climate science to project climate change at the regional scale, thus allowing anticipation of climatic influence on agriculture, ecosystem status, and the human environment. CIRES is involved in all aspects of climate research: data collection, data management, modeling, instrument development, and experimentation. Priorities for climate research within CIRES reflect NOAA's needs for application of climate science to human welfare.

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

CIRES contributes to NOAA's weather and water mission goal through research on observation systems and modeling. CIRES is a leader in the analysis of regional air quality, which varies critically under the influence of weather. Through its field experiments in New England and Texas in collaboration with other research entities, CIRES has contributed substantially to some of the most ambitious and technically sophisticated air-quality analyses on record. CIRES also supports research efforts in drought prediction and associations between drought and runoff with implications for water supply and agriculture. CIRES uses advanced observing tools such as lidar at the state of the art, producing innovations that can be transferred to routine weather observing systems.

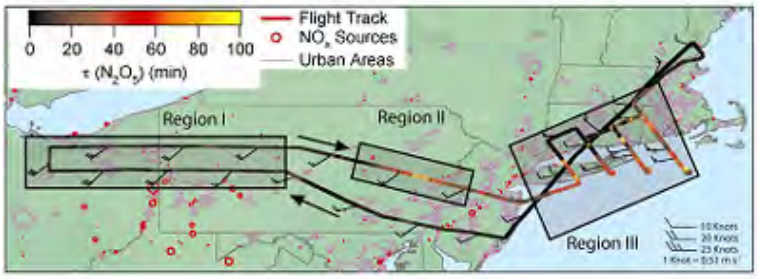
> *Commerce and Transportation Mission Goal:* Support the nation's commerce with information for safe, efficient, and environmentally sound transportation.

CIRES contributes to the transportation goal primarily in relation to aviation. The capability of CIRES to produce new instrumentation and data analysis methods that improve detection of atmospheric conditions relevant to aviation will assist NOAA in improving the reliability and safety of aviation.

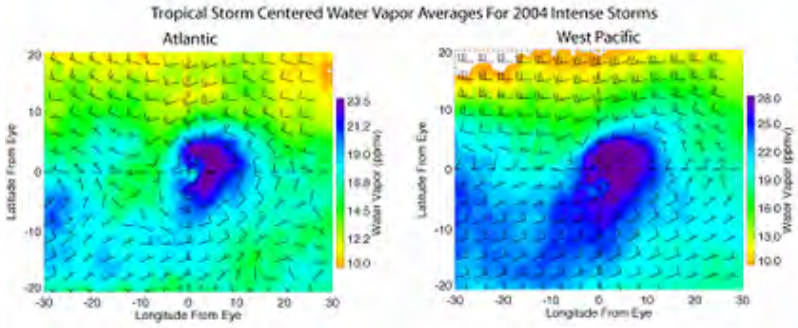


Ecosystem Mission Goal: *Sensing network to protect Sacramento from flooding*

Climate Mission Goal: *Loss of ice mass*



Weather and Water Mission Goal: *Regional pollution in relation to weather*



Commerce & Transportation Mission Goal: *Sensing wind velocity and moisture for storms*

Figure 4. Examples of CIRES support for NOAA goals

Defining New Directions

Over the last twelve months, new CIRES Director, Konrad Steffen, has led CIRES through a comprehensive analysis of its programs and resources, which is the basis for a new strategic plan for CIRES. Elements of this new plan are as follows.

1) *Improved Communication and Collaboration Internally and with NOAA Scientists.* Consolidation of the NOAA labs under ESRL provides a natural opportunity for CIRES to intensify its efforts to make all components of CIRES perceive themselves as important contributors to the overall goals of CIRES, and to strengthen ties with NOAA scientists. Increased administrative and staff interchange between the campus and federal laboratory facilities of CIRES has been undertaken, and a sense of community has been advanced through the creation of an annual all-CIRES research celebration. These and other initiatives will increase the coherence of CIRES and CIRES-NOAA over the coming years.
2) *Centers.* The director has authorized restructuring of the Center for the Study of Earth from Space following the retirement of its director, Alex Goetz, in 2006. A new director will be recruited and the center will be aligned with current priorities in global data collection systems. In addition, the director, with support of the fellows, has authorized creation of a new Center for Polar Studies, which will enhance the existing global reputation of CIRES in studies of the polar regions.
3) *New Hiring.* CIRES has proposed at least one new faculty hiring annually by CU, and has identified specific areas of hiring based on research initiatives: Climate system specialist with interests in abrupt climate change, polar climatologist, InSar specialist, environmental system predictability specialist.
4) *Space for Research.* CIRES is seeking additional space on the Boulder Campus for research to accommodate its increasing research productivity. In the initial stages, the Boulder Campus has been responsive to this request.
5) *Infrastructure Review.* The director has undertaken a review of all administrative infrastructure and is making changes that improve the efficiency and responsiveness of infrastructure for the benefit of CIRES scientists.

During 2006, CIRES passed through the program review program process of the CU Boulder Campus, which is the means by which the university diagnoses the status of campus administrative units. The review, which involves a self-study, a study by an internal committee, and a study by an external committee, has produced consistently positive feedback and strong recognition of CIRES as a vigorous research unit with a bright future and excellent leadership.

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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 the Complementary Research Section of this report.

Employee Recognition Program

CIRES annually convenes a team to review and recommend awards for outstanding professional achievement. Four awards of $2,000 each were given this year, for the first time designated as two for science and two for service. The awards were presented to each individual or research team at the CIRES Members' Council Rendezvous symposium (see below). This year CIRES recognized for Science ***Christopher Williams*** (PSD), ***Bill Dubé*** and ***Craig Simons*** (CSD), and for Service ***Bobbie Klein***, ***Ami Nacu-Schmidt***, and ***Linda Pendergrass*** (Center for Science and Technology Policy Research), and ***Michael Hartman*** (NGDC). CIRES has expanded its recognition of employee accomplishments by providing matching funding for the Department of Commerce Awards for outstanding papers. This year, awards went to ***Dezso Devenyi, Dale Hurst, George Grell***, and ***Tatiana Smirnova***.

Visiting Fellows Program

CIRES annually conducts a competitive visiting-fellowship program that promotes collaborative research at the forefront of scientific knowledge. One-year fellowships are made to Ph.D.-level scholars and university faculty planning sabbatical leave. 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, priority is given to candidates with research experience at institutions outside the Boulder scientific community. The program is open to scientists from all countries, and appointments can begin at any time during the year. 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 competitive Graduate Research Fellowship program. The program was reviewed and redesigned last year to provide more opportunities for current or prospective outstanding Ph.D. students. Support can range from salary and travel for summer research to out-of-state tuition for a full year. This program is being used to 1) attract new candidates to give them a boost in their early years, and 2) to support graduating students who can then place a greater emphasis upon completing and publishing their research projects. Selections are based on the promise of candidates to contribute to environmental science, on the basis of their applications to the University of Colorado, and on their accomplishments thus far. Independence, a passion for science, and ability to communicate are qualifications characteristic of successful candidates.

Innovative Research Program (IRP)

CIRES-wide competitions are conducted each year to foster an innovative research environment where risk-taking is allowed and even encouraged. The Innovative Research Program (IRP) is designed to stimulate a creative research environment 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 or rule out further consideration. The program 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 where results can be quickly acquired. Activities can range from instrument development, lab testing, and field observations to model advancement.

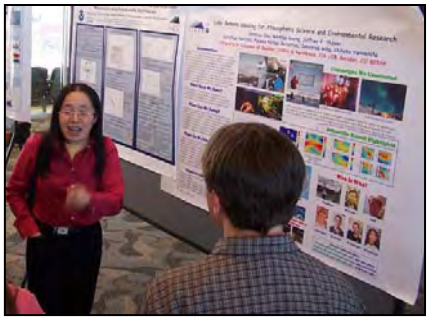
Education and Outreach (EO)

The CIRES Education and Outreach program provides science education opportunities for educators, students and scientists. Their work emphasizes scientific inquiry, links with research scientists and current research, and uses of place-based and field-based teaching methods. The impact and scope of the program is increased through strategic partnerships with other geoscience organizations. Examples of programs for educators include Earthworks, a week-long Earth System Science retreat for Secondary Science Teachers, and Front Range Math and Science Partnerships. Programs designed for students include the National Ocean Sciences Bowl (NOSB) and the GK-12 Graduate Student Fellows Program, which places graduate students into middle and high school science classes. Programs supporting scientists include the Ocean Interactions/Teacher at Sea Experience program, Resources for Scientists in Partnerships with Education (ReSciPE) and collaboration with proposing scientists to include educational components within geoscience research projects. Further examples include professional development workshops at national meetings and leadership within the Digital Library for Earth System Education (DLESE) program.

Western Water Assessment (WWA)

The Western Water Assessment is CIRES' signature integrating activity that involves personnel from the Climate Diagnostics Center, 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 for Arctic and Alpine Research. Its 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 is responsive to 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 Office of Global Programs as part of their Regional Integrated Sciences and Assessments (RISA) program.

Rendezvous! CIRES Members' Council Symposium



April 2006 saw the first CIRES Members' Council symposium. Mirroring the purpose of the old west's gathering of tribes, traders and settlers for an exchange of goods, information and good will, the meeting was dubbed "*Rendezvous*." This day-long symposium featured presentations by Director Konrad Steffen, the six associate directors, Associate Director for Administration Jon Rush, and brief (one-minute) poster introductions by presenters of each of the 90 posters. CIRES took advantage of the occasion to honor the winners of the 2005 Outstanding Performance Awards, this year divided into two science and two service awards. Several poster sessions, a town meeting, and a luncheon rounded out the successful day. CIRES was pleased to host not only its own members, but also several visitors from CU and NOAA administration. Organized by the Members' Council, this symposium was deemed to be one of CIRES' most successful and inclusive days of science, featuring members, fellows, and students in an informative and entertaining array of CIRES research.

Policy, Politics, and Science in the White House: Conversations with Presidential Science Advisors

The Science and Technology Policy Research Center's lecture series, "Policy, Politics, and Science in the White House: Conversations with Presidential Science Advisors" began during the last fiscal year and concluded on April 11, 2005 with a talk by Dr. Frank Press, science advisor to President Jimmy Carter from 1977-1980. Dr. Press addressed a crowd of about 100 people at the University of Colorado and discussed successful and failed efforts to provide science advice to policymakers.

Dr. Edward E. David, Jr.: Science advisor to President Richard Nixon "Advice for President Richard Nixon"
Dr. Neal Lane: Science advisor to President William Clinton, "Threats to the Future of U.S. Science and Technology"
Dr. Donald Hornig: Science advisor to President Lyndon Johnson
Dr. George (Jay) Keyworth II: Science advisor to President Ronald Reagan. "Policy**,** Politics and Science in The White House: The Reagan Years"
Dr. Frank Press: Science advisor to President Jimmy Carter

Distinguished Lecture Series

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

Steve Boyes, Meyer's Parrot Project, Research Centre for African Parrot Conservation, University of KwaZulu-Natal, on "The Okavango Delta – Africa's Wetland Wilderness"

Walter Pitman, Lamont Doherty Earth Observatory, Columbia University, on "Evidence for and Implications of the Black Sea Noah's Flood: Geology, Archaeology, Language and Myth"

Lonnie G. Thompson, Department of Geological Sciences, Byrd Polar Research Center, The Ohio State University on "Glaciological Evidence of Abrupt Tropical Climate Change: Past, Present and Future"

George Philander, Knox Taylor Professor of Geosciences, Princeton University, on "State of Fear the Day After Tomorrow?"

Michael Tjernström, Professor of Meteorology, Stockholm University, "So, What's So Special About Arctic Clouds?"

Myles Allen, Atmospheric, Oceanic and Planetary Physics, University of Oxford, on "How Much Carbon Can We Afford to Emit?"

Meghan Miller, Dean of the College of the Sciences, Central Washington University, on "GPS Constraints on Seismic Hazard in the Pacific Northwest"

Symposia and Conferences

Listed below are additional events which CIRES sponsored, organized and/or participated in:

Northeast Front Range Math/Science Partnership, Summer 2005
The Poles Together Workshop, July 2005
Math/Science Partnerships: Physics Institute, Force and Motion, Summer 2006
Math/Science Partnerships: Life Science Institute: Cells, Human Systems, and Heredity, Summer 2006
13th WMO/IAEA Meeting of Experts on Carbon Dioxide Concentration and Related Tracers Measurement Techniques, September 2005
7th International Carbon Dioxide Conference, September 2005

Frameworks Workshop, September 2005
IRP Research Program Poster Session: September 2005
ReSciPE: Resources for Scientists in Partnership with Education, September 2005
International Polar Year Meeting, October 2005
United Nations Environment Program (UNEP) Working Group Meeting, October 2005
Center for Snow and Avalanche Studies: Snow System Science, the Emerging Why, Where, Who and How, October 2005
Visiting Fellows Poster Session, November 2005
CIRES Reception for Richard Spinrad, Assistant Administrator for NOAA Research, December, 2005
International Polar Year Focus Group Meeting, January 2006
Science, Technology, and Decision Making, February 2005
Regional Ocean Sciences Bowl, Mountain Mariner Challenge, February 2006
Countdown to the International Polar Year, March 2003
National Science Foundation Regional Grants Conference, March 2006
Sustainable and Renewable Energy Initiative, March, 2006
Dan Albritton Retirement Symposium, May 2006
NOAA Science Research Council reception, May 2006
CU Energy Initiative, Maya 2006
Earthworks, June 2006

Presentations by Other Guest Speakers:

(Center for Science and Technology Policy Research)

Kiki Jenkins, Werewolves &silver bullets: Lessons on the use of marine conservation technology, June 2006
Martijntje Smits, Taming monsters: The cultural domestication of new technology, April 2006
Jerry Peterson, A nuclear option for a hydrogen economy, April 2006
Coping with Climate Change: A symposium Hhghlighting activities at the University of Colorado to help decision makers prepare for the future, April 2006
Krister Andersson, Municipal politics and forest governance: Comparative analysis in Bolivia & Guatemala, April 2006
Erik Fisher, Integrating societal concerns into nanotechnology research, March 2006
Diane McKnight, Climate change, acid mine drainage, mountain sports in Colo Rocky Mtns, March 2006
Steve Quane, Peak Oil and the struggle for sustainable energy: A Congressional staffer's perspective, February 2006
Adam Briggle, President's Council on Bioethics, February 2006
Rudy Juliano, UNC's Dept. of Pharmacology, Roundtable discussion: Building a science policy program, January 2006
Marilyn Averill, My experiences at the Conference of the Parties to the Climate Change Convention, January 2006
Carl Mitcham, What are the connections between science policy and ethics?, November 2005
Hans von Storch, Research collaborations related to climate modeling (for policy) & extreme events, November 2005
Juan Lucena, Changing policies for the promotion of science and engineering education at NSF, November 2005
Lisa Dilling, Tools for the new frontier: Practical steps to creating usable science, October 2005
Peggy Lamm, Why in the world would any sane person run for public office? October 2005.
Carol Byerly, Finding the flu: Explaining the silence regarding influenza epidemic of 1918, September 2005
Marilyn Averill, EPA authority to regulate greenhouse gas emissions, September 2005
Diana Josephson, Becoming proactive through strategic planning, September 2005
Elizabeth McNie, Climate change, experiential education, and teenagers, September 2005

NOAA-CIRES Accomplishments by Scientific Theme

Scientific Theme: ADVANCED MODELING AND OBSERVING SYSTEMS

AMOS-01: Instrumentation Design, Prototyping and Analysis
- CSD01 (AL01): Instrumentation for Atmospheric Observation and Analysis
- PSD08 (ETL01): Sensor and Technique Development

AMOS-02: Data Management, Projects and Infrastructure Systems
- NGDC01 (same): Geospatial Technology for Global Integrated Observing and Data Management Systems
- NGDC02 (same): Marine Geophysics Data Stewardship
- SEC03 (same): Information Technology and Data Systems

AMOS-03: Prediction, Model Development and Evaluation
- CSD02 (AL02): Chemical Transport Model Research
- PSD09 (ETL02): Environmental Monitoring and Prediction
- GSD01 (FSL01): Regional Numerical Weather Prediction
- GSD03 (FSL03): Verification Techniques for the Evaluation of Aviation Weather Forecasts
- NGDC03 (same): Space Weather
- SEC01 (same): Solar Disturbances in the Geospace Environment
- SEC02 (same): Modeling the Upper Atmosphere

AMOS-04: Observing Facilities, Campaigns and Networks
- GMD01 (ARL01): Central Ultraviolet Calibration Facility
- GMD02 (ARL02): Surface Radiation Network

AMOS-01: Instrumentation Design, Prototyping and Analysis

CSD01 (*formerly AL01*): Instrumentation for Atmospheric Observation and Analysis

GOALS:

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 CSD01.1:***
> Develop instruments to measure the size distribution of aerosols, including a white-light optical particle counter to measure coarse particles (0.6 to 0.8 µm diameter) and a scanning condensation particle sizer to measure fine particles (0.005 to 0. µm diameter).

ACCOMPLISHMENTS FOR CSD01.1:

During 2005-2006, two new instruments were successfully developed; a white-light optical particle counter (OPC) designed to measure coarse-particle-size distributions from 0.6 to 8.0 µm in diameter, and a variable condensation particle sizer to measure ultra-fine particle-size distributions from 0.005 to 0.05 µm in diameter.

The white-light OPC design is based on an earlier instrument by *Wollny et al.* [2004]. The modifications to this earlier design included improved detection optics and signal processing electronics to allow the detection of smaller particles, and a dehumidification system to permit measurement of the dry size of the particles after water has been removed from the sample air stream. A numerical model of the performance of this instrument was developed and confirmed by experimental evaluation. The improved performance of this instrument will allow much more accurate and robust measurements of the coarse fraction of the atmospheric aerosol. These particles are often poorly sampled

from aircraft, yet they can dominate aerosol climate-forcing and health-related properties during periods of forest fire and agricultural combustion, as well as during desert dust transport episodes. The design and performance of this instrument is the subject of a manuscript in preparation, as is the analysis of measurements made by this instrument in intense forest fire smoke plumes from western Canada and Alaska.

The variable supersaturation condensation particle sizer is a novel technique to inexpensively measure particle-size distributions from 0.005 to 0.05 μm in diameter. A prototype instrument was designed, constructed, and tested under the support of the CIRES Innovative Research Program (IRP). The design and performance of this instrument was published in the journal *Aerosol Science and Technology* [*Gallar et al., 2006*]. The instrument met or exceeded all design specifications and is now being used by CIRES researchers for laboratory investigations of particle nucleation from biogenic organic compounds.

> ***MILESTONE CSD01.2:***
> Continue the development of instruments to characterize the chemical content of atmospheric aerosol particles by: (i) testing the single-particle cavity ring-down aerosol instrument on laboratory-generated aerosols, and planning for its use as a field instrument; and (ii) conducting initial field trials using the instrument for the collection and analysis of the organic content of aerosols.

ACCOMPLISHMENTS FOR CSD01.2:

Addressing part (i):

The optical properties of aerosols are of central importance in the determination of radiative forcings by these particles in the atmosphere. The radiative forcings determine whether a particular class of aerosols contributes a net heating or cooling effect on the atmosphere and the degree to which this occurs. The manner in which aerosols scatter and absorb radiation (i.e., visible light and infrared) leads to the so-called direct aerosol effect. The particular quantity of interest with the direct aerosol effect is the single-scattering albedo. This quantity is defined as the ratio of the amount of scattering to the amount of extinction (scattering + absorption) of radiation by an aerosol. Accurate measurements of this quantity are critically important in climate forcing calculations for aerosols due to the fact that albedo values contribute a great deal of uncertainty to the calculations. Black carbon aerosols will be the initial focus of these measurements as their sources are largely anthropogenic in nature (biomass burning and incomplete combustion processes) and these aerosols absorb solar radiation leading to a positive (warming) forcing for the atmosphere.

Work is continuing in the development of a laboratory-based instrument for the measurement of single-scattering albedos of single aerosol particles. The system consists of a diode laser locked to an external cavity containing an aerosol scattering cell. The scattering cell collects the total scattered light along with the forward and backward scattered light in separate channels as individual particles traverse the cavity beam. The extinction of the cavity light due to the particles is obtained by either a cavity ringdown measurement or an absorption spectrum-type measurement where the depletion in the transmitted cavity beam due to absorption and scattering by the particles is recorded. Initially in this work, scattering and extinction measurements were made using the cavity ringdown method on purely scattering polystyrene latex spheres of known diameters. Changes in cavity ringdown times due to the particles being present were observed along with the scattered light. The experimentally simpler absorption spectrum measurement is currently being investigated to determine which method provides a more robust and reliable way to measure the single-scattering albedos. This method has shown a clear dependence of the forward to total scattered light ratio (a measure of particle size) to the diameter of particles introduced. The calculated albedos (scattering/extinction) also show qualitatively correct behavior with absorbing spheres having lower albedos (more absorption) than the purely scattering particles. Future work will center on eliminating optical and electronic sources of noise to allow for detection and measurement of smaller particles as well as to improve the data spread to allow for smaller changes in the properties of different particles to be resolvable. A full characterization of the laboratory instrument will be carried out with particles similar to those of interest that are found in atmospheric environments. The laboratory instrument will then be modified to carry out field measurements centering on black carbon aerosols.

Addressing part (ii):

Organic material has been observed to comprise a significant fraction of aerosol mass in many regions of the troposphere, but detailed measurements of the individual species that comprise the organic fraction have been severely limited in spatial extent and temporal resolution. The organic compounds that make up the organic fraction

of atmospheric aerosol have the potential to affect the radiative and microphysical properties of the aerosol, with concomitant impacts on the role of the aerosol in climate forcing through direct and indirect effects. Knowledge of the organic species present in atmospheric aerosols is needed to understand their effect on aerosol properties as well as to elucidate the role of aerosols in the chemistry of the atmosphere through their interaction with gas-phase compounds. The speciated measurement of aerosol organic compounds poses a significant experimental challenge due to the complexity and large number of organic species, and the low concentration at which individual species are present.

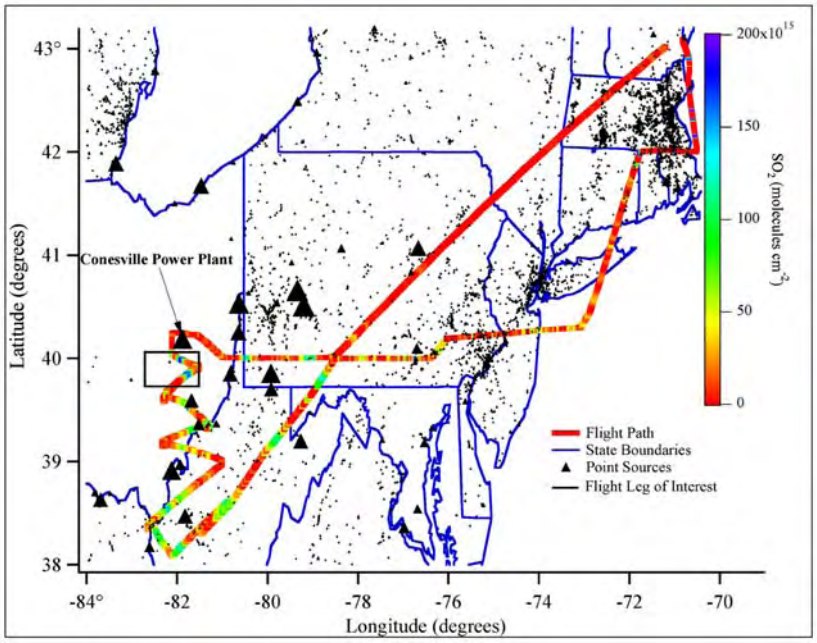
During the past year, the continuing effort to develop a method for determining the speciated composition of organic aerosol with both good sensitivity and relatively short time response has focused on a novel instrument that couples a short (few minutes) aerosol collection to prompt thermal desorption and *in situ* mass spectrometric analysis. This instrument has an aerosol inlet to direct particles onto a target stage for a variable collection time. The stage is then rapidly heated to volatilize the aerosol organic compounds into a carrier gas flow. This flow is directed into an ion drift tube where the organic compounds are ionized by proton transfer from H_3O^+ and then detected using a custom ion trap mass spectrometer. A prototype instrument demonstrated the capability to measure representative organic compounds in laboratory-generated aerosols, and appears suitable for use in laboratory studies such as secondary organic aerosol formation. A second-generation version of the instrument has been constructed, based on the prototype but incorporating a number of design improvements, and is being deployed during late summer 2006 aboard the NOAA R/V *Ronald H. Brown* in the Gulf of Mexico/Houston ship channel area to contribute to the characterization of aerosols in this region.

MILESTONE CSD01.3:
Evaluate data taken by a new UV spectrometer, which measured scattered sunlight during the summer 2004 New England Air Quality Study/Intercontinental Transport and Chemical Transformation (NEAQS/ITCT) campaign.

ACCOMPLISHMENTS FOR CSD01.3:
Sulfur dioxide (SO_2) emissions are regulated under the National Ambient Air Quality Standards (NAAQS) as a "criteria pollutant" because of its role in the formation of acid rain. However, SO_2 also contributes to other atmospheric chemistry processes such as the formation of sulfur-containing particles that play a critical role in climate change.

Therefore, an ultraviolet spectrometer was designed to measure sulfur dioxide (SO_2). The spectrograph was deployed to Portsmouth, New Hampshire, during the summer of 2004 for the New England Air Quality Study/Intercontinental Transport and Chemical Transformation (NEAQS /ITCT) mission. The spectrometer was aboard the NOAA WP-3D aircraft. The aircraft flew through point and regional air pollution plumes.

This work used SO_2 total column measurements from the spectrometer to verify emissions from point sources that will allow the scientific community to better understand the role of these compounds in acid rain, photochemical smog, and radiative forcing of the climate system in the New England region.



Flight path on August 6, 2004 as a function of SO_2 molecules per square centimeter measured by the spectrograph. The black box indicates the flight leg of interest. Four passes of the Conesville power plant are analyzed for emissions verification.

MILESTONE CSD01.4:
Develop a multi-wavelength cavity ring down spectrometer and a photo acoustic spectrometer to measure aerosol extinction and absorption onboard an aircraft and a ship to provide climate-related information for calculating radiative forcing by aerosols and to assess air quality issues related to PM2.5.

ACCOMPLISHMENTS FOR CSD01.4:
Light absorption by aerosols is one of the most uncertain parameters associated with the direct and indirect aerosol effects on climate and is one of the most difficult quantities to measure. This work developed a sensitive method of measuring aerosol absorption at 532 nm with excellent time response (detection limit: 0.08 Mm^{-1}, 60 second average) using photoacoustic absorption spectroscopy. An accurate calibration method (accuracy of 1-2%) at atmospherically relevant absorption levels and independent validation of the photoacoustic technique was accomplished. An upper limit to the instrument precision for aerosol absorption measurement is ~6% (2σ, 30 sec) while instrument accuracy is calculated to be ~5%.

PSD08 (*formerly ETL01*): Sensor and Technique Development

GOALS:
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 PSD08.1:
Develop a compact ultraviolet lidar for measuring profiles of ozone and aerosol from aircraft using the DIAL (Differential Absorption of Light) method.

ACCOMPLISHMENTS FOR PSD08.1:
The development of a new, compact airborne lidar for measuring profiles of ozone and aerosol has been completed. The lidar transmitter is based on a solid-state laser which emits tunable ultraviolet light. The tunability aspect represents a significant improvement over previous, fixed-wavelength ozone lidars, as it allows the operator to choose transmit wavelengths that optimize system performance for a wide range of atmospheric ozone concentrations. The new lidar system was integrated and tested on a NOAA Twin Otter aircraft in May and June of 2006. Its first deployment will occur during the TexAQS II air quality study in the Houston, TX area in August/September 2006.

MILESTONE PSD08.2:
Lead planning for an icebreaker-based international field program to the Arctic Ocean during the International Polar Year 2007-2008.

ACCOMPLISHMENTS FOR PSD08.2:
Discussion began with various national and international scientists regarding research to be done during the International Polar Year (IPY). Two proposals (NSF and NASA) were submitted for conducting research onboard, near, and above the Swedish icebreaker Oden during the International Polar Year, and another proposal was submitted to NSF to fund satellite-based studies of surface energy fluxes during the International Polar Year.

MILESTONE PSD08.3:
Prepare plans for a roving calibration standard for ship flux measurements.

ACCOMPLISHMENTS FOR PSD08.3:
This system has been designed and most major components have been ordered. Conversion from cables to wireless technology was tested on the 2005 Stratus cruise on the *Ronald H. Brown*. A computer-controlled mechanism for motion-stabilized radiative flux measurements has been designed and built. This system will be tested in the laboratory next year. A poster presentation on the project was made at the NOAA Climate Observation Program 4th Annual System Review, Silver Spring, MD, 10-12 May 2006.

MILESTONE PSD08.4:
Develop capability for ship-based ozone flux measurements

ACCOMPLISHMENTS FOR PSD08.4:
A new ozone sensor has been built at the University of Colorado's Institute for Arctic and Alpine Research (INSTAAR) (Detlev Helmig is leading the project). The sensor was tested in the laboratory for sensitivity, frequency response, and noise. Problems with sensor cooling were solved. The sensor was field tested in conjunction with an ESRL sonic anemometer and data acquisition system at the Table Mountain field site for about two months. Ozone-vertical velocity cospectra were computed and analyzed with other cospectra (wu and wt) and found to be of high quality. The frequency response of the sensor-ventilation system was found to be adequate for flux measurement over the ocean. The system will be deployed on the *Ronald H. Brown* in the TexAQS field program in later summer 2006.

MILESTONE PSD08.5:
Investigate propagation of low-frequency acoustic signals through the ocean waveguide perturbed in internal waves.

ACCOMPLISHMENTS FOR PSD08.5:
We have demonstrated that propagation of statistical moments of acoustic variables provides efficient means to study acoustic implications of various descriptions of environmental fluctuations.

WKB-type simplifications of the Garrett-Munk spectrum are employed in many internal wave models and sound scattering theories. We have shown that these simplifications result in significant underestimation of the acoustically relevant characteristic of cross-range sound speed gradients which are responsible for internal wave-induced random horizontal refraction.

With a rigorous implementation of the Garrett-Munk spectrum in terms of modes of internal waves, RMS bearing errors due to random horizontal refraction over 1Mm path reach 0.38° and 0.32°, when internal waves with horizontal spatial scales greater than l_{min} = 125 m and 250 m are taken into account, respectively. With a fixed propagation range, the minimum spatial scale of random environmental inhomogeneities that contribute horizontal refraction is determined by sound frequency; l_{min} decreases and horizontal refraction intensifies when sound frequency increases. Corresponding simulations with a simplified model of the internal wave field give RMS bearing errors that do not exceed 0.29° and 0.27° in the high- and low-resolution cases, respectively. The simplified internal wave model underestimates both the magnitude of random horizontal refraction and its frequency dependence.

Similar discrepancies have been found between statistical moments of other acoustic observables calculated using rigorous and simplified implementations of the Garrett-Munk spectrum. These results suggest that care should be taken in accurately describing details of internal wave spectrum if acoustic measurements are to be used to characterize spatially-averaged absolute strength of internal waves in the ocean.

It has been demonstrated that the average acoustic field for the Gaussian, horizontally homogeneous statistics of the refraction index of the acoustic waveguide satisfy a linear integral-differential equation. The non-local (mass) operator is represented as a sum of corresponding irreducible diagrams which describe interactions between the acoustic and internal wave modes. The Fourier transform of this equation results in a 1-D equation with respect to vertical coordinate which consists of the standard differential vertical operator and an integral term. Thus, acoustic modes corresponding to the average field are generally different from the standard acoustic modes. The expression for the average Green function to the lowest order in perturbation parameter coincides with the standard expression, but with the propagation constants having imaginary parts which represent the decrement of attenuation of the corresponding acoustic mode. The explicit expression for the decrement of attenuation in terms of the internal wave spectrum is obtained. Both 2-D and 3-D cases have been considered. It has been demonstrated that the possibility of neglecting 3-D effects depends on the shape of the internal wave spectrum and also requires sufficient smoothness of the sound speed fluctuations with respect to depth.

The computer code for calculation of the decrements of attenuation of the acoustic modes has been developed. Preliminary estimates show that the decrement strongly depends on mode number and for 65 Hz acoustic frequency can vary from hundreds to many thousands of kilometers. The decrement decreases for higher acoustic modes.

Strong dependence of the modal decrements of the average field attenuation on the acoustic mode number provides a possibility to use this dependence for retrieving the spatial spectrum of internal gravity waves from measurements of the average acoustic field with long vertical receiving arrays. Knowledge of the mode-number dependence of the decrements also provides an opportunity to improve the quality of acoustic transmissions in the ocean by proper selection of the carrier acoustic modes.

MILESTONE PSD08.6:

Conduct a technology evaluation to determine which type of wind profiler (915-MHz vs. ¼-scale 449-MHz) is best suited to coastal and marine weather applications.

ACCOMPLISHMENTS FOR PSD08.6:

The side-by-side comparison of 915-MHz and ¼-scale 449-MHz profiling technologies is being carried out at the University of California's Bodega Bay Marine Laboratory. A CIRES investigator is the scientific lead on this project. The evaluation began in September 2005 and will end in August 2006. Feedback on usage of the profiler data and products from the NWS Weather Forecast Office in Monterey and the California-Nevada River Forecast Center in Sacramento has been collected and reviewed. The next step will be to produce a report for NOAA's Integrated Ocean Observing System with recommendations for which technology is best suited to coastal and marine forecast applications.

MILESTONE PSD08.7:

Compare the performance characteristics of wind profiles retrieved from NEXRAD Velocity Azimuth Display (VAD) versus wind profiles measured with a collocated 915-MHz Doppler Wind Profiler. CIRES investigators will use extended datasets from Pittsburgh, PA and Denver, CO to compare the relative performance of each observing system for detecting different atmospheric phenomena over the course of varying climatological regimes. The investigators will also compare performance when different types of contaminating signals are present (e.g., migrating birds, radio frequency interference).

ACCOMPLISHMENTS FOR PSD08.7:

CIRES investigators have accomplished the following steps in this milestone:

a) The required year-long datasets consisting of Doppler wind profiler data, NEXRAD VAD wind profiles, and NWS rawinsonde profiles have been assembled for Pittsburgh, PA.
b) The VAD wind profiles have been extracted from the large binary WSR-88D data stream.
c) A sophisticated height interpolation scheme was developed so that the height ranges of data used in each comparison (profiler vs rawinsonde and NEXRAD vs rawinsonde) are accurate.

The next step is to produce performance stastistics using the rawinsonde as the standard for wind measurements.

MILESTONE PSD08.8:

Use *in-situ* observations and high resolution numerical simulations to assess the accuracy of TRIM/GPM satellite maritime precipitation measurements in two, high-impact, Pacific landfalling extratropical cyclones.

ACCOMPLISHMENTS FOR PSD08.8:

Scientists performed numerical simulations of the Feb. 19, 2001, eastern Pacific storm and compared the simulation analyses with the simultaneous satellite TRMM analyses and the aircraft analyses. The three sources of data were in very good agreement, but showed some different aspects of the storm. Results were presented at the 32nd Radar Conference in Albuquerque and at the NASA Precipitation Measurement Missions Meeting in Monterey. Plans were made to convert the conference papers to journal articles, but additional funding was needed for this. A short proposal was written, and was funded in 5/2006.

MILESTONE PSD08.9:

Develop a remote sensing method to retrieve rainfall rates aloft from vertically pointing measurements from millimeter-wavelength radars deployed at the Atmospheric Radiation Measurement (ARM) Program testbed sites. The retrieval results from this method will include vertical profiles of rainfall rates in the atmospheric column. For validation purposes, these results at the lowest available range gate will be compared to the surface rain measurements by disdrometers and gauges.

ACCOMPLISHMENTS FOR PSD08.9:

An attenuation-based method to retrieve vertical profiles of rainfall rate from vertically pointing measurements of 8-mm wavelength ARM radars has been developed. The method was applied to a wide variety of rainfall events observed at different ARM testbed sites. It was demonstrated that this method can successfully retrieve rainfall rates in a range from 5 to more than 100 mm/hr. Comparisons with the ground measurements showed that the retrieval results at the lowest possible radar range gate were in good agreement with surface estimates.

MILESTONE PSD08.10:

Develop capability for routine ship-based CO_2 flux measurements.

ACCOMPLISHMENTS FOR PSD08.10:

This project involves the repackaging of fast CO_2 sensors to permit continuous unattended deployment on the NOAA ship *Ronald H. Brown*. The goal is to obtain an extensive data base of CO_2 flux and transfer velocity for a variety of verification and parameterization development objectives. The project has been underway for about a year. A system has been designed and sensors acquired. A prototype configuration has been assembled and testing has begun at the pier at Duck, NC. The system will be field tested on a ship later in the summer of 2006.

MILESTONE PSD08.11:

Examine surface-based Doppler lidar data from recent field programs to evaluate performance factors for a space-based Doppler lidar system.

ACCOMPLISHMENTS FOR PSD08.11:

CIRES researchers have assembled data from several different ship-based deployments of Doppler wind lidars over the open ocean and used the data to characterize wind fields and turbulence in each deployment area. Preliminary performance models for a space-based Doppler lidar system were created and the effects of the observed atmospheric dynamics on space lidar system performance were characterized. Preliminary results of the study were presented at two meetings of the Lidar Working Group on Space-Based Winds.

MILESTONE PSD08.12:

Upgrade ground-based ozone- and aerosol-profiling lidar and operate at the Texas air quality study.

ACCOMPLISHMENTS FOR PSD08.12:

CIRES researchers have upgraded a ground-based ozone and aerosol lidar in preparation for a shipborne deployment during TexAQS II. Upgrades include a) a light-weight scanner which permits scanning the lidar beam in a vertical plane, b) an improved motion-compensation system, c) a new Raman cell design for generating ultraviolet laser light, d) a more efficient transmitter and receiver design, and e) an improved data acquisition system including real-time display of ozone and aerosol profiles. The lidar system will be deployed on the NOAA research vessel *Ronald H. Brown* during TexAQS II in the Houston, TX area in August/September 2006.

AMOS-02: Data Management, Projects and Infrastructure Systems

NGDC01: Geospatial Technology for Global Integrated Observing and Data Management Systems

GOALS:

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 is compliant with national FGDC (Federal Geographic Data Committee) and international ISO (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 NGDC01.1:***
> Design and implement a database system for storing and providing access to information stored in headers of satellite data and product files.

ACCOMPLISHMENTS FOR NGDC01.1:

This system, termed the "rich inventory," has been designed and implemented for a variety of *in-situ* observing systems and satellite products, including a suite of Level 2 and 3 Sea Surface Temperature products. The system includes a web-based visualization tool.

> ***MILESTONE NGDC01.2:***
> Improve systems for creating, managing, and integrating metadata for different data types and from different sources.

ACCOMPLISHMENTS FOR NGDC01.2:

The NOAA Metadata Manager and Repository has been used for creating and managing metadata records for NESDIS and NGDC data sets. Significant research was done to discover diverse existing sources of documentation and to integrate the content of those into standards-compliant metadata structures. This was done primarily by taking advantage of the Remote Sensing Extensions to the FGDC Metadata Standard.

> ***MILESTONE NGDC01.3:***
> Design and implement an internet-based Geographic Information System for access to meteorological and air quality data.

ACCOMPLISHMENTS FOR NGDC01.3:

This task was completed working with the Texas Environmental Council and NOAA's Chemical Sciences Division. The interactive map includes meteorological information from the Air-Now system as well as updated emissions inventory information from the EPA.

NGDC02: Marine Geophysics Data Stewardship

GOALS:

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 research and throughout the environmental science community.

> ***MILESTONE NGDC02.1:***
> Complete a Laurentian Great Lakes Coastline and Lake Huron bathymetry to bring the Great Lakes Project to a natural state of suspension awaiting final, Canadian Lake Superior data for conclusion of the entire project.

ACCOMPLISHMENTS FOR NGDC02.1:
New contours, digitized for Lake Huron, are now available to the public at *http://map.ngdc.noaa.gov/website/mgg/greatlakesbathy/viewer.htm*. These contours include a coastline, which was digitized, in part, from the individual smooth sheets of data used in the production of the contours. The web site also makes contours available for Lakes Erie, Ontario, and Michigan.

> ***MILESTONE NGDC02.2:***
> Web delivery of customizable, monitoring data by means of the adaptation of metadata, acquired systems, and the integration and evolution of current systems to the web environment.

ACCOMPLISHMENTS FOR NGDC02.2:
The MultiBeam Bathymetric Data Base (MBBDB) continues to grow as a worldwide, comprehensive, bathymetric data base. The present data volume is over 500 Gigabytes of data with over 800 surveys, all available for download. An online data submittal website, complete with metadata submittal forms for each survey, has been developed and will soon be active online. Internal tracking systems were also developed for continual management monitoring of data flow through the system.

SEC03: Information Technology and Data Systems

GOALS:
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 SEC01 and SEC02 with fast and efficient access to appropriate data sources.

> ***MILESTONE SEC03.1:***
> Migrate off older and non-supported computing platforms to newer platforms. Complete and deploy next generation SEC status monitor and lay down a project plan for integrating existing applications to the new status monitor. Complete version 2.0 of the "GetData" server and clients to provide fill-value functionality, domain-name based data-retrieval, and auto-switching between main and warehouse data stores.

ACCOMPLISHMENTS FOR SEC03.1:
Researchers completed an architecture and migration plan for moving off legacy systems by consolidating platforms and languages. The architecture analysis research was carried out with strong emphasis on security and high-availability. Several status monitor off-the-shelf products were evaluated and a selection was made. The selected product is currently installed at SEC computers and researchers are doing extensive tests to further ensure that the product will meet SEC's current and future status monitoring requirements. Research was carried out to simplify, improve and document the data flow between SEC and AFWA (Air Force Weather Agency). The Interface Control Document was updated and has gone through several review iteration and is getting ready for final approval by SEC and AFWA.

The "GetData" (Data Bridge) server now supports version 2.0, fill-value functionality, thereby providing greater value to research clients for their modeling and forecasting applications. Switching between main and warehouse data store is currently supported through XML configuration files on the client side.

A key component needed for migrating off legacy SEC data systems, the Data Subscription Service, is currently under development. Once deployed, this service, along with other shared services that are already in place, like the messaging service, data bridge service, the SWDS data base server, and the logging service, will enable SEC to start the migration of aging client programs like the Data Display System (DDS) and the Real-Time Data System (RTDS), to the new high-availability architecture.

> ***MILESTONE SEC03.2:***
> Develop and deploy a secure and reliable data ingest, storage, processing and dissemination system for space weather data streams. Re-architect 4-5 existing applications to reduce complexity and increasing reliability by integrating them with the new SEC shared services.

ACCOMPLISHMENTS FOR SEC03.2:
Researchers completed the porting of RGON pre-processor to the new Linux platform. The new GOES-13 pre-processors now users the SEC shared messaging service to implement core inter-system notifications.

SXI processor is being re-factored to eliminate RSI/IDL in the PNG image generation process, and move to a pure Python based implementation. SXI-processor was also re-factored to eliminate a custom C-interface to RSI/IDL software, by introducing capability to directly access the RSI/IDL DLL SEC (Spread) Messages Service to support new deployment of RTIS clients. In addition, we upgraded to the COMM system to acquire data from additional data sources. A prototype implementation of the TMO magnetometer was completed to port the existing legacy system off the older QNX platform. Researchers also completed a prototype for the USGS magworm ingest system. These new ingest systems will be windows-based applications writing to the new SWDS database.

> ***MILESTONE SEC03.3:***
> 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.

ACCOMPLISHMENTS FOR SEC03.3:
Researchers completed the development and testing of the GOES-N (GOES-13) ground data system comprising ingest, processing, archival and display systems. This system is currently under testing and further refinement during the GOES-13 PLT period. Real-time SXI clients are currently being used by researchers at multiple computers inside SEC, and at various external locations like SOCC and Lockheed. Data from GOES-13 is also archived at the SWDS data and file stores. The new GOES-13 ground data systems use the new XML based SEC messaging service for implementing certain inter-system notifications.

AMOS-03: Prediction, Model Development and Evaluation

CSD02 (*formerly AL02*): Chemical Transport Model Research

GOALS:
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.

> ***MILESTONE CSD02.1:***
> Continue to use measurements of ozone, aerosols, and their precursors made during the 2004 New England Air Quality Study to evaluate the forecast capability of the current tracer and chemical forecast models.

ACCOMPLISHMENTS FOR CSD02.1:
Air quality forecast models are currently used by the National Weather Service, research labs, and private companies to provide accurate pollution forecasts one to two days into the future. Much like weather forecasts, improving the accuracy of air quality forecasts is an ongoing objective. The focus of this research is on using data collected during the ICARTT/NEAQS-2K4 field campaign and from the dense surface networks of ozone and PM2.5 aerosol (particulate matter of diameter 2.5 micrometers or less) to validate existing air quality forecast models. During the 2004 field study, the NOAA/ESRL Chemical Sciences Division collected detailed air quality and meteorological forecast results from nine forecast models in real-time. These forecasts were from two NOAA agencies (NWS/NCEP, and NOAA/ESRL/PSD), the Meteorological Services of Canada, a private corporation (Baron Advanced Meteorological Services, Inc.), and one university (University of Iowa). The model results have been statistically evaluated using observations from 342 AIRNow ozone surface monitors in the Northeast U.S. and Southeast Canada, resulting in five publications relating directly with improvements in ozone forecasts [*Pagowski et al*., 2005; *McKeen et al*., 2005; *Pagowski et al*., 2006; *Delle Monache et al*., 2006; *Wilczak et al.,* 2006]. One important conclusion is common within these studies: The most accurate forecast is obtained by combining all of the model results together into an "ensemble" forecast. Because all of the forecast models over-predict ozone, corrections to the forecasts are necessary to make the optimum forecast from the resulting ensemble. Various

techniques for forecast correction, adapted from accepted methods used in weather forecasting, are proposed and compared in these publications. The last two publications also analyze a promising approach to relay pollution forecast information—using the ensemble to give a probability a particular day will exceed a pollution limit, just as weather forecasts predict the probability that rain will occur on a given day.

While forecasts of ozone have been available for some time and operational at the National Weather Service since 2004, numerical forecasts of aerosol PM2.5 are a much more recent development. Seven forecast models also provided aerosol PM2.5 predictions for the ICARTT/NEAQS-2K4 study period, and these have been statistically evaluated using observed aerosol properties collected on board the NOAA WP-3 aircraft, the NOAA *Ronald H. Brown* research vessel, and PM2.5 surface monitors operational during the field experiment [*McKeen et al.,* 2006]. Evaluations with the surface network shows that six of the seven models have more skill at predicting mid-day PM2.5 levels compared to analogous forecasts of O_3, and that the ensemble PM2.5 forecast again provides the best possible prediction. Despite the good results in predicting average PM2.5 pollution, the models do not do such a good job of predicting the hourly, diurnal changes in PM2.5 or the composition of PM2.5. All models severely under-predict the organic fraction of PM2.5 aerosol, which is one of the dominant PM2.5 components. The other dominant component, sulfate, is found to be under-predicted by forecast models that do not include the process of sulfur dioxide (SO_2) oxidation within clouds, but over-predicted by those models that do. These evaluations with the detailed observations from the ICARTT/NEAQS-2K4 field program are critical for testing the models' underlying components and assumptions, leading to improvements in forecast ability, and insuring the forecasts get the right answer for the right reasons. The web site: *http://www.al.noaa.gov/ICARTT/modeleval/* provides many of the details and summary statistics from which the evaluations are based.

MILESTONE CSD02.2:
Use model sensitivity studies to examine the effects of changing power plant nitrogen oxide (NO_x) emissions on the formation of ozone over the eastern USA.

ACCOMPLISHMENTS FOR CSD02.2:

Ozone is formed by photochemical reactions of volatile organic compounds and the oxides of nitrogen. The largest sources of human-made nitrogen oxide emissions in the US are transportation and fossil-fueled power plants. Motor vehicle nitrogen oxide emissions have remained relatively constant, as decreased emission rates per mile driven resulting from pollution control technology have been offset by increased vehicle miles traveled.

In the 1990s, regulatory attention turned toward nitrogen oxide emissions from fossil-fueled power plants, usually located in rural areas that are often rich in emissions of VOCs from forests. The nitrogen oxide emissions from these power plants can affect the ability of Eastern US urban areas to comply with the US ozone standard by elevating regional ozone levels. To mitigate this ozone formation, the EPA mandated reductions of point source nitrogen oxide emissions that focused primarily on coal-fired power plants across the Eastern US.

We used airborne measurements to quantify emission ratios of sulfur dioxide to nitrogen oxides from power plants in the Eastern US. We then compared our observations with measured emissions reported by these plants. We updated nitrogen oxide emission inventories to correspond with observed levels. The impact of these emission reductions on ozone levels was simulated with an air quality model.

Reports from these fossil-fueled power plants suggest there has been a significant reduction in their nitrogen oxide emissions over the past four years (Figure 1, next page). Our aircraft observations agreed well with the most recent emission ratios reported by the power plants, confirming the accuracy of the plants' monitoring systems (Figure 2, next page). Model simulations indicated nitrogen oxide emission reductions resulted in important changes in regional ozone concentrations (Figure 3, next page).

Pollution controls at fossil-fueled power plants, though costly to implement, have resulted in verifiable reductions in nitrogen oxide emissions and atmospheric nitrogen oxide levels. Nitrogen oxide emission reductions generally lead to less ozone produced by these plants under typical summertime conditions. Further modeling simulations are needed to understand the full implications of power plant nitrogen oxide emission reductions on regional ozone levels.

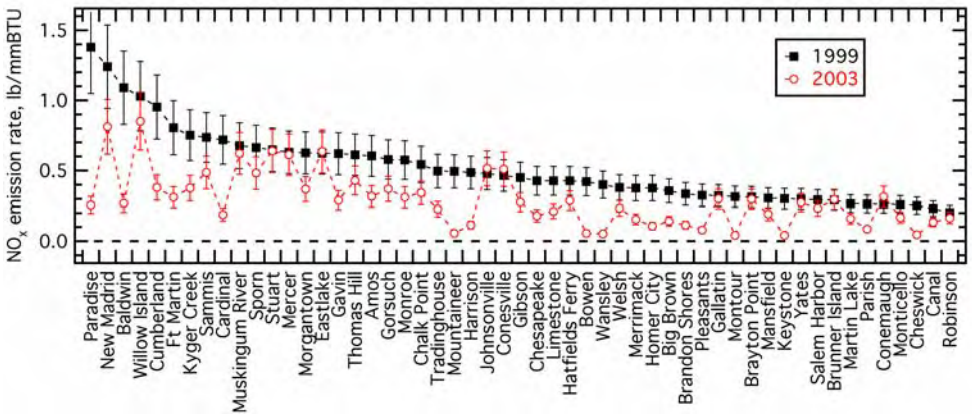


Figure 1. Comparison of summer 1999 and 2003 NOx emissions from 53 Eastern US power plants measured by continuous emission monitoring systems (CEMS).

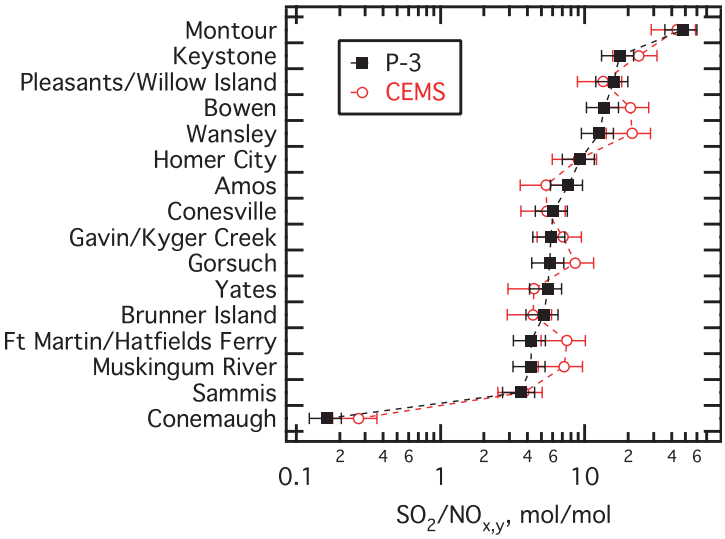


Figure 2. ICARTT 2004 NOAA P-3 observations of sulfur dioxide to total nitrogen oxide (SO_2/NO_y) ratios in the plumes of Eastern US power plants compared with summer 2004 CEMS SO2/NO_x emission ratios for these plants.

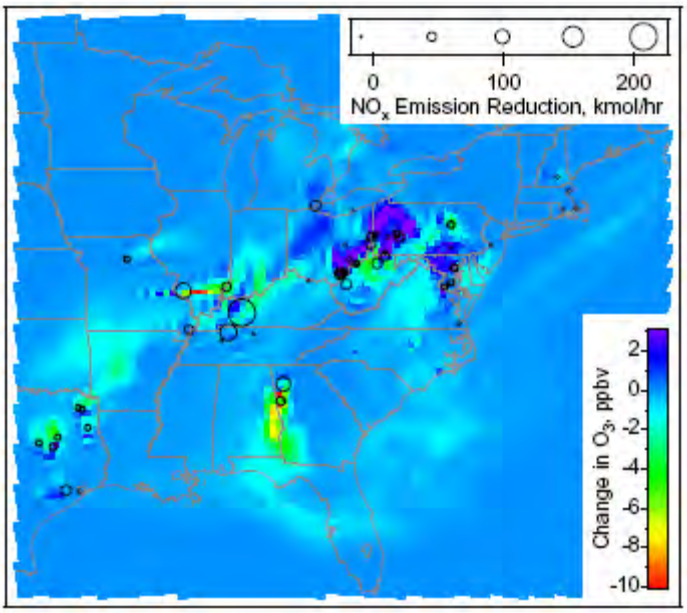
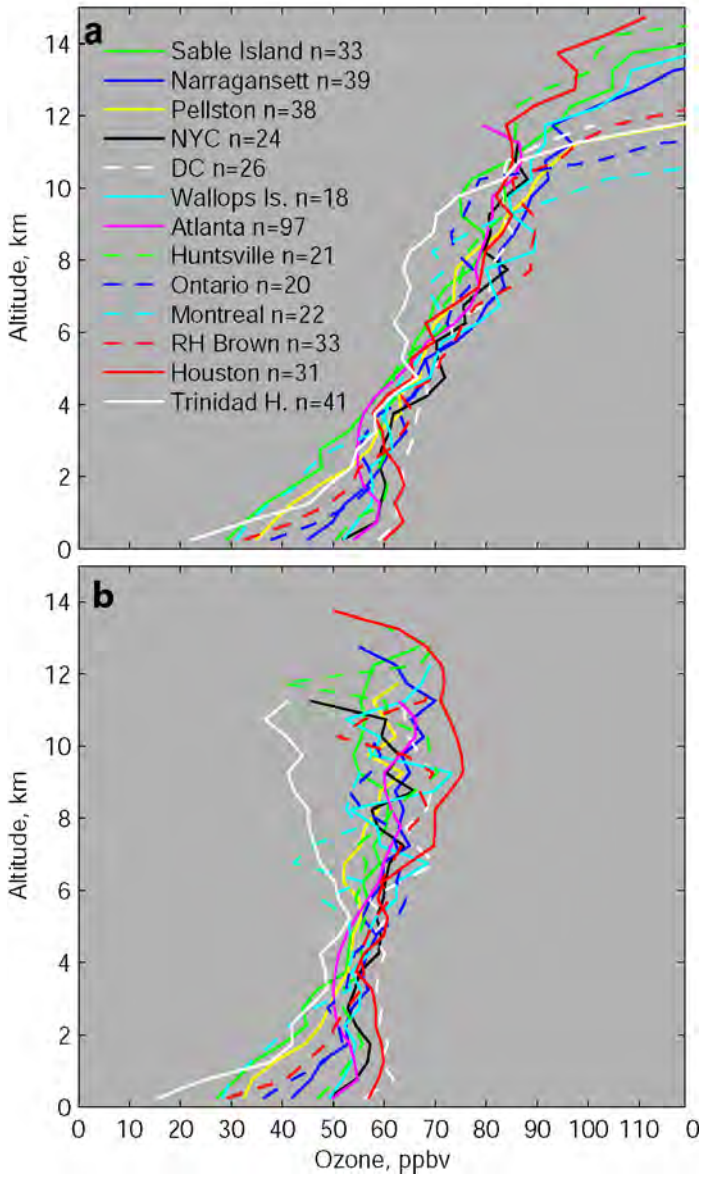


Figure 3. Change in modeled O_3 on the afternoon of 21 July 2004 after reducing NO_x emissions from 1999 to 2003 levels at 53 eastern US power plants (shown by black circles sized to indicate the plant's NO_x emission reduction).

MILESTONE CSD02.3:
Examine the influence of transport pathways on the ozone profiles across North America during the International Consortium for Atmospheric Research on Transport and Transformation (ICARTT) experiment, as measured by ozonesondes, research aircraft, and commercial aircraft.

ACCOMPLISHMENTS FOR CSD02.3:
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 issues of air quality. Currently, international research programs are focusing research on the dynamics and composition of the upper troposphere and lower stratosphere because of this region's influence on global climate change, with ozone once again a trace gas of primary interest.

In the past, quantifying the North American ozone budget has been difficult due to the limited number of profiling sites across the continent. To finally measure the daily ozone distribution across mid-latitude North America during the most photochemically active part of the year, NASA, NOAA, Environment Canada, and several U.S. universities launched ozonesondes from multiple sites under the IONS (INTEX Ozonesonde Network Study) program during July-August 2004. Additional ozone profiles across eastern North America were obtained from five instrumented commercial aircraft that fly between North America and Europe under the European MOZAIC program. MOZAIC profiles were combined with ozonesonde profiles from nearby locations to form 13 monitoring sites, yielding the most detailed set of ozone measurements ever gathered across mid-latitude North America. A particle dispersion model calculated the quantity of stratospheric ozone influencing each site. These quantities were subtracted from the ozone profiles to yield profiles of tropospheric residual ozone at each site (figure left).



Of the 13 ozone profile sites, Trinidad Head on the west coast had the least amount of ozone in the upper troposphere while Houston in the southern U.S. had the most, with enhanced upper tropospheric ozone across eastern North America. The transport of nitrogen oxide (NO_x) tracers from North American anthropogenic, biogenic, biomass burning, and lightning emissions was simulated for the upper troposphere of North America with a particle dispersion model. Overall, we estimate that 69-84% (11-13 ppbv) of the 16 ppbv ozone enhancement above eastern North America is due to *in situ* ozone production from lightning NO_x, with the remainder due to transport of ozone from the surface or *in situ* ozone production from other sources of NO_x.

a) Median ozone profiles at all thirteen sites for July 1 - August 15, 2004, reported in 500 m layers with the sample size indicated by n. b) Median tropospheric ozone profiles after the estimated stratospheric influence from the past 20 days has been removed.

PSD09 (*formerly ETL02*): Environmental Monitoring and Prediction

GOALS:
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 PSD09.1:***
> Develop a method to correct the High-Resolution Infrared Radiation Sounder (HIRS) satellite radiances from biases in diurnal sampling caused by polar-orbiting satellites drifting from their sun synchronous orbit.

ACCOMPLISHMENTS FOR PSD09.1:
A method for correcting diurnal sampling bias in HIRS data was developed using HIRS simulated data from the Geophysical Fluid Dynamics Laboratory (GFDL) global atmospheric model (AM2). The investigation found several tropospheric temperature channels (11.1, 13.4 and 13.7 micron) and water vapor channels (8.3 and 7.3 micron) were significantly affected by changes in diurnal sampling caused by orbital drift by the NOAA polar-orbiting satellites. The effect of orbital drift causes trends in the HIRS brightness temperature data that are solely due to changes in sampling that could be misinterpreted as climate variation. The correction method removes this bias and makes these data more suitable for climate studies.

GSD01 (*formerly FSL01*): Regional Numerical Weather Prediction

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

> ***MILESTONE GSD01.1:***
> Develop procedures to use Level II high-resolution (1 km in the horizontal, 15 levels in the vertical), three-dimensional, high-frequency National Weather Service WSR-88D radar data in the initialization of cloud and precipitation hydrometeors.

ACCOMPLISHMENTS FOR GSD01.1:
A procedure has been developed to use the three-dimensional reflectivity product produced by the National Severe Storms Lab of NOAA. In this procedure, the reflectivity from the NSSL product is combined with the existing RUC cloud analysis, which combines a RUC 1-hour forecast with satellite cloud top information, surface observations and now three-dimensional radar reflectivity to construct a three-dimensional initial field of hydrometeors. The radar reflectivity, where it is present and considered to result from precipitation rather than other reflectors (e.g., birds, insects, and ground clutter), is converted to mixing ratio of either snow or rain (or a mixture) depending on the temperature of the model background. This assimilation of the radar reflectivity shows promise of improving the RUC's performance in prediction of ceiling, visibility and precipitation during the first few hours of the model run, because for the first time we have quantitative information on three-dimensional hydrometeor content. Operational exploitation of this capability awaits operational availablity of the NSSL mosaic product at NCEP.

> ***MILESTONE GSD01.2:***
> Adapt a state-of-the-art 3-dimensional analysis procedure (Gridded Statistical Interpolation) to run efficiently in a rapid-updating context.

ACCOMPLISHMENTS FOR GSD01.2:
Gridpoint Statistical Interpolation (GSI), a state-of-the-art three-dimensional variational analysis (3dvar) system, developed mostly by the National Centers for Environmental Prediction (NCEP), has been installed on both supercomputers of the Earth System Research Laboratory. The installation of GSI required deep study of the code and introduction of features not available in the basic version. After successful installation, single observation experiments were performed to test the background and observation terms in GSI. Besides checking on the correctness of basic GSI set-up, these experiments helped to understand balance and other intervariable relationships in GSI. Based on experience gathered during single observation experiments, test cases have been run for a Global

Forecast System (GFS) case and also two others for the two WRF dynamical cores. For WRF both netCDF and binary inputs have been tested. Test analyses with GSI have also been made using WRF model forecasts over the CONUS as background.

Successful completion of these tests has enabled us to begin real-time cycling with WRF and GSI. Over a sub-CONUS domain covering the eastern US a 12-hour intermittent assimilation cycle using GSI and the WRF chemistry model has now been running satisfactorily in real time for the past two months. Presently we are setting up a 12-hour real-time assimilation cycle for both versions of the WRF core using GSI and observations routinely available at ESRL/GSD.

> ***MILESTONE GSD01.3:***
> Investigate the two primary WRF dynamical cores (NMM and ARW) for their suitability as the forecast model for the new North American Rapid Refresh application under development in FSL.

ACCOMPLISHMENTS FOR GSD01.3:

The Rapid Refresh (RR) Core Test, designed to investigate the WRF-ARW and the WRF-NMM dynamical cores for their suitability for RR application, is nearing completion. This test has been conducted jointly by the Global Systems Division of ESRL, the Developmental Testbed Center and the Product Development Teams of the FAA's Aviation Weather Research Program. Based on the outcome of this test, ESRL/GSD will recommend to NCEP that either the ARW or NMM core should be used in the 2008 implementation of the Rapid Refresh.

This RR core test is the first time that a rigorous comparison of the performance of the two WRF dynamical cores, the Non-hydrostatic Mesoscale Model (NMM), and the Advanced Research Wrf (ARW). By dynamical cores, we refer to those parts of the model codes that solve the discretized, finite-difference form of the adiabatic portion of the governing equations for that particular core, including horizontal and vertical advection, marching forward in time, and any numerical filtering or diffusion introduced to preclude energy buildup at scales too small to be accurately resolved.

To accomplish the aim of isolating the influence of the different cores from other, confounding factors, it was necessary to do much planning and preparation. This was an extensive project, involving close coordination between the three organizations noted above. There were many challenges, but the major ones were 1) implementing updated versions of three physics routines, currently used in the operational Rapid Update Cycle (RUC) model, into both the NMM and ARW and 2) ensuring that all physics operated the same way in both cores, and that feedbacks between the physics schemes were handled identically in both cores. This last task was essential to the integrity of the core test. We also wanted to compare dynamical core performance with physics routines that are similar to what are likely to be included in the RR when it becomes operational. Tanya Smirnova of CIRES was the central figure in this preparation. She and Georg Grell (also CIRES) implemented and tested the necessary RUC physics routines in both the WRF-ARW and WRF-NMM. She also performed extensive trial runs and debugging to ensure that the physics routines indeed worked identically in each core.

This and other components of core-test preparation took about five months, involving scientists at NCAR and the National Centers for Environmental Prediction of the National Weather Service, in addition to the participants from the three primary organizations.

Close to 480 model forecasts were made in total. Evaluation is continuing, using a combination of statistical and subjective methods. Results so far show the models to be overall very similar in their forecast performance. The evaluation will be completed in August 2006 and the core recommendation to NCEP made by 1 September.

> ***MILESTONE GSD01.4:***
> Investigate different options for physical parameterizations to be used in the Rapid Refresh application of the WRF model.

ACCOMPLISHMENTS FOR GSD01.4:

As part of the Rapid Refresh (RR) Core Test (see Accomplishments under Milestone #3), we ran two distinct physics suites. The so-called Phase 1 of the core test ran twice daily 24-h forecasts for four one-month long retrospective periods, one month in each of the four seasons. This used approximately the same physics as are now being used in the operational “North American Mesoscale” run at NCEP.

Phase 2 of the Core Test used another suite of physics, similar to the physics that is being run operationally in the Rapid Update Cycle model at NCEP. The main differences between the phase 1 and phase 2 physics are the land-surface model (LSM), the representation of convection and the cloud and precipitation microphysics. The RUC LSM used in phase 2 is an overall simpler scheme than the NAM scheme used in phase 1, but has some distinct advantages in its treatment of snow cover. The Grell-Devenyi convection scheme used in phase 2 is a "mass-flux" scheme, whereas the Betts-Miller-Janjic (BMJ) scheme used in phase 1 is an adjustment scheme. The precipitation patterns they produce are often very different, with the BMJ producing the better precipitation verification scores by the traditional measures of Equitable Threat Score and Bias. However, the G-D scheme has some advantages in the feedbacks to the microphysics schemes. We have paid particular attention to differences in the microphysics schemes, particularly in their prediction of supercooled liquid water, an important parameter for prediction of inflight aircraft icing. The Ferrier scheme used in phase 1 is more computationally efficient than the new NCAR-Thompson scheme tested for the first time in phase 2, but the Thompson scheme is superior in its potential benefit to icing prediction. A third microphysics possibility is an older version of the NCAR microphysics that is more computationally efficient, but less accurate than the NCAR scheme tested in phase 2 of the core test.

In summary, there has been extensive testing in 2005-6 of two physics suites that are candidates for use in the RR when it becomes operational in 2008. During FY07 we will continue this evaluation of the physics, particularly the LSM and microphysics, with whatever WRF dynamical core is chosen for the model component of the RR.

MILESTONE GSD01.5:
Explore the use of High Performance Computing and Communications within the context of the new NOAA Research and Development High Performance Computing System (RDHPCS) and the National Lambda Rail (NLR) network.

ACCOMPLISHMENTS FOR GSD01.5:
Accomplishments include the testing of 10-gigabit ethernet tuning and testing using a DWDM link to NCAR. This testing incorporated the MAN link to the University of Colorado as well. Long-haul network tuning was done using the National Lambda Rail (NLR) research network at 1 and 2 gigabits. This testing also integrated security concerns including network performance of firewall hardware.

Future plans include implementing 10-gigabit LAN connections between major components of the Boulder-based high performance computing systems. Future plans also include collaborating with NOAA sites in Princeton, NJ and Washington, DC regarding a high-speed national NOAA network.

GSD03 (*formerly FSL03*): 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 GSD03.1:
Enhance the design and functionality of the Real-Time Verification System (RTVS) for the verification of aviation-related forecasts, such as forecasts of convection and turbulence.

ACCOMPLISHMENTS FOR GSD03.1:
Scientists completed an entire redesign of the data ingest capability, relational database, and web-based access to the turbulence module within RTVS. This redesigned capability will be extended to other functions within RTVS and provides improved access to statistical results and common user displays.

MILESTONE GSD03.2:
Investigate and develop new verification techniques for evaluating the operational impact of convective forecasts.

ACCOMPLISHMENTS FOR GSD03.2:

Preliminary concepts for using aircraft situational display data for evaluating the operational impact of convective forecasts were tested. In addition, analysis of convective forecast likihood for the Collaborative Convective Forecast Product (CCFP) was completed. These results were presented to the Weather Evaluation Team and used to determine future forecast requirements for the CCFP.

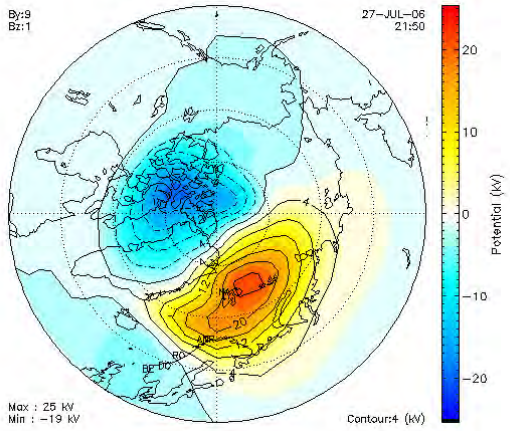
NGDC03: Space Weather

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 NGDC03.1:

Construct a 15-year gridded database of results from an assimilation model, Assimilated Model of Ionospheric Electrodynamics, a coupled ionosphere-thermosphere model, Global Ionosphere Thermosphere Model, and an inner magnetosphere model, Inner Magnetosphere Model.



ACCOMPLISHMENTS FOR NGDC03.1:

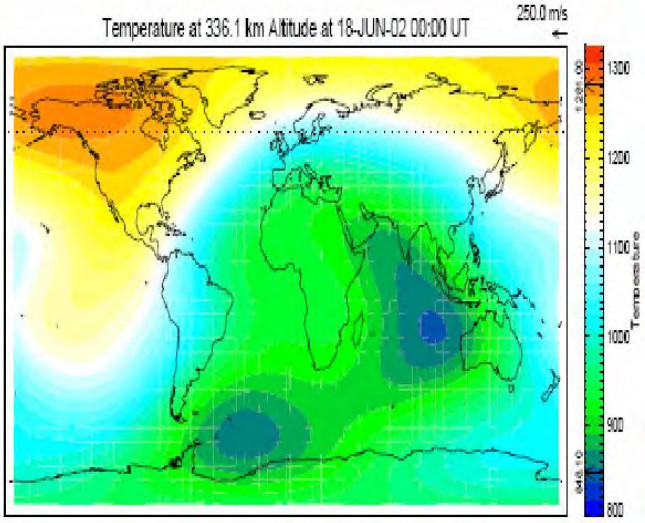
We have constructed a comprehensive gridded database that spans the years 1989 through 2002. This database consists of an Assimilated Model of Ionospheric Electrodynamics, a Global Ionosphere Thermosphere Model, and a Simple Inner Magnetosphere Model. These products are all available through the archives at the NGDC.

MILESTONE NGDC03.2:

Publish project results via web and integrate them with ongoing research projects.

ACCOMPLISHMENTS FOR NGDC03.2:

A website has been developed for the Space Weather Analysis project. The purpose of this site is to provide technical and support information for the three SWA models (Simple Inner Magnetosphere Model, Global Ionosphere Thermosphere Model, and Assimilative Mapping of Ionospheric Electrodynamics), along with an interface that allows users to view sample model outputs and to order output data sets.



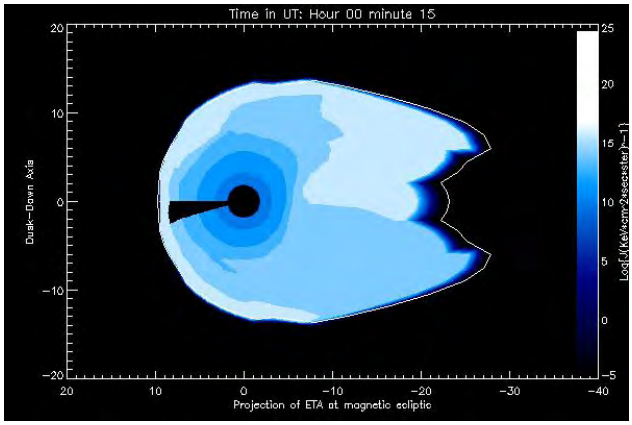
MILESTONE NGDC03.3:

Integrate the CDAWeb data resources with the SPIDR system.

ACCOMPLISHMENTS FOR NGDC03.3:

The Mirrion comprehensive Ionosonde database has been developed. Mirrion provides the world's most extensive archive of ionograms, and provides a growing network of near real-time soundings for near real-time space weather and communications models.

MILESTONE NGDC03.4:
Assess, upgrade and operate the Boulder ionosonde observatory.



ACCOMPLISHMENTS FOR NGDC03.4:
Several accomplishments have been achieved on the Boulder Ionosonde site. A new array of receive antennas have been installed to support a new generation of ionopsheric sounders. Continuous maintenance has allowed for regular operation of the site, and a new transmission tower has been purchased and is waiting for installation. Preliminary work has been done to assess the aging condition of the current site to assure continuous operation and an emergency maintenance plan should equipment failure occur.

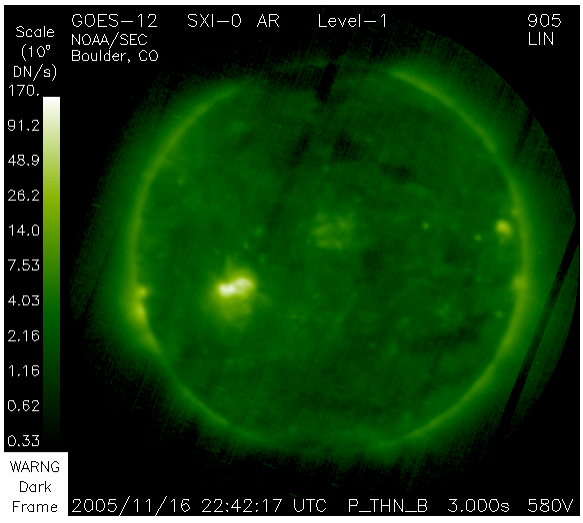
SEC01: Solar Disturbances in the Geospace Environment

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 (CMEs) 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 SEC01.1:
Rocket Data: Update GOES solar X-ray instrument calibration using a reference spectrum and forward models of the instruments.

ACCOMPLISHMENTS FOR SEC01.1:
The Solar X-ray Imager (SXI) and disk-integrated X-ray Sensor (XRS) instruments currently flying are undergoing a sounding rocket 'underflight' calibration with the Avalanche X-ray Spectrometer (AXS) which made solar observations simultaneously with the GOES instruments. The AXS measurements provide the reference or 'solar truth' which will be compared to the response functions of the GOES instruments. We have developed a forward model that takes the AXS spectrum and accounts for each element of the SXI instrument, including the prefilter, mirror, and analysis filter. The results from this forward model have been compared to the observed SXI total intensity and a similar forward model comparison has been done for the XRS instrument. Applying these models will improve knowledge of SXI and XRS instrument response and the improved measurements will be beneficial to space weather forecasting.

An example SXI image is shown to the left. We have developed a forward model that takes the AXS spectrum and accounts for each element of the SXI instrument, including the prefilter, mirror, and analysis filter. The AXS spectrum is shown on the right at the top and the change to the spectrum with each element of the SXI instrument lower the overall signal and are displayed in the same figure. The results from this forward model have been compared to the observed SXI total intensity and a similar forward model comparison has been done for the XRS instrument. We have



An example of solar image observed by SXI telescope onboard NOAA GOES spacecraft.

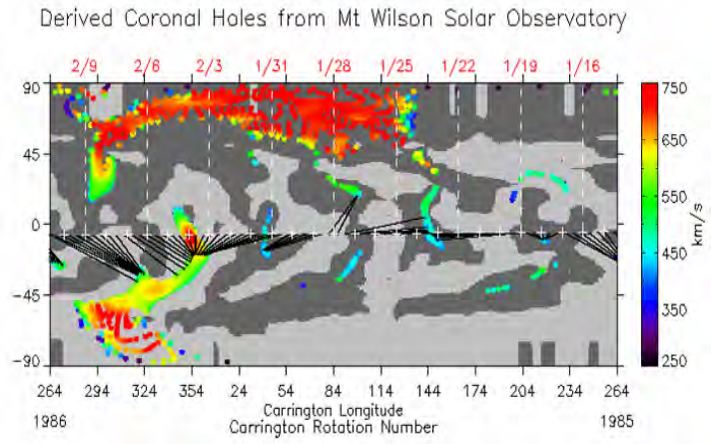
found a significant factor difference between the predicted intensity based on the AXS spectrum and the measured spectra at both XRS and SXI. We are currently working to resolve this discrepency. Once that is complete, we will look more closely at noise, contaminating signals, and secondary effects like vignetting. Along with this effort, we will parameterize our instrument models and adjust those parameters to obtain the best fit to the observations. Applying these models will improve knowledge of SXI and XRS instrument response and the improved measurements will be beneficial to space weather forecasting.

MILESTONE SEC01.2:

Global Solar Wind Predictions: Port all existing codes and web interfaces to new SEC computer system and continue production of synoptic maps and Wang-Sheeley-Arge source-surface model output. Make improvements to 3D magnetohydrodynamic propagation model and expand web page to include its flow parameter predictions.

ACCOMPLISHMENTS FOR SEC01.2:

Wang-Sheeley-Arge model has been ported to a new SEC computer. Newly formatted data output included metadata. There have been improvements in the empirical relationship for solar wind prediction. The WSA model has been included as part of CISM solar wind models. WSA has been coupled with the ENLIL MHD model.



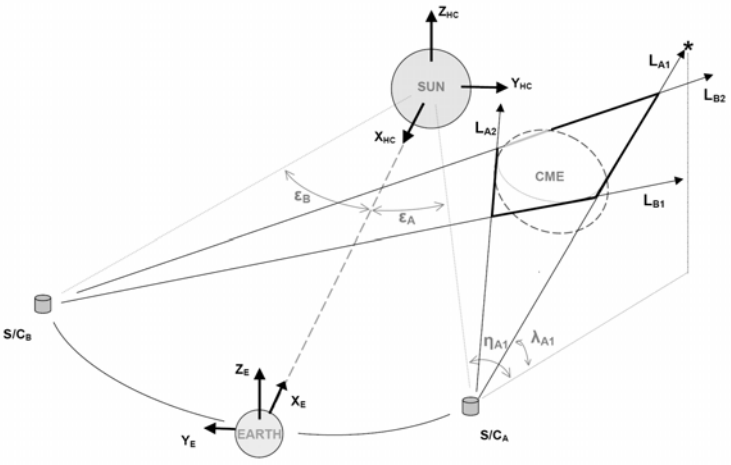
Outflow solar wind velocities from the evolving coronal holes.

MILESTONE SEC01.3:

Coronal Mass Ejection (CME) Locator: Implement for prototype operational purposes the geometric technique developed at SEC for the determination of key CME properties (location, direction, speed, shape) using multi-view coronagraph observations from the NASA STEREO mission.

ACCOMPLISHMENTS FOR SEC01.3:

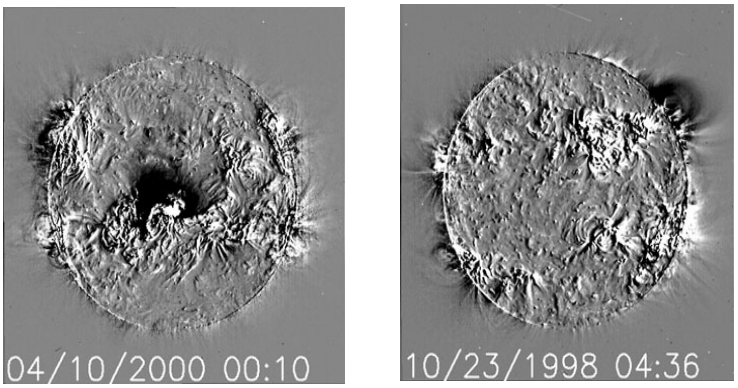
The aim of this project is to develop, test, and implement methods and forecast tools for the analysis of data from the upcoming NASA/STEREO spacecraft mission, which is presently scheduled to be launched Sept 18. The primary tools in this regard are a geometric localization technique developed by *Pizzo and Biesecker* [2004] for determining in near real time the position, shape, and speed of coronal mass ejections (CMEs) using STEREO coronagraph observations. The prototype of this tool has been written and it has undergone extensive testing using simulated data.



Schematic of the geometric triangulation technique for constraining the CME boundary.

MILESTONE SEC01.4:
EIT waves and dimmings: Compute EUV dimming intensities and explore various techniques for computing the associated mass loss to facilitate comparison to white-light CME masses.

ACCOMPLISHMENTS FOR SEC01.4:
Coronal dimmings are a phenomenon frequently associated with CMEs (coronal mass ejections). Below are shown two examples of dimming events, the left one in the center of the solar disk and the right one on the solar limb. Dimmings can vary in size, shape and intensity, with observations suggesting a relationship between the mass loss from the dimming region and the mass contained within the CME. We are conducting a statistical analysis of CME-associated dimming regions observed with the EIT (Extreme ultraviolet Imaging Telescope) on board the SOHO (Solar and Heliospheric Observatory) spacecraft. In this analysis we first determine the relative dimming of each event compared to a pre-event image and then determine the area and intensity of each dimming. We have done this for more than 100 events and now have the statistics to determine some general characteristics of dimming events. For example, we find that the average duration of a dimming event is 7.4 ± 4.0 hours. This duration can be divided into a depletion time of 2-3 hours and a recovery time of 4-5 hours. In the future, we will extend this analysis and compare dimming events and EIT waves with CME-related characteristics. The results from this study are expected to provide insight into CME origins and may help improve predictions of CME-related parameters.



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

MILESTONE SEC01.5:
Magnetospheric response: Assess the response of the magnetosphere to solar disturbances by implementing already available magnetic field models and making long-term and detailed comparisons to observed data to assess data quality.

ACCOMPLISHMENTS FOR SEC01.5:
This milestone was completed in FY2005 and accomplishments reported in the CIRES FY2005 Annual Report.

SEC02: Modeling the Upper Atmosphere

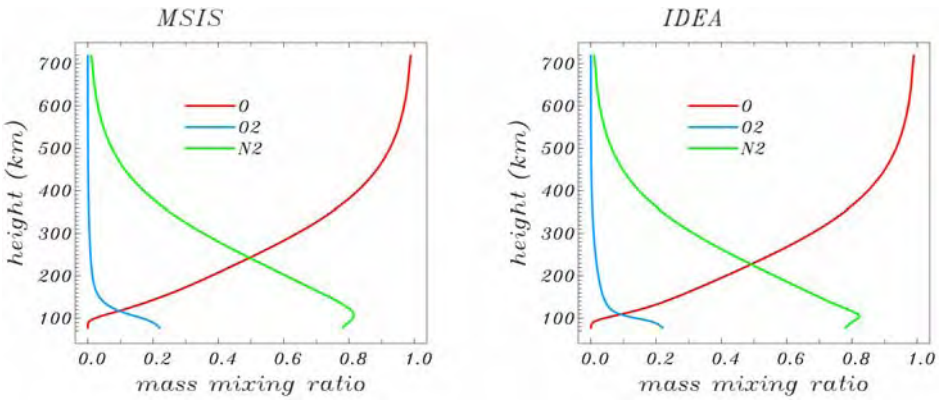
GOAL:
Understand responses of the upper atmosphere to solar, magnetospheric, and lower atmosphere forcing, and the coupling between the neighboring regions. Since many of the space weather effects occur in the ionosphere and neutral upper atmosphere it is important to develop an understanding of the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

MILESTONE SEC02.1:
Develop the infrastructure to extend the Global Forecast System (GFS) model into the middle and upper atmosphere to enable the Integrated Dynamics through Earth's Atmosphere (IDEA) to be performed. Determine the necessary additional physics modules required to characterize the dynamics and energy budget of the stratosphere, mesosphere, and thermosphere.

ACCOMPLISHMENTS FOR SEC02.1:

In collaboration with the NOAA/NCEP Environmental Modeling Center (EMC) a new vertical structure for the GFS general circulation model (GCM) has been developed and implemented on EMC supercomputers. The new IDEA-GFS model has been extended from the standard altitude of about 60 km up to over 600 km with an unprecedented vertical resolution of 150 layers.

Physical processes important in the upper atmosphere and not represented in the original GFS model have been implemented: Molecular heat conduction and viscosity and solar heating by the solar extreme ultraviolet radiation (EUV). Next, interactive major species O, O_2, and N_2 have been introduced in the thermosphere with their respective photochemical, dynamical, and diffusive processes. Particular effort has been devoted to numerical treatment of all the diffusive (viscous) processes, and especially to the mutual diffusion of the major species. As characteristic times of these processes become very short in the thermosphere, simple explicit numerical schemes can no longer provide a stable numerical solution with reasonable time steps and implicit time integration has to be employed. Because diffusive velocities of each of the major species depend on the distribution of the other species, the corresponding implicit equations have to be solved simultaneously. A special matrix tri-diagonal solver has been developed, tested, and implemented in the GFS code. The figure compares global mean distributions of the major species in the thermosphere as represented by the NRL-MSIS empirical model and simulated by the IDEA-GFS code for equinox conditions at medium solar activity ($F_{10.7}$=150).



Global mean vertical profiles of mass mixing ratios of the major thermospheric species O, O_2, and N_2 for September equinox conditions and medium solar activity ($F_{10.7}$=150) as represented by the NRL-MSIS empirical model (left) and simulated by the IDEA-GFS code (right).

Lower-atmospheric GCMs typically treat the atmosphere as a mixture of two components: dry air and water vapor, the latter being a minor species. In the upper atmosphere the composition changes dramatically, both in space and time, within the model domain (see figure) and so do such important thermodynamical parameters as the specific heat Cp and the gas "constant" R. It has been found that the standard framework to account for such changes currently adopted in the GFS code and based on using the so-called virtual temperature as a prognostic variable becomes excessively cumbersome if the number of species increases. A new general framework applicable to arbitrary number of components has been developed and transferred to the EMC for implementation within a new vertical hybrid-coordinate scheme. This will also possibly incorporate a variable gravity acceleration g, which changes appreciably (by about 15%) within the extended vertical domain but is routinely assumed constant in lower-atmospheric GCMs.

> ***MILESTONE SEC02.2:***
> Obtain the operational version of the data assimilation model Global Assimilation of Ionospheric Measurements (GAIM). Implement in a test mode utilizing available global ground-based GPS and ionosonde data, and perform a preliminary validation of differential TEC using GPS dual frequency phase data.

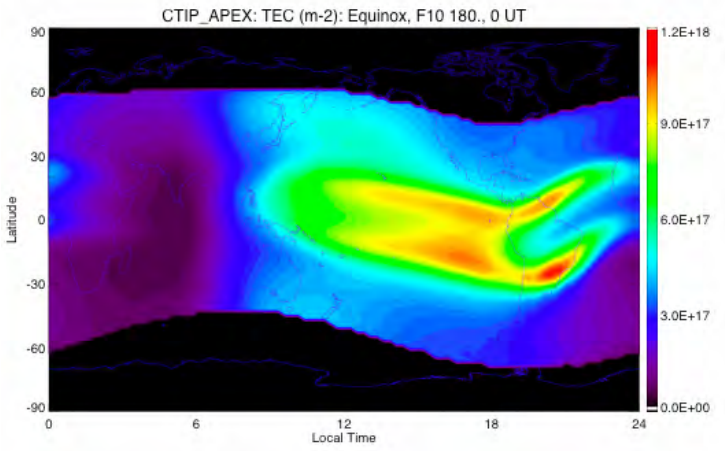
ACCOMPLISHMENTS FOR SEC02.2:

The GAIM model has only just been received from the developer, so that testing and validating could not proceed in the last year. This activity is now beginning in earnest and will be a new milestone for the coming year.

MILESTONE SEC02.3:
Develop a stand-alone ionosphere-plasmasphere-electrodynamic module suitable for coupling with neutral dynamics modules.

ACCOMPLISHMENTS FOR SEC02.3:
In collaboration with scientist George Millward at University College London a new version of the Coupled-Thermosphere-Ionosphere-Plasmasphere-electrodynamics (CTIPe) model has been developed, by incorporating a more realistic representation of the Earth's geomagnetic field. A realistic magnetic field model is essential to reproduce an accurate description of the ionospheric plasma distribution and the associated electrodynamics in the Earth's upper atmosphere.

In the previous simulations with CTIPe, the geomagnetic field was assumed to be a tilted dipole. In reality, however, the low-latitude geomagnetic field differs considerably from a tilted dipole; for example, the magnetic equator departs from the dipole equator by more than 10 degrees over the Atlantic Ocean and Africa. Previous comparisons between the model results and observations of the ionospheric parameters derived using the tilted dipole assumption tended to show significant discrepancies, especially in those longitudinal sectors. Furthermore, the ionospheric dynamo electric fields depend on the field-line integrated ionospheric conductivity (dependent on magnetic field strength) and neutral wind. Thus, the wind-driven currents and electrodynamics are likely to be compromised.



An example of the total electron content (TEC) [m-2] obtained from the new version of the CTIPe model.

Recently, we have explicitly included the International Geomagnetic Reference Field (IGRF) in CTIPe, in order to introduce a true longitude dependence of the field. The figure illustrates an example of the ionospheric total electron content (TEC) obtained in the new coordinate system. Ionospheric plasmas are distributed on either side of the magnetic equator with a clear longitude dependence. The figure illustrates the distortion of the geomagnetic field between the American and African sectors. TEC is important in the signal delay or phase advance from GPS satellites, and therefore impacts satellite navigation and positioning accuracy. The new model will also include the longitude dependence in electrodynamics, which is important for the transport of ionospheric plasma at mid and low latitudes and contributed the overall global structure depicted in the figure.

The new version of the model is undergoing extensive testing and validation, and will be used in the IDEA project (see other accomplishment) and in the coupling with the Rice University Inner Magnetosphere Convection Model (RCM).

Additional Research

Longitude Dependence of Low Latitude Vertical Plasma Drift

We have demonstrated that realistic, low latitude, daytime vertical **ExB** drift velocities can be obtained from ground-based magnetometer observations in different longitude sectors. This advance will enable the relationships between the Interplanetary Electric Field (IEF) and low latitude electric fields to be investigated.

Quiet-time, vertical **ExB** drift velocities at two different longitude sectors have been derived from magnetometer observations at Jicamarca (0.8 N. dip lat.) and Piura (6.8°N. dip lat.) in Peru, and from Davao (1.4°S. dip lat.) and Muntinlupa (6.3°N. dip lat) in the Philippine sector, for the period between January, 2001 and December, 2004. Data from geomagnetically "quiet" days were chosen, when the three-hourly Kp value was 3 or less over the entire day, and when the daily A_p value was less than 10. Over 450 quiet days were available during this time period.

These data were "binned" into three seasons, December Solstice, Equinox, and June Solstice periods. A neural network trained for the Peruvian sector was applied to each of the days in both the Peruvian and Philippine sectors providing ΔH-inferred vertical **ExB** drift velocities between 0700 and 1700 Local Time. For each season, the average drift velocity curves were compared with the Fejer-Scherliess climatological model in both the Peruvian and Philippine sectors. In the Peruvian sector, the comparisons were excellent and in the Philippine sector they were very good. The figure below displays the comparison of quiet day ΔH-inferred **ExB** drift velocities as a function of local time in the Peruvian sector for equinoctial months. The red line is the average drift velocity for the 160 days, which is in excellent agreement the Fejer-Scherliess climatological drift model shown in blue.

The analysis will enable the relationship between the interplanetary electric field (IEF) and the vertical plasma drift to be determined at any longitude sector where magnetometer data are available. It will also be possible to determine if electric field responses are similar under disturbed conditions in the different longitude sectors, and are consistent with the current ideas on promptly penetrating electric fields and magnetospheric shielding effects at low latitudes.

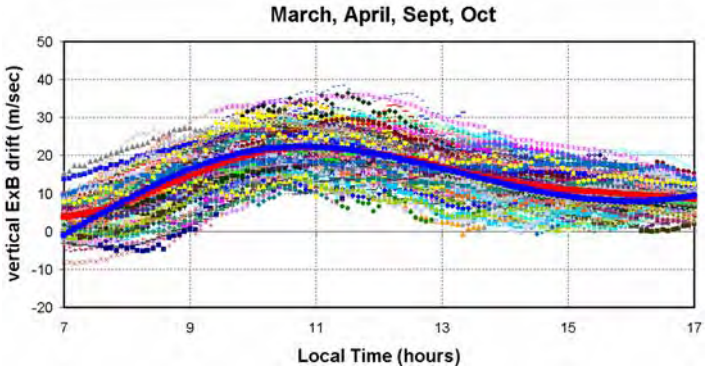


Illustration of the excellent agreement between vertical drifts derived from magnetometer data on and off the magnetic equator in the Peruvian longitude sector.

Improved data coverage for US-TEC

Significant improvements have recently been made by CIRES scientists to the Space Environment Center (SEC) operation product US-TEC. US-TEC follows the real-time evolution of the total electron content (TEC) over the contiguous United States from the base of the ionosphere, at about 80 km, up to GPS satellite altitudes. TEC affects the delay of GPS signals and is therefore important for satellite navigation systems and positioning accuracy.

US-TEC uses a Gauss-Markov Kalman filter to assimilate data from a network of dual-frequency, ground-based, GPS receivers. Recent efforts have been directed towards improved reliability, efficiency, and number and quality of the data sources. Since its implementation as an experimental product, US-TEC has been ingesting real-time data provided by the CORS (Continuously Operating Reference Stations) network, administered by the National Geodetic Survey (NGS), an office of NOAA's National Ocean Service. This has restricted the product to assimilate about 60 real-time stations available from the US Coast Guard National Differential System.

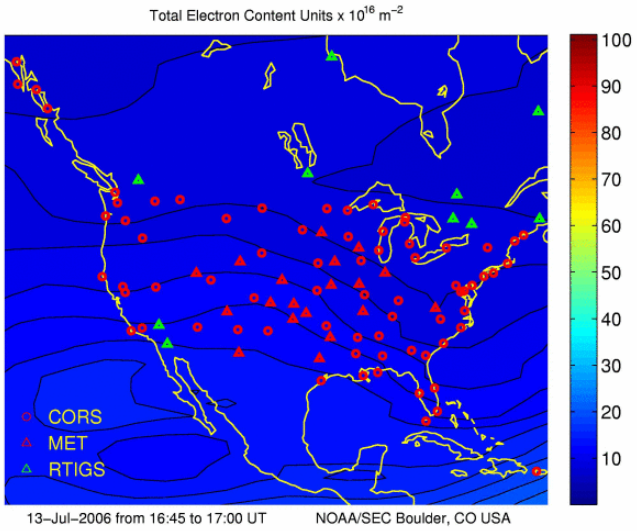


Illustration of the number of stations being ingested by the US-TEC model.

In the past year, two new datasets have been added to the US-TEC product. These include the NOAA/GSD Ground-Based GPS Meteorology (GPS-MET) sites, and the Real Time International GNSS (Global Navigation Satellite Systems) Services (RTIGS) sites in Canada. The improved data coverage for the product is shown in the figure, which shows that the number of available stations has increased from about 60 to well over 100, significantly improving the accuracy of the maps. The MET data has improved the density of stations within the CONUS itself, and the Canadian data has improved the coverage to the north.

AMOS-04: Observing Facilities, Campaigns and Networks

GMD01 (*formerly ARL01*): 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 GMD01.1:***
> Publish two papers related to the evaluation of the performance of the international suite of instruments involved in the June 2003 comparison of spectral radiometers at Table Mountain, Colorado.

ACCOMPLISHMENTS FOR GMD01.1:

One paper has been published.

> ***MILESTONE GMD01.2:***
> The Central UV Calibration Center (CUCF) is characterizing over 45 UVMFRSR's for out-of-band rejection, temperature dependence of their diffusers, as it effects the absolute calibration.

ACCOMPLISHMENTS FOR GMD01.2:

In the past few years some of the detectors in UVMFRSRs have failed at an unacceptable rate since these are deployed at remote sites. Consequently, the GaP detectors used in five channels of the 7-channel instrument were replaced with more robust Si detectors. Subsequent to that it was discovered that the longer wavelength response of the Si with the same UV filters was able to detect the long wavelength (beyond 800 nm) where the GaP detectors had no response. Calibration in the laboratory produced responsivities that were too high leading to field-measured data values that were too low. All of the UVMFRSRs were characterized for their out-of-band corrections in the past year, which should correct all of the data taken since the Si detectors were substituted for the GaP detectors.

Researchers have found that teflon changes its transmission character at about 19°C. This effect was suggested to amount to 1-2% change, which would have a significant effect on the accuracy of the data reported from our instruments that have teflon-based diffusers. Careful study in a controlled laboratory environment suggests that the magnitude of the effect on our instruments is less than about 0.3%. The effect is likely as small as we observe because the diffuser acts as a multiple scattering device, which is only slightly affected if the transmission is reduced slightly, i.e., the change in optical thickness is slight.

> ***MILESTONE GMD01.3:***
> Intercompare the CUCF's vertical and horizontal irradiance scale with the National Institute of Standards and Technology's vertical irradiance scale as part of the interagency project between the CUCF and NIST to intercompare U.S. national standards. Calibrate and characterize broadband and filter radiometers in existing UV networks.

ACCOMPLISHMENTS FOR GMD01.3:

Patrick Disterhoft presented and published a paper in Proceedings of SPIE in August 2005, Vol 5886, pgs 58860G-1-58860G-12. The paper was titled "Stability characterisitics of 100 watt FEL-type QTH lamps during the seasoning and screening process." The work addresses the important issues pertaining to the selection process of FEL lamps for use as secondary standards of irradiance. The methods that are employed by the CUCF in tracking their NIST primary standards of irradiance, transfer of the NIST vertical irradiance scale to the CUCF maintained horizontal irradiance scale and the long-term effects of lamp operation are also detailed.

The absolute spectral irradiance scale is transferred from NIST to the CUCF. The scale is the basis of all of the UV calibrations performed by the CUCF. It is therefore very important that the scale is maintained and tracked for stability. From the beginning of its use by the CUCF in 1997 there were two changes to the scale; one by the NIST and the second by the CUCF. The first scale change occurred when the NIST altered their procedure for establishing

the irradiance scale. Originally, it was produced by comparing it to a gold-point blackbody, which is a source-based scale. In 2001 the NIST changed over to a detector-based scale that uses a high accuracy cryogenic radiometer as its reference. This change resulted in lower uncertainties in the scale, but caused a shift in the level. The second change in the scale occurred when the CUCF laboratory was moved from the University's RL3 lab to the NOAA building. A bias was introduced in the alignment of the optical components of the scale transfer system. Due to extenuating circumstances that are outside the scope of this report the bias was not immediately found. After finally identifying, characterizing and correcting the bias and determining the magnitude of the NIST change, corrections factors were calculated for each period of change in the scale. All lamp calibration certificates were then corrected accordingly and all brought "up to" the same irradiance scale. The CUCF now has an accurate irradiance scale all the way back to its inception.

The National Institute for Standards and Technology produce irradiance lamps that are standards for spectral irradiance instruments that can be calibrated if they face horizontally. Most solar irradiance measurements are made pointed in the zenith and many are affected by tilting the instrument to a horizontal facing position for calibration. The CUCF has implemented a method to transfer the horizontal calibration to a vertical one to a reproducibility of less than 0.5%. The confirmation of this at the NIST laboratory in Gaithersburg, Maryland, is awaiting their cooperation in this effort.

Seventy broadband UVB and UV multi-filter rotating shadowband radiometers were calibrated in the past year at the CUCF. The biggest customer for these instruments is the USDA UV network operated out of Colorado State University's Natural Resources Ecology Laboratory. In addition the NIWA spectroradiometers operated by NOAA/GMD were calibrated using the CUCF's portable calibration system tha uses the vertical calibration capability discussed earlier.

GMD02 (*formerly ARL02*): Surface Radiation Network

GOAL:

Collect long-term research-quality up-welling and down-welling 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 GMD02.1:***
> 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 rawinsonde station.

ACCOMPLISHMENTS FOR GMD02.1:

None.

> ***MILESTONE GMD02.2:***
> Continue development of an automated aerosol optical depth retrieval algorithm for the SURFRAD network.

ACCOMPLISHMENTS FOR GMD02.2:

For SURFRAD, Langley calibration data are selected using periods identified as completely cloud free by the *Long and Ackerman* (2000) clear-sky analysis. This method was used to calibrate the MFRSR 500-nm channel in *Augustine et al.* (2003). Advances achieved since *Augustine et al.* (2003) include:

1. Interpolation of periodic Langley calibrations;
2. Expansion of the MFRSR calibration and optical depth analysis to all five aerosol channels of the MFRSR;
3. Better Rayleigh scattering corrections using the measured station pressure;
4. Automated retrieval of daily total ozone over the web;
5. Implementation of a "propagation of error" analysis to the aerosol optical depth product;
6. Application of a cloud-screening algorithm in aerosol optical depth time series.

MILESTONE GMD02.3:

Analyze the 10-year SURFRAD data record for trends in the context of the current global dimming issue.

ACCOMPLISHMENTS FOR GMD02.3:

In preparation for this analysis corrections are continuing to be applied to the SURFRAD archived data. Many of those improvements are outline in the paper referenced under milestone 2 and repeated here.

1. Downwelling infrared measurements are now shaded, which ensures a smaller dome correction term for these measurements and consequently improves the uncertainty.
2. An Eppley black & white (model 8-48) pyranometer is now used for all of the diffuse measurements. This instrument eliminates the offset error associated with the instrument in previous use, which could produce offsets of up to 30% in extreme cases for the diffuse irradiance measurement. Consequently, a scheme was developed and applied to correct the historic diffuse data.
3. A clear-sky identification algorithm has been applied to SURFRAD data that is used to predict the clear-sky irradiance as if the sky were clear for the entire day. This is then ratioed to the actual total and diffuse downwelling irradiance to assess cloud forcing.
4. The SURFRAD broadband ultraviolet B instruments are calibrated using a set of three standards that are calibrated by the CUCF. Linear interpolation of the calibration constants between calibrations was implemented in the latest revision to the UV data to remove the step transitions in the data time series and allow a better determination of trends in this parameter.

MILESTONE GMD02.4:

Improve the automated BSRN data submission procedure to include data version numbers, and the implementation of better error flagging.

ACCOMPLISHMENTS FOR GMD02.4:

Two posters were presented at the 2006 Baseline Surface Radiation Network meeting held May 29 - June 2, 2006, at the German Weather Service office in Lindenberg, Germany. This meeting is the premiere international meeting for those involved in making ground-based radiation measurements of the highest quality. The papers outlined the data record that has been submitted to the BSRN archive and the number of sites and length of their records of contributed data. One poster represented the SURFRAD data and the other the DOE/Atmospheric Radiation Measurement program data that CIRES processes for that program. Data records through February 2006 for SURFRAD and through November 2005 for ARM have been submitted to the archive in Zurich, Switzerland.

Scientific Theme: CLIMATE SYSTEM VARIABILITY

CSV-01: Detection of Climate Modes, Trends and Variability
- GMD03 (ARL03): Climate Trend Analysis
- PSD04 (CDC04): Decadal Climate and Global Change Research
- NGDC04 (same): Paleoclimatology—Understanding Decadal- to Millennial-Scale Climate Variability

CSV-02: Mechanism and Forcings of Climate Variability
- CSD03 (AL03): Chemistry, Radiative Forcing, and Climate
- PSD01 (CDC01): Modeling of Seasonal to Interannual Variability
- PSD02 (CDC02): Understanding and Predicting Subseasonal Variations and their Implications for Longer-Term Climate Variability
- GMD04 (CMDL01): Climate Forcing

CSV-03: Stratospheric Ozone Depletion
- CSD04 (AL04a): Tropospheric and Stratospheric Transport and Chemical Transformation
- GMD05 (CMDL02): Ozone Depletion

CSV-04: Climate Dynamics
- PSD06 (AL05): Climate Dynamics
- CSD06 (AL06): Turbulent Meteorological Motions
- PSD03 (CDC03): Empirical and Process Studies
- PSD15 (ETL04): Surface Processes

CSV-05: Climate Research Database Development
- NSIDC01 (same): Digitizing Analog Cryospheric Data under the Climate Database Modernization Program
- NSIDC02 (same): Observations for SEARCH–Data Integration for Arctic Reanalysis and Change Detection
- NSIDC03 (same): World Data Center for Glaciology, Boulder–Current Programs

CSV-06: Regional Climate Systems
- PSD10 (ETL03): Cloud and Aerosol Processes

CSV-07: Climate Services
- PSD05 (CDC05a): Experimental Regional Climate Services
- PSD07 (CDC05b): Experimental Climate Data and Web Services

CSV-01: Detection of Climate Modes, Trends and Variability

GMD03 (*formerly ARL03*): Climate Trend Analysis

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 on hydrological variables of relevance to society.

MILESTONE GMD03.1:

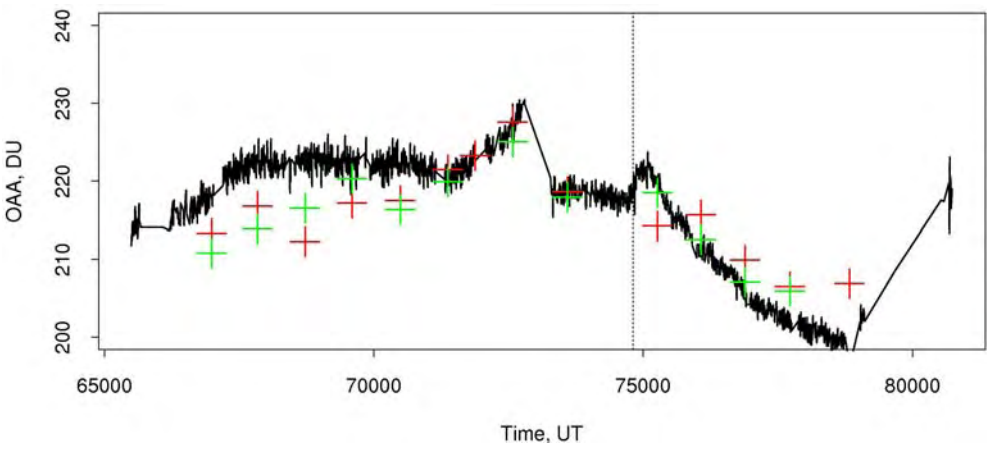
Assess newly updated ozone-profile database for trends and changes in trends and validate it against ozone products derived from remote and *in situ* measuring systems such as satellites and

ozone-sounding. Develop and evaluate total ozone and profile retrieval from traditional Dobson and Brewer radiometric measurements, as well as from photo-actinic flux hyper-spectral measurements on board of an aircraft under a variety of atmospheric conditions. Provide data to OMI/AURA satellite validation campaigns.

ACCOMPLISHMENTS FOR GMD03.1:

Researchers analyzed multiple airborne actinic flux measurements by the CCD-based Actinic Flux Spectroradiometers (CAFS) for ozone column information. This research is supporting AURA validation activities by deploying new solar radiation measurement instrumentation on the NASA WB-57 and DC-8 platforms for the determination of ozone column abundance. An algorithm to derive partial ozone columns from CAFS data was field-tested during several AVE (Aircraft Validation Experiments) campaigns carried out in years 2005 and 2006. An elaborate data set of partial ozone columns has been provided for the first-round of the Aura satellite validation including OMI (Ozone Monitoring Instrument) and MLS (Microwave Limb Sounder) integrated ozone profiles.

Collocated Aura-MLS ozone profiles have been derived for the AVE campaigns. Multiple MLS ozone profiles integrated above the aircraft altitude were compared against CAFS partial ozone columns. Results indicate that MLS and CAFS agree better than 3% (see figure below). In addition, a collocated SBUV (NOAA-16 and NOAA-17, V8 algorithm), and OMI (SBUV V8 algorithm) ozone profiles have been derived for the two last AVE campaigns (courtesy of L. Flynn and T. Beck, NOAA/NESDIS). Results indicate that SBUV and CAFS agree within 5% (bias of 5% at 12 km in AVE 2005, no bias in CR-AVE 2006), OMI/SBUV derived profiles agree within 5% (bias of 2%).



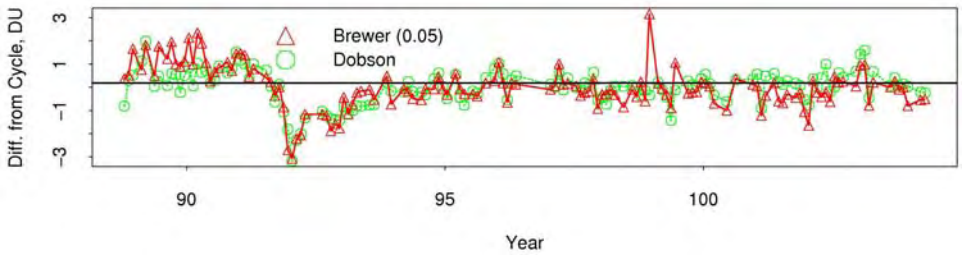
Left. Time series of the ozone column integrated above altitude of the WB-57 flight on January 22, 2006. The CAFS data are shown as black line. Vertical red (cloudy) and green (clear sky) lines mark co-incidental MLS ozone profile integrated above pressure of the aircraft.

The description of the new Umkehr ozone profile retrieval algorithm (UMK04) was published in GRL, 2005. It was found that the Umkehr technique is too noisy to monitor short-term variability in atmospheric ozone. However, UMK04 is capable of monitoring long-term changes in Monthly Mean Averages (MMA) with less then 5% uncertainty in the stratosphere, and with no influence from *a priori* information. The new algorithm performance is better than operational algorithm (UMK92) in the lower atmospheric layers (below 25 km). All existing historical Dobson Umkehr data were re-processed in 2005. The newly processed data are archived at the WMO Ozone and UV Data center in Canada (*http://www.woudc.org/data_e.html*).

Researchers continued work on validation of satellite ozone profile products, such as BUV type (Geophysical Research Letters, 2005b). The Umkehr and SBUV data were compared "side by side". Both data sets have similar vertical resolution: profiles are derived in pressure coordinates, while ground-based microwave instruments and satellite occultation instruments (SAGE, POAM etc.) measure in altitude coordinates. Satellites use operational Brewer/Dobson sensors: no extra associated costs. BUV-type satellite instruments are planned by Europe and US on operational satellites (ENVISAT and NPOESS) for at least the next 15 years. The Umkehr and SBUV comparisons show that no major discord was found in two types of independent measurements from 1979 through 2001 time period. It was found that the northern mid-latitude data comparisons did not suggest any long-term time-dependent shifts or trends in the SBUV data at the 2% per-decade level, while providing a solid source of information for satellite validation efforts, such as detection of potential NOAA-9 SBUV/2 calibration problems.

The algorithm development work for ground-based remote-sensing instruments was extended to assess the Brewer Umkehr measurements for profile information. The Dobson Umkehr algorithm was modified to accommodate optical and spectro-radiometric differences between the two instruments, such as difference in wavelength, a polarization issue, and level of measurement noise. The test of the algorithm was done on the coincident subset of Dobson and Brewer Umkehr measurements taken at the MeteoSwiss ground-based station in Arosa, Switzerland since 1998. The retrieved data were compared against Dobson (about 1500 measurements) and then a comparison was done with SBUV. The findings suggested that the Brewer retrieved more ozone in layers 4-8 and less ozone in layers 0-3 as compared to Dobson. At the same time, the Brewer mean ozone in layers 8 and 7 agrees better with SBUV.

Time series of the ozone at 40 km retrieved from co-incident Dobson and Brewer data at Arosa station. Nearly the same inter-annual ozone variability is observed by the two systems in both the lower and upper atmosphere.



PSD04 (CDC04): Decadal Climate and Global Change Research

GOAL:

i) Improve understanding of long-term climate variations through analysis of observations and hierarchies of GCM experiments. (ii) Seek dynamical explanations of oceanic variability and changes through observational analyses and GCM experiments. (iii) Provide attribution for long-term regional climate changes.

> ***MILESTONE PSD04.1:***
> Publish a study demonstrating the opposite sensitivity of the global climate response to the warming of the tropical Indian and western Pacific oceans.

ACCOMPLISHMENTS FOR PSD04.1:

The current generations of climate models are in substantial disagreement as to the projected patterns of sea surface temperatures (SSTs) in the Tropics over the next several decades. In a recently published study, we show that the spatial patterns of tropical ocean temperature trends have a strong influence on global mean temperature and precipitation and on global mean radiative forcing. We identify the SST patterns with the greatest influence on the global mean climate and find very different, and often opposing, sensitivities to SST changes in the tropical Indian and West Pacific Oceans. Our work stresses the need to reduce climate model biases in these sensitive regions, as they not only affect the regional climates of the nearby densely populated continents, but also have a disproportionately large effect on the global climate.

> ***MILESTONE PSD04.2:***
> Conduct studies assessing the global impacts of ENSO- and non-ENSO related changes of tropical sea surface temperatures over the last century.

ACCOMPLISHMENTS FOR PSD04.2:

What role have longer-term tropical SST changes unrelated to ENSO, associated with natural decadal climate variations as well as changes in natural and anthropogenic radiative forcings, played in global climate changes over the past century? In particular, what has been the role of the very "non-ENSO"-like warming trends in the Indian/West Pacific oceanic warm pool and Atlantic Ocean over the past half-century? We are planning a comprehensive investigation of such questions by determining the global responses of the NCAR and NCEP atmospheric GCMs to prescribed observed tropical SST anomaly fields, as well as their "ENSO" and "non-ENSO" parts, over the last century. To this end, we have already partitioned the observed monthly SST anomaly fields over the past 135 years into these components using a multi-pattern-based filter developed by us to isolate ENSO signals in evolving SST fields. This in itself is a significant accomplishment. We have also recently generated large

ensembles of AGCM simulations with the prescribed 50-yr tropical SST trend fields associated with the “full” "ENSO", and “non-ENSO”, SST anomalies. The analysis of these siimulations is still in progress.

> ***MILESTONE PSD04.3:***
> Publish a study of the causes of the prolonged recent 4-year drought (1998-2002) in many areas of the northern hemisphere, with emphasis on clarifying whether it was a result of a lingering La Niña event or a regional manifestation of global warming.

ACCOMPLISHMENTS FOR PSD04.3:

The four-year drought from mid-1998 through mid-2002 affecting the United States and large portions of southern Europe and Asia has been linked to remarkably persistent cold SST anomalies in the east tropical Pacific and remarkably warm SST anomalies in the west tropical Pacific during this period. Either of these anomalous SST conditions could have caused the drought; their simultaneous occurrence apparently made it much worse. The cold east Pacific SSTs were clearly associated with a lingering La Niña event, but the warm west Pacific SSTs have been argued to be “consistent with greenhouse gas forcing.”

In our just-completed study, we argue from observations and GCM simulations of the last 50 years that the four-year average precipitation anomaly pattern during 1998-2002 was mostly caused by the persistent La Niña forcing. Although the four-yr average tropical SST anomaly pattern was indeed to a first approximation a La Niña pattern plus a spatially uniform "global warming" trend pattern, and the latter made a substantial contribution to the extratropical surface temperature anomalies, it was much less important in causing the precipitation anomalies. This conclusion is further supported by the fact that after 2002, the hemispheric pattern of annual-average precipitation anomalies changed radically, but that of the surface temperature anomalies has not.

> ***MILESTONE PSD04.4:***
> Complete a comprehensive study of the sensitivity of the global climate to sea surface temperature changes in different parts of the tropical oceans.

ACCOMPLISHMENTS FOR PSD04.4:

We have performed a comprehensive sensitivity analysis of the global atmospheric response to a regular array of localized SST anomaly patches prescribed throughout the tropics in the NCAR CCM3.10 atmospheric GCM. An important result is that the GCM's global atmospheric responses to globally prescribed observed SSTs over the last 50 years is well approximated by linear combinations of the responses to our localized SST patches. Further analysis establishes the low-dimensionality of the linear operator G linking the global response to tropical SSTs. In other words, the sensitivity of the global climate to tropical SSTs can be understood in terms of a remarkably small set of "optimal" forcing/response pattern pairs. Our study is the first to clearly establish the dominance, linearity, and low-dimensionality of tropical influences upon the the global climate. Another suprising result of practical importance is the opposite sensitivity of many aspects of the global response to SSTs in the Indian and west Pacific halves of the tropical oceanic “warm pool.” This dipole sensitivity makes it critical for coupled climate models used in global change research to accurately predict the details of the projected ocean warming in this part of the world.

> ***MILESTONE PSD04.5:***
> Publish studies elucidating the mechanisms through which decadal SST variations can occur in the tropical Pacific Ocean, such as i) slow variations of coupled air-sea interactions within the tropical Pacific basin, and ii) forcing of slow equatorial upwelling fluctuations by slow variations of subtropical surface wind stresses and heat fluxes, that may themselves be partly associated with slow variations in higher latitudes.

ACCOMPLISHMENTS FOR PSD04.5:

CDC scientists are pursuing these studies in a conceptual framework in which the tropics affect the extratropics through the atmosphere, and the extratropics feed back on the tropics through oceanic subtropical cells (STCs). They have developed diagnostics to investigate these interactions in observations and models. Using these diagnostics, and also through careful GCM experiments, they demonstrated a link between the excessive simulated SPCZ precipitation in the NCAR-CCSM3 and its cold and fresh equatorial bias through the equatorial upwelling of excessively cold and fresh subducted subtropical water. They also showed that the Atlantic equatorial undercurrent is maintained mostly by subducted South Atlantic water. Two manuscripts describing these results were submitted.

In a separate study, CDC scientists used output from an NCAR OGCM forced with observed surface fluxes to better understand the causes of decadal variability in the subtropical cell (STC) and SSTs along the equator. The low frequency variability in this simulation is close to observations. They showed that this variability is primarily controlled by wind stress forcing in the tropics rather than by wind or buoyancy forcing in the subtropics. The changes in the STC vary zonally across the Pacific in association with baroclinic Rossby wave adjustment, raising questions about the conventional emphasis on examining only zonal mean STC variability.

> ***MILESTONE PSD04.6:***
> Publish a study of the causes of the prolonged North American drought during the mid-Holocene (about 6000 years ago), with emphasis on the possible role of unusual tropical Pacific Ocean conditions.

ACCOMPLISHMENTS FOR PSD04.6:
Paleoclimatic evidence suggests that during the mid-Holocene epoch (about 6000 yr ago) North America and North Africa were significantly drier and wetter, respectively, than at present. Previous modeling efforts to attribute these differences to changes in orbital parameters and greenhouse gas (GHG) levels had limited success, especially over North America. In our recently published study, the importance of a possibly cooler tropical Pacific Ocean during the epoch (akin to a permanent La Niña–like perturbation to the present climate) in causing these differences was emphasized. Systematic sets of atmospheric GCM experiments, with prescribed sea surface temperatures (SSTs) in the tropical Pacific basin and with coupling to a mixed layer ocean elsewhere, were performed. The contributions of the altered orbital forcing, GHG levels, and tropical Pacific SST conditions to the different mid-Holocene climates were quantified. Our simulated response to the total anomalous forcing was generally more consistent with the available evidence from paleovegetation and sedimentary records than previous studies. In our simulations, the small drying tendency over North America associated with the coupled response to the orbital and GHG changes was greatly amplified by the local response to La Niña–like conditions in the tropical Pacific. Consistent with the paleoclimatic evidence, the simulated North American drying was also most pronounced in the growing (spring) season.

NGDC04: Paleoclimatology—Understanding Decadal- to Millennial-Scale Climate Variability

GOAL:
Improve our 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 NGDC04.1:***
> Develop new community-driven datasets and continue to improve existing ones. A particular focus in FY06 is the continued development of the paleofire database and the historical data catalog.

ACCOMPLISHMENTS FOR NGDC04.1:
We expanded and improved the International Multiproxy Paleofire Database, and Michael Hartman received a CIRES Service Award for the development of this Internet-accessible database.

We performed extensive quality control on the tree ring data sets, using the community-developed COFECHA algorithms. We have made this quality-control information accessible via the Internet and augmented it with supplemental information that increases the usability of the data. Achieving these milestones has improved the quality of paleoclimate data distributed to scientists around the world.

> ***MILESTONE NGDC04.2:***
> Develop new systems for the archive and access of a wide spectrum of paleoclimatic data resulting in a multi-proxy paleoclimatic database system, with new systems for the sharing, visualization and analysis of gridded paleoclimatic data.

ACCOMPLISHMENTS FOR NGDC04.2:
We conducted initial tests and experiments to share paleoclimate information among computers via the Internet using XML, and the Open Architecture Iniative (OAI) Protocol for Metadata Harvesting (PMH). These protocols

will be fully implemented in 2007. The significance of this new technology is that Paleoclimatology metadata (e.g., site information such as title, author, and location) will soon be shared among different data centers and indexed by web crawlers. This will yield new ways of searching for paleoclimate information and make data easier to discover. Furthermore, it will allow NOAA to harvest information located at remote data centers, and thus offer our users new and unique combinations of information resources.

> ***MILESTONE NGDC04.3:***
> Develop new approaches for communicating paleoclimatic information to resource managers, and decision-makers. Plans for FY06 include collaborations with water resource managers and land management agencies.

ACCOMPLISHMENTS FOR NGDC04.3:

We collaborated with FRAMES, the Fire Research And Management Exchange System, to provide data on fire history and past climate to the interdisciplinary fire history community. We became the content managers for the fire history subject area of the FRAMES project. These efforts will improve assessments of the natural frequency of forest fires throughout the western United States.

We developed a new system for FRAMES, the fire history analysis and exploration system, to provide new analysis tools for fire history data. We led a diverse working group consisting of university, government, non-government, and private industry partners, in order to create new tools that could be used by a broad audience.

For the National Integrated Drought Information System (NIDIS), we chaired a committee on Information Technology, spearheaded the implementation of portal technology for NIDIS, created a portal for NIDIS development, and contributed to the planning for this important U.S. drought resource.

CSV-02: Mechanism and Forcings of Climate Variability

CSD03 (*formerly AL03*): Chemistry, Radiative Forcing, and Climate

GOAL:

(i) Observe and model the radiative forcing due to stratospheric ozone changes and tropospheric radiatively active gases. (ii) 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. (iii) Quantify the chemical and optical properties that determine the lifetimes, abundances, and trends of greenhouse gases. (iv) Use passive cloud observations to develop techniques that can be used to estimate cloud properties.

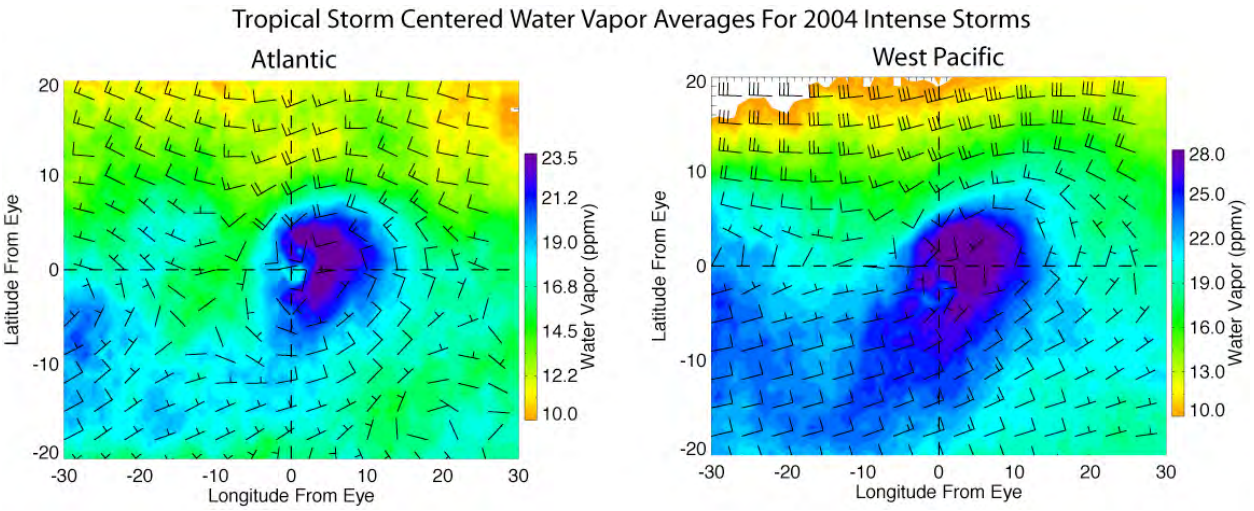
> ***MILESTONE CSD03.1***:
> Use observations of vertical profiles of key climate-related gases (water vapor, methane, and ozone) in the deep tropics from the surface to 19 km to understand the roles of chemistry, transport, and convection in maintaining the composition and radiative balance there.

ACCOMPLISHMENTS FOR CSD03.1:

The tropical upper troposphere and lower stratosphere is an important region for climate and global change. Deep convection and transport associated with intense tropical storms have a significant impact on the chemical composition of this region. Related to this topic we have done an analysis on AIRS satellite water vapor and cloud property data from the 2002-05 tropical storm seasons in the Atlantic and Pacific Ocean basins to investigate the impact of these storms on the chemical composition of the upper troposphere. We gathered tropical cyclone positions and intensities from the Joint Typhoon Warning Center and the Hurricane Research Center best track data sets for the different ocean basins. For each year and ocean basin region we compiled average water vapor and cloud properties in the upper troposphere during intense tropical storms (category 4 hurricane or larger).

AIRS water vapor mixing ratios and NCEP wind fields at the 173 hPa pressure level averaged over all the intense tropical storms in the Atlantic and western Pacific in 2004 are shown in the figure (next page). Some interesting features of these figures include the location of the peak region of elevated water vapor to the east of the eye of the

storms, the region of elevated water vapor advected to the southwest by the upper level anticyclonic flow around the storms, and the larger water vapor perturbation in the West Pacific compared to the Atlantic. Average storm centered water vapor from 2003 and 2005 have similar features to those seen in 2004 suggesting that the vigorous convection in the most intense tropical storms consistently acts to hydrate the subtropical and tropical upper troposphere.



Water vapor mixing ratios and wind fields at the 173 hPa pressure level, averaged over the 2004 intense tropical storms of the Atlantic and western Pacific.

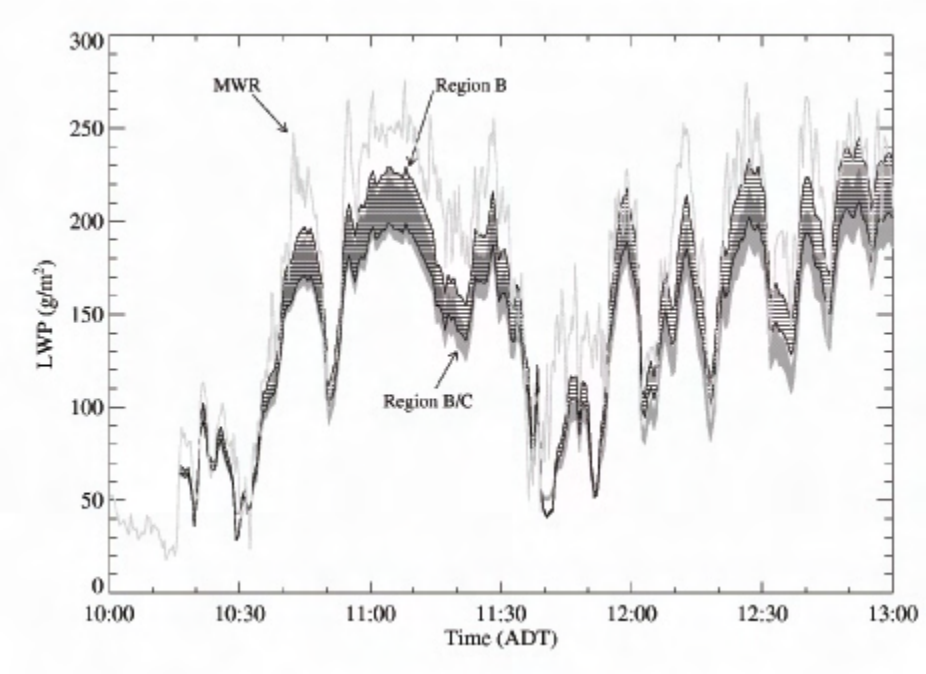
MILESTONE CSD03.2:
Evaluate field observations to improve remote observations of cloud properties and solar radiation.

ACCOMPLISHMENTS FOR CSD03.2:

The importance of clouds to the accurate modeling of our climate system has been recognized for decades. Representing clouds and cloud processes in general circulation models (GCMs) remains a significant source of the variation in estimates of the future climate impact of greenhouse gases. Furthermore, the role that aerosols play in changing the radiative properties of clouds is uncertain, with even the sign of the forcing undetermined. Several studies have been undertaken to address these information needs.

The need for remotely sensing clouds is becoming more apparent with the desire to achieve a global estimate of the radiative forcing due to changes in clouds to improve predictive climate models. A network of ground-based or satellite measurements are the most likely means for providing the high temporal and spatial resolution required to reduce some of the uncertainty that currently exists for global cloud properties. The measurement of atmospheric clouds by spectroscopic observations is an inexpensive means of assessing these properties. An intensive ground-based measurement campaign was conducted at the Aerosol and Radiation Measurement site at Barrow, Alaska, from September 12th to October 21st, 2004. Spectral measurements were made in the near-infrared wavelength region between 900 and 1700 nm, and solar radiances were measured at 500 nm and 780 nm.

Collaboration between CIRES and the NOAA CSD has led to the development of a new technique for deriving the path-integrated liquid water path (PLWP) and ice water path (PIWP), both climatically important parameters, from the spectral measurements. This method measures cloud properties very simply, using scattered light in the near-infrared. The solar radiance measurements are combined with the PLWP values to provide an estimate of the effective radius of the cloud particles and liquid water path (LWP). We have shown that both cloud liquid and cloud ice water can be measured with this new method (*Daniel et al*., in press, JGR, 2006). Auxiliary measurements conducted during the Barrow campaign with microwave and radar instruments can also be combined with these data products to obtain effective radius, leading to an improvement in remote sensing capabilities of cloud information. Thus the approach holds great promise for furthering the understanding of clouds, and cloud/aerosol interactions.



Spectrally retrieved liquid water path estimates from the new technique developed in this work, compared to estimates from the ARM microwave radiometer.

MILESTONE CSD03.3:

Evaluate the climate friendliness of hydrofluorocarbons (HFC's), substitutes for the now-banned chlorofluorocarbons (CFCs), by measuring the rate coefficient for their reaction with hydroxyl radicals and calculating its atmospheric lifetime.

ACCOMPLISHMENTS FOR CSD03.3:

Rate coefficients for reaction of the hydroxyl radical (OH) with three hydrofluorocarbons (HFCs) $CF_3CH_2CH_3$, HFC-263fb, (k_1); CF_3CHFCH_2F, HFC-245eb, (k_2); and $CHF_2CHFCHF_2$, HFC-245ea, (k_3), which are suggested as potential substitutes to chlorofluorocarbons (CFCs), were measured using Pulsed Laser Photolysis – Laser Induced Fluorescence (PLP-LIF) between 235 and 375 K. The Arrhenius expressions obtained are

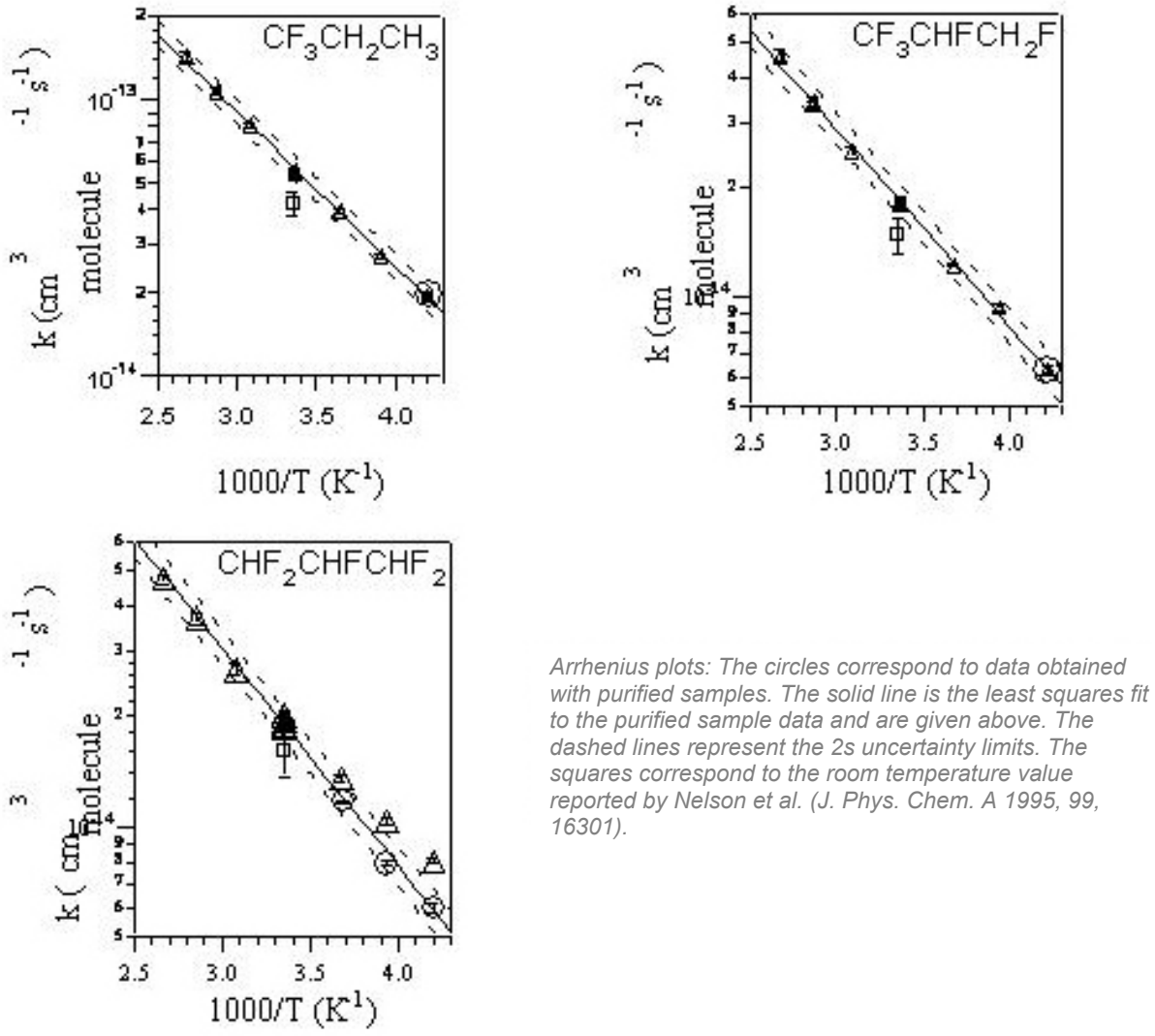
$k_1(T) = (4.36 \pm 0.72) \times 10^{-12} \exp[-(1290 \pm 40)/T]$ cm^3 molecule^{-1} s^{-1}

$k_2(T) = (1.23 \pm 0.18) \times 10^{-12} \exp[-(1250 \pm 40)/T]$ cm^3 molecule^{-1} s^{-1}

$k_3(T) = (1.91 \pm 0.42) \times 10^{-12} \exp[-(1375 \pm 100)/T]$ cm^3 molecule^{-1} s^{-1}

The quoted uncertainties are 95% confidence limits and include estimated systematic errors.

The IR absorption cross sections at room temperature for these compounds were measured over the range of 500 to 4000 cm^{-1}. The global warming potentials (GWPs) of $CF_3CH_2CH_3$(HFC-263fb) , CF_3CHFCH_2F(HFC-245eb) and $CHF_2CHFCHF_2$(HFC-245ea) were calculated to be 234, 962 and 723 for a 20-year horizon, 70, 286 and 215 for a 100-year horizon and 22, 89 and 68 for a 500-year horizon; and the atmospheric lifetimes of these compounds are 0.8, 2.5 and 2.6 years respectively. It is concluded that these compounds are acceptable substitutes for CFCs in terms of their impact on Earth's climate.



Arrhenius plots: The circles correspond to data obtained with purified samples. The solid line is the least squares fit to the purified sample data and are given above. The dashed lines represent the 2s uncertainty limits. The squares correspond to the room temperature value reported by Nelson et al. (J. Phys. Chem. A 1995, 99, 16301).

PSD01 (CDC01): 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 PSD01.1:***
> Investigate the predictability of extratropical weather statistics (also known as "storm tracks") from seasonal to decadal scales using several atmospheric general circulation models.

ACCOMPLISHMENTS FOR PSD01.1:

We continued our studies of the potentially predictable component of stormtrack variations associated with global sea surface temperature (SST) changes on interannual scales, and its magnitude relative to the unpredictable noise. The SST-forced stormtrack signal in each northern winter in 1950-2003 was estimated as the mean stormtrack anomaly in an ensemble of atmospheric general circulation model (AGCM) integrations for that winter with prescribed observed SST boundary conditions. For four particular winters, the El Niño of JFM 1987, the El Niño of JFM 1998, the La Niña of JFM 1989, and the La Niña of JFM 1999, the stormtrack signals and noise were estimated more accurately using additional large AGCM ensembles. Our principal conclusion is that a predictable SST-forced

stormtrack signal exists in many winters, but its strength and pattern can change substantially from winter to winter. The pattern correlation of the SST-forced and observed stormtrack anomalies is high enough in the Pacific-North American sector to be of practical use. In the Euro-Atlantic region, we find much lower correlations, which we argue arise from substantial AGCM error in representing the regional response to tropical SST forcing, rather than intrinsically low predictability.

MILESTONE PSD01.2:
Evaluate the impact of the most recent El Niño on short-term climate forecasts (6-10 days and Week Two) in real-time during the northern hemisphere winter.

ACCOMPLISHMENTS FOR PSD01.2:
We routinely updated and archived seasonal forecasts of North American climate at the beginning and middle of each month, using the NCAR and NCEP atmospheric GCMs with persisted SST anomalies to generate large ensembles. The forecasts were discussed in regular monthly conference calls with NOAA/CPC as part of CDC's Experimental Seasonal Forecast Guidance project.

MILESTONE PSD01.3:
Develop a prototype ensemble data assimilation system for generating daily 3-D gridded atmospheric circulation analyses for 1938-48 using only the surface pressure observations available for the period.

ACCOMPLISHMENTS FOR PSD01.3:
We completed our comprehensive investigation of the feasibility of a 100-year reanalysis of the daily near-surface and tropospheric circulation from the late 19th century to the present, arguing that a useful reanalysis of the Northern Hemisphere is possible back to 1893, and of the Southern Hemisphere back to 1930. Our peer-reviewed paper on this topic has generated great interest, and was also featured on the cover of the *Bulletin of the American Meteorological Society.*

Based on the feasibility work, we submitted a proposal to the OAR Administrator to produce a reanalysis of 1938-1948. The proposal was funded. We have since completed a pilot reanalysis for 1947 that demonstrates the capabilities of our reanalysis technique, and were invited to present it at a recent ECMWF workshop.

PSD02 (*formerly CDC02*): 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 PSD02.1:
Investigate the variability and predictability of extratropical subseasonal variations in all seasons of the year using a linear empirical-dynamical model that includes both 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.

ACCOMPLISHMENTS FOR PSD02.1:
To examine the relative influence of tropical versus stratospheric influences on extratropical tropospheric variability and predictability, we have constructed a Linear Inverse Model (LIM) using weekly averaged anomalies of Northern Hemisphere sea level pressure, mid-tropospheric and stratospheric circulation, and Tropical diabatic heating in the winters of 1968-2003. Forecast skill of an earlier version of this model, using only tropospheric circulation and heating as variables, was previously shown to be comparable at both Week 2 (Days 8 to 14) and Week 3 (Days 15 to 21) to that of a comprehensive global medium range forecast (MRF) model developed at the National Centers for Environmental Prediction (NCEP).

The updated LIM is able to reproduce the observed time-lagged covariance statistics of low-frequency variability remarkably well. In particular, the lag-covariances for lags greater than two weeks are accurately predicted just from knowledge of the 5-day lag statistics, suggesting that the dynamics of weekly averages are effectively linear. By experimenting with the linear dynamical evolution operator, we further demonstrate that persistent variability over Southern Asia, the Pacific and American sectors, and Africa is largely due to tropical forcing, whereas persistent variability over the North Atlantic and polar regions is about equally due to tropical and stratospheric forcing.

MILESTONE PSD02.2:
Develop an empirical-dynamical coupled atmosphere-ocean model of tropical subseasonal variations.

ACCOMPLISHMENTS FOR PSD02.2:
We are primarily motivated in this project by a desire to quantify the impact of air-sea coupling on the predictability of weekly-averaged SST and atmospheric circulation and diabatic heating variations in the Tropics. To this end, we have constructed a coupled empirical-dynamical linear inverse model (C-LIM) from the observed zero-lag and 7-day lag covariance statistics of weekly averaged SST, streamfunction, chi, and diabatic heating anomalies in the years 1982-2003. The C-LIM accurately reproduces the power spectra of the data, including intraseasonal and interannual spectral peaks, and similarly reproduces 0- through 90-day lag covariability of all the model variables.

The importance of air-sea coupling can be investigated in the C-LIM by deleting the relevant portions of the linear dynamical evolution operator. We find that the eigenmodes of the uncoupled operator are quite different from eigenmodes of the coupled operator on interannual timescales, but are almost unchanged on intraseasonal timescales. Thus, coupling SST to the atmosphere has a notable impact on interannual variability, but only a minor effect upon intraseasonal variability, acting to slightly lengthen propagation and persistence timescales.

GMD04 (*formerly CMDL01*): Climate Forcing

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

MILESTONE GMD04.1:
Collaborative support with NOAA, WMO, NCAR, and NIST on the Seventh (Quadrennial) International Conference on Carbon Dioxide (ICDC7).

ACCOMPLISHMENTS FOR GMD04.1:
The Seventh International Carbon Dioxide Conference was held near Boulder, Colorado during the last week of September, 2005. Through direct support and through Joint Institute personnel collaboration, CIRES was critical to the success of this conference (which was hosted for the first time in the United States). There were more than 400 participants at the conference.

MILESTONE GMD04.2:
Collaborative support with NOAA, WMO, and IAEA on the 13th WMO/IAEA Meeting of Experts on Carbon Dioxide Concentration and Related Tracer Measurement Techniques.

ACCOMPLISHMENTS FOR GMD04.2:
The 13th WMO/IAEA Meeting of Experts on Carbon Dioxide Concentration and Related Tracer Measurement Techniques was held in Boulder, Colorado on the campus of the University of Colorado during the week prior to (and in conjunction with) the Seventh International Carbon Dioxide Conference. Through direct support and through Joint Institute personnel collaboration, CIRES was critical to the success of this meeting. There were approximately 100 participants at the meeting.

MILESTONE GMD04.3:
Establish five new small-aircraft and three new tall-tower sites for the NOAA/GMD North American Carbon Observing System (Carbon America). This will bring the total number of North American aircraft and tower vertical profiling sites to 19 and 6 respectively.

ACCOMPLISHMENTS FOR GMD04.3:
Due to NOAA budget cuts for the federal fiscal year 2006, the original plans were scaled back to match funding levels. Initially, three new aircraft sites were installed, but later three older sites were temporarily discontinued due to reduced program funding (see next milestone regarding sampling frequency). Project efforts were redirected to improving existing systems and focusing on quality control efforts to be well placed for continued network expansions in the future when funding is restored.

MILESTONE GMD04.4:
Establish weekly sampling at all appropriate NOAA/GMD Carbon America aircraft vertical profile sampling sites.

ACCOMPLISHMENTS FOR GMD04.4:
Due to NOAA budget cuts for the federal fiscal year 2006, the original plans were scaled back to match funding levels. Weekly sampling was initially established and maintained for approximately three months prior to being scaled back to approximately half that frequency as a result of reduced program funding.

MILESTONE GMD04.5:
Publish a paper on the diminishing carbon uptake by the Northern Hemispheric biosphere. An analysis of NOAA/GMD CO_2 data from 1992-2003 shows that the uptake of carbon in northern mid-latitudes decreased by about 1.5 billion tons over a 12-year period.

ACCOMPLISHMENTS FOR GMD04.5:
This paper was submitted to *Science* in May 2005, and after one year in review was rejected. It will be modified and resubmitted in 2006.

MILESTONE GMD04.6:
Conduct intensive airborne trace-gas sampling above the Brazilian Amazon. This will be the most detailed airborne survey to date and the first major airborne mission in nearly 20 years.

ACCOMPLISHMENTS FOR GMD04.6:
Yet again, permission from the Congress of Brazil and the Ministry of Defense was not obtained in time to conduct this experiment. However, permission should be obtained in late summer 2006 from the MoD to conduct these flights in November, 2006.

MILESTONE GMD04.7:
Use CO_2 measurements from NOAA/CMDL surface, tower, and airborne platforms across North America to determine CO_2 fluxes at 2 × 2 degree and weekly resolution.

ACCOMPLISHMENTS FOR GMD04.7:
The new "SEAT-A", carbon data assimilation system has been operational for much of 2006, allowing for calculation of weekly carbon exchange both in North America and globally at a resolution of 6 × 4 degrees.

MILESTONE GMD04.8:
Incorporate carbon stable isotope ratio data ($\delta^{13}C$) into operational flux inversions globally and for North America.

ACCOMPLISHMENTS FOR GMD04.8:
At this point, carbon-13 modules have been developed for the "SEAT-A" carbon data assimilation system (see milestone #7). They have yet to be incorporated into the data assimilation process, however.

CSV-03: Stratospheric Ozone Depletion

CSD04 (*formerly AL04a*): Tropospheric and Stratospheric Transport and Chemical Transformation

GOAL:

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

> ***MILESTONE CSD04.1:***
> Determine the role of transport processes on all observable scales on the horizontal and vertical over the eastern Pacific Ocean in the maintenance of the water, ozone and methane distributions, using aircraft and sonde observations.

ACCOMPLISHMENTS FOR CSD04.1:

Transport and chemical transformation in the upper troposphere and stratosphere have a large impact on the radiative and photochemical balance of the atmosphere. We completed two activities related to this topic. The first was a study of *in situ* measurements of methane, ozone and water vapor near Costa Rica. We found there was a well-defined decrease in methane mixing ratio between approximately 12 and 15 km in each of the profiles, 2–5 km beneath the thermal tropopause, correlated with sharp changes in water vapor and equivalent potential temperature. The methane observations are interpreted as meaning that air is recirculated between the lower stratosphere and the upper tropical troposphere. At the point on each vertical profile where the water vapor had its minimum value, the air was never saturated or apparently supersaturated, although apparent supersaturation with respect to ice was observed in vertically extensive layers with tops some 200–300 m below the water vapor minimum on all profiles. From these measurements we conclude that the formation and evaporation of small ice particles in the lower tropical stratosphere determines the lowest water vapor mixing ratios, and that furthermore some of this air is recirculated to the upper tropical troposphere, often via midlatitudes. The stratosphere thus has a means of influencing the water vapor feedback from global warming. It can also influence the abundance of methane there, via the recirculation; this is an increasing greenhouse gas.

A second activity related to this topic was our participation in planning flights during the Winter Storms 2006 campaign based out of Honolulu, HI. This campaign produces valuable high resolution ozone measurements in the upper troposphere and lower stratosphere over the central subtropical Pacific from the Gulfstream IV aircraft. We planned flights to intersect the subtropical jetstream since distributions of ozone in this region provide a means of determining how much air has been exchanged between the stratosphere and troposphere and where and when the exchange took place. The high resolution, *in situ* measurements reveal many regions of very large ozone gradients within small spatial distances in the lower stratosphere. These large gradients result from the dynamical stirring and mixing of air across the subtropical jet stream. The implication of these gradients is that very different chemical reactions can occur between small distances in the lower stratosphere. This is important since climate models do not have the resolution necessary to resolve the smallest scales of variability and thus may not accurately reproduce chemical reactions in this region.

GMD05 (*formerly CMDL02*): Ozone Depletion

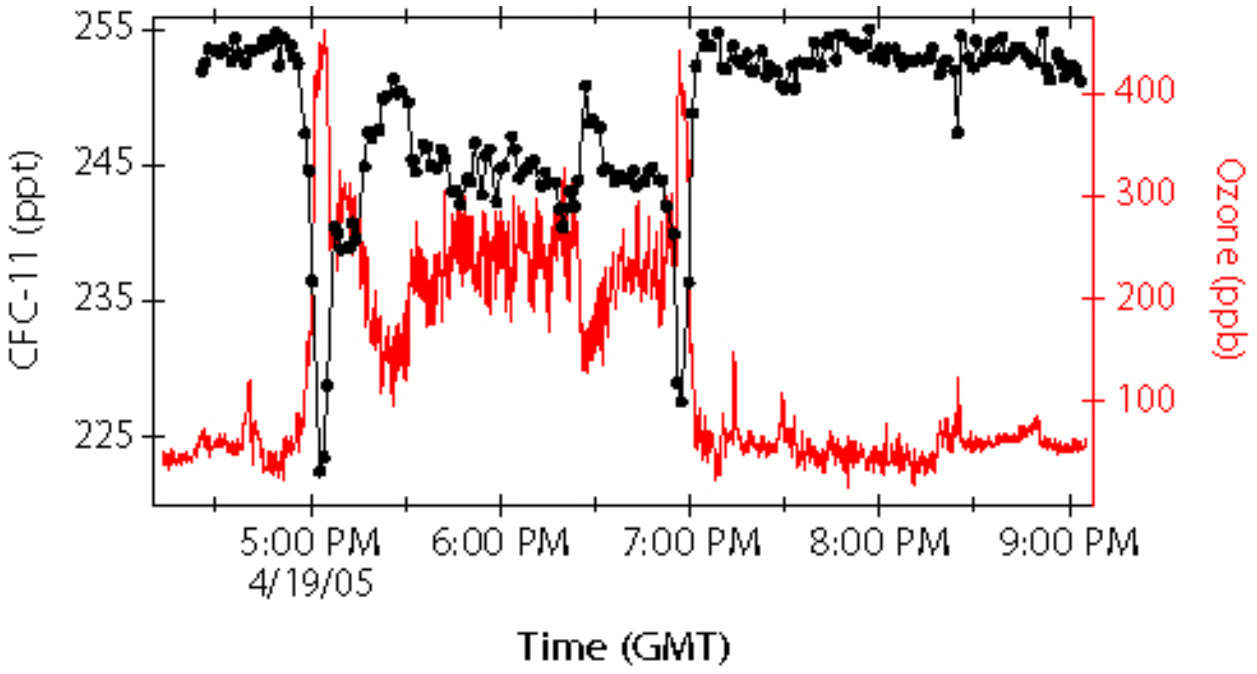
GOAL:

(i) 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. (ii) 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. (iii) Stratospheric Aerosols: Conduct experiments and measurements on aerosols to determine their impacts on solar insolation. (iv) Stratospheric Water Vapor: Conduct measurements to determine the change in water vapor and its coupling with aerosols.

MILESTONE GMD05.1:
In collaboration with NOAA scientists, measure ozone and ozone-depleting substances (ODSs) in the troposphere and lower stratosphere from an unmanned aerial vehicle (UAV). The measurements will be made *in-situ* by a two-channel gas chromatograph and ozone photometer that have already flown aboard the Altair UAV up to an altitude of 45,000 feet.

ACCOMPLISHMENTS FOR GMD05.1:
Ozone (O_3) and ozone-depleting substances (ODSs) were measured *in situ* from the Altair unmanned aerial vehicle (UAV) during the 2005 NOAA UAV Demonstration flights conducted near Palmdale, CA. The two-channel UAV Chromatograph for Atmospheric Trace Species (UCATS), built by the NOAA/ESRL Global Monitoring Division, measured ozone-depleting nitrous oxide (N_2O), chlorofluorocarbons (CFCs) -11 (CCl_3F) and -12 (CCl_2F_2), and Halon-1211 ($CBrClF_2$) every 70 seconds during flights. UCATS also measured the potent greenhouse gas sulfur hexafluoride (SF_6) at 70-s intervals. An ozone photometer (OZ) mounted within the UCATS enclosure measured O_3 and reported 10-s averaged mixing ratios. The measurements were made in the troposphere and lower stratosphere during more than 60 flight hours of Altair, including one long-duration (18.4 hr) flight in November 2005. Our objective of demonstrating the utility of a UAV as a long-duration airborne platform for *in situ* measurements of atmospheric trace gases was achieved.

The data sets generated include surveys of ODS distributions in the horizontal and vertical, between 1.5 and 14 km (5000 and 46,000 ft) altitude. Data are archived at *http://uav.noaa.gov/altair/data.html*. This page also contains a hyperlink to evidence that Altair flew through a tropopause fold above Victorville, CA on 19 April, 2005 (click on "Stratosphere-Troposphere Exchange - NOAA/ESRL/GMD and CIRES"). Data obtained by UCATS and OZ during the 19 April flight clearly show that air masses with stratospheric character were present in the free troposphere. (See figure below).



MILESTONE GMD05.2:
Publish emission estimates for Montreal Protocol-restricted ozone-depleting substances (ODSs) in the United States and Canada during 2003. These estimates are based on a geographically extensive set of *in situ* measurements of several ODSs obtained from a small jet aircraft over the USA and southern Canada.

ACCOMPLISHMENTS FOR GMD05.2:

The CO_2 Budget and Regional Airborne – North America (COBRA-NA) study, conducted in May-June 2003, produced a geographically extensive set of measurements of Montreal Protocol-restricted ozone-depleting substances (ODSs) over the United States and southern Canada. These measurements were combined with the output of a Lagrangian transport model to deduce the large-scale emissions of six restricted ODSs in the United States and Canada during 2003. The emission estimates, soon to be published in JGR-Atmospheres, reveal that combined American and Canadian emissions of CFC-11, CFC-12, CFC-113, Halon-1211 ($CHClF_2$) and methyl chloroform (CH_3CCl_3) during 2003 were globally significant, representing 7-40% of global emissions in that year. The demonstrated persistence of ODS emissions in these two countries indicates that important reservoirs (banks) of these chemicals still exist, more than seven years after their production was banned, and suggests that other developed countries may also hold globally important ODS banks. An increased persistence of future ODS emissions in developed countries would result in (1) a delay in the recovery of the Antarctic ozone hole and global stratospheric ozone, and (2) greater than anticipated radiative forcing by atmospheric halocarbons in future years.

CSV-04: Climate Dynamics

PSD06 (*formerly AL05*): Climate Dynamics

GOAL:

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

> ***MILESTONE PSD06.1:***
> Analyze the North American Monsoon Experiment (NAME) field campaign data collected by multiple Doppler radar profilers on the West coast of Mexico. Data were collected to estimate the vertical air motion and raindrop size distributions of the monsoon rain.

ACCOMPLISHMENTS FOR PSD06.1:

A summary of results was presented showing the profiler observations collected during NAME at the NASA Precipitation Measurement Missions (PMM) Science Team Meeting, December 2005 (*Williams et al.* 2005).

A general description of the profiler observations during NAME was included in a *Bulletin of the American Meteorology Society* article (*Higgins et al.* 2006).

A comparative analysis between the vertical structures of precipitation observed by the ground based profilers with the NASA TRMM Precipitation Radar was presented in a *Journal of Climate* article (*Williams et al*. 2006).

> ***MILESTONE PSD06.2:***
> Investigate the climatological structures and variability of equatorially trapped atmospheric Rossby waves and analyze their relationships to the Madden Julian Oscillation (MJO) and intraseasonal oceanic Kelvin waves.

ACCOMPLISHMENTS FOR PSD06.2:

At the Conference on Hurricanes and Tropical Meteorology April 2006 in Monterey, CA, researchers presented a summary of results showing that the interaction between the MJO and ER waves enhances the strongest westerly wind bursts and their ability to amplify Kelvin waves in the ocean.

> ***MILESTONE PSD06.3:***
> Document the daily cycle of lower-tropospheric winds along the Gulf of California and adjacent west coast of Mexico during the 2004 North American Monsoon season, and the relationship of that cycle to surface fluxes and convection in the region.

ACCOMPLISHMENTS FOR PSD06.3:

- Analysis began of daily cycle revealed by wind profiler data collected during NAME 2004 at Estacion Obispo, Los Mochis, Bahia Kino, Puerto Penasco, and aboard the R/V Altair.
- Analysis began of daily cycles of subsurface, surface, and flux quantities collected during NAME 2004 at Estacion Obispo.
- Results were presented at AMS 18th Conference on Climate Variability and Change (Atlanta, Georgia) and AMS 27th Conference on Hurricanes and Tropical Meteorology (Monterey, California); two articles have been submitted to journals; and results were included in a student intern's paper & presentation as part of the SOARS program.

CSD06 (*formerly AL06*): Turbulent Meteorological Motions

GOAL:

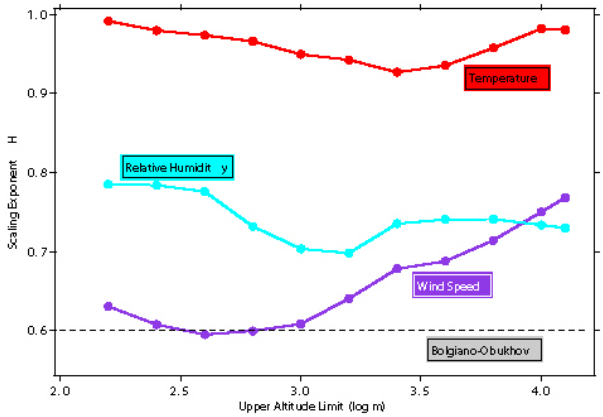
Understand the mechanisms and effects by which turbulence influences atmospheric chemistry, composition, radiation, and transport on all scales, from that of molecular diffusion to that of the globe, some nine orders of magnitude.

> ***MILESTONE CSD06.1:***
> Continue the investigation of high quality, high resolution observations to understand transport on all scales, and the fundamental definition of atmospheric temperature on all scales from molecular to global in the light of the fluctuation-dissipation theorem and the principle of maximum entropy production.

ACCOMPLISHMENTS FOR CSD06.1:

Examination of wind speed, temperature, and relative humidity data is central to understanding the structure of the atmosphere. In a bid to understand in more detail the atmosphere's vertical structure, we analyzed wind speed, temperature and relative humidity data from 261 dropsondes deployed from the NOAA Gulfstream 4 aircraft over the eastern Pacific Ocean during the Winter Storms 2004 campaign. For each of these quantities we computed the composite vertical scaling exponent H, which measures the smoothness of a scaling signal. A scaling signal is one in which the large-scale structure is replicated at smaller scales. The quantity H for such signals is in the range from 0 to 1, where 0 corresponds to a rough signal (negative neighbor-to-neighbor correlation) and 1 corresponds to a smooth signal (positive neighbor-to-neighbor correlation). Classical Bolgiano-Obukhov theory says that a vertical cross-section through the atmosphere should yield H=0.6, indicated on the figure below by the horizontal dashed line. Note that on the figure the only place where the Bolgiano-Obukhov value characterizes the vertical scaling is for wind speed with cross-sections extending no higher than about 1000 meters. Taking taller cross-sections yields increasingly higher scaling exponents for wind speed, indicating that large-scale wind speed structures (the jet streams) affect the vertical scaling to a degree not predictable by Bolgiano-Obukhov theory. We believe this is the first time such calculations have been made with high-quality dropsonde data. (Another researcher performed similar calculations over a decade ago using ascent phase wind speed data from balloon-borne instruments. That researcher also found disagreement with Bolgiano-Obukhov theory.)

As shown on the accompanying figure, Bolgiano-Obukhov theory is also not adequate to characterize the vertical scaling behavior of temperature and relative humidity. While we are still in the initial stages of interpreting the results for relative humidity, in the case of temperature we believe that the high (near one) values of H are indicative of the effect of gravity acting through the hydrostatic equation. This result is consistent with basic theoretical derivations from both microscopic and macroscopic points of view appearing in standard text books.



Scaling exponent H as a function of upper altitude limit (in log meters) of vertical cross-section; the lower altitude limit was always the surface. The dashed horizontal line indicates the Bolgiano-Obukhov theoretical value of H=0.6.

In collaboration with a colleague from McGill University we also looked at the Richardson number for the dropsonde data. The Richardson number measures the ability of a layer to sustain turbulence. By computing the Richardson number at different scales throughout the full range of dropsonde altitudes, we have concluded that there is really no such thing as a homogeneously stable layer. Within any apparently stable layer there are sublayers of instability and vice versa. Together with the scaling results, this discovery has important implications for atmospheric transport and modeling. For example, one of the main questions we aim to answer with this work is what fraction of the total energy distribution in the atmosphere is represented by microscopic fluctuations. If the fraction is substantial, then atmospheric models will have to be amended to account for it.

PSD03 (*formerly CDC03*): 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 (i) Moist atmospheric convection, (ii) Radiative transfer in cloudy areas, and (iii) Air-sea interaction.

> ***MILESTONE PSD03.1:***
> Investigate the role of various aspects of diabatic physics in the MJO, including total heating, cloud-radiative heating, latent heating in convective and stratiform precipitation, and subgrid momentum tendencies. Publish studies clarifying the influence of the MJO on South American rainfall, particularly on the timing of the tropical South American rainy season.

ACCOMPLISHMENTS FOR PSD03.1:

We have been particularly active in this area, publishing over six peer-reviewed articles in the last two years clarifying various aspects of MJO structure, dynamics, and physics from observational amd gridded reanalysis datasets. Among the new results is a clear demonstration of the distinctive top-heaviness of the diabatic heating profile during MJO episodes, the highly viscous nature of the oscillation, and a 10-15% contribution from radiative heating that is largely in phase with the latent heat release. We are also documenting the MJO-simulation capabilities of 14 IPCC AR4 models, NCEP's GFS and CFS models, and NASA/GMAO's GEOS5 model.

> ***MILESTONE PSD03.2:***
> Investigate improved methods of representing subgrid-scale variability in clouds and radiative transfer in weather and climate models, conceptually as a series of sub-columns within a GCM's large-scale column. Explore connections with more traditional single-column parameterizations as well as "super-parameterizations" being developed by other researchers.

ACCOMPLISHMENTS FOR PSD03.2:

We have been working for several years on a scheme to account for subgrid-scale variability in clouds and water vapor in the atmospheric component (AM2) of GFDL's climate model. Work to date has focused on how to predict this variability and how to compute radiation fluxes in variable cloud fields. In 2005 we began exploring how information about subgrid-scale variability might be linked to convective parameterizations. Combining the plume model at the heart of the Donner convection scheme with three-dimensional cloud-resolving model simulations of convection, we have explored the roles of variable boundary-layer and mid-tropospheric humidity in the triggering and development of convection. We are working to link this to large-scale models by, for example, providing a range of CAPE and CIN values to the convective parameterization.

PSD15 (*formerly ETL04*): Surface Processes

GOAL:

Develop and/or improve physical representations of atmosphere-surface interactions.

> ***MILESTONE PSD15.1:***
> Investigate the climatology of the snow-level in the atmosphere using profiler measurements collected along the U.S. West Coast to see if there is any correlation between recent warming in the West (measured at the surface) and the observed snow-level.

ACCOMPLISHMENTS FOR PSD15.1:
CIRES investigators have begun work on this task. The snow-level detection algorithm code was rewritten as a module in the LAP-XM radar control software. This work was part of the wind profiler CRADA with Vaisala, Inc. The new code made it easier for investigators to produce large volumes of snow-level datasets, and this has been accomplished for one long-term wind profiler measurement site in California. The next step will be to produce seasonal (winter) composites for snow level and surface temperature to look for any possible correlation between the observed snow-level and interannual climate variability.

> ***MILESTONE PSD15.2:***
> Incorporate new ice/snow scheme into MM5 and evaluate improvements in winter and summer Arctic simulations.

ACCOMPLISHMENTS FOR PSD15.2:
No progress made on this during 7/2005-6/2006.

> ***MILESTONE PSD15.3:***
> Study the spatial correlations of cloud and surface energy budget terms at past, current, and planned Arctic "supersites" to be used for monitoring Arctic climate change. Prepare ground-based turbulent flux instrumentation for later deployment.

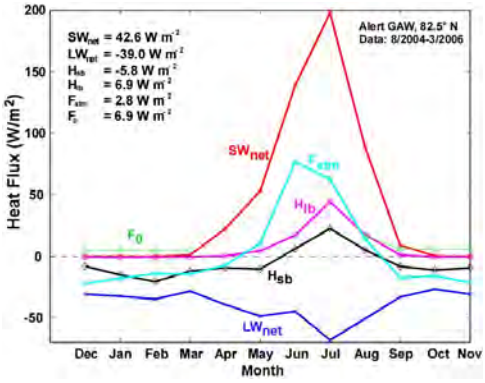
ACCOMPLISHMENTS FOR PSD15.3:
Sonic anemometer system was prepared and deployed to Alert, Canada. Parts for surface energy flux system were acquired and are being tested, to be deployed later to Eureka, Canada. Preliminary analysis has been done on surface energy budget at Alert using data collected since 2004. This analysis shows the importance of topographically forced mesoscale processes in affecting surface energy budget. Results of analysis were presented at two NOAA venues in Boulder and at an international scientific conference. Three proposals were written to use SEARCH data in Arctic analyses and to supplement the SEARCH observations during the International Polar Year.

In order to obtain a complete surface energy heat budget, and hence understand what is causing the near-surface environmental changes at the long-term SEARCH observatory sites, the entire surface energy budget must be measured. Therefore, the turbulent sensible and latent heat fluxes must be obtained in addition to the broadband incoming and outgoing radiative fluxes. While radiative fluxes are measured at many Arctic sites, turbulent heat fluxes are generally not directly measured but can be estimated using bulk algorithms. Unfortunately, these bulk algorithms have been determined for conditions typical of the midlatitudes and assume the validity of Monin-Obukhov Similarity Theory. The presence of frequent gravity waves at these Arctic sites would invalidate the use of these algorithms. Direct covariance measurements of turbulent heat fluxes are needed at the Arctic sites in order to obtain measurements of the complete surface energy budget and to validate and improve the bulk algorithms for Arctic conditions.

A heated sonic anemometer system to measure the turbulent heat and momentum fluxes through the covariance technique was designed by CIRES/NOAA/ESRL in collaboration with Atmospheric Technology Incorporated (ATI) of Longmont, CO, to supplement the radiation measurements being made at Alert, Nunavut. The system was designed and tested in Boulder, Colorado, during the late fall of 2005, and installed at Alert in February 2006. The removal of rime ice from the instrument is necessary in the Arctic conditions, and the heating of the transducer arms is a unique feature being tested.

Preliminary analysis of the surface energy budget was done on the Alert SEARCH data collected between August, 2004, and March 2006. The radiative energy fluxes were measured by instruments installed by NOAA/ESRL/ GMDL. The turbulent surface heat fluxes were estimated using bulk flux algorithms previously used over the Arctic pack ice. The analysis showed that mesoscale processes associated with local topography and the nearby coastline contributed significantly to the variability of individual surface energy terms and of the net surface energy flux. Hence, in future climate change scenarios, the response of the net surface energy budget, and hence the local climate at this site, will depend on the response of the mesoscale processes to the larger-scale climate forcing. This response may be such that the local climate may change in a totally different manner from the larger-scale climate changes. In addition, the surface energy budget analysis at Alert showed that the annual variability at the SEARCH terrestrial sites of all of the terms is significantly greater than the variability of the terms over the pack ice (see figure next page). Hence,

understanding surface energy budgets and climate change over the pack ice cannot easily be done using the data from the SEARCH terrestrial sites.



Monthly means of the surface energy budget terms for Alert (left) (coastal site) and SHEBA (right) (pack ice site). The annual mean of the various terms are given to the upper left in each frame.

Presentations of the analysis at the Alert site were made at the European Geophysical Union Symposium in Vienna, Austria, and at the Global Monitoring Annual Review. Some of the Alert analysis and a description of the efforts to instrument the SEARCH long-term observatories were presented at the NOAA/ESRL/Physical Sciences Division Science Day. A NOAA Hollings Scholar under the direction of Dr. Ola Persson helped analyze the data during the summer of 2006. Another Hollings scholar helped develop the surface energy budget system to be installed at Eureka during 2007.

CSV-05: Climate Research Database Development

NSIDC01: 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 NSIDC01.1:***
> Add an additional 100 to 500 (depending on availability) photos to the glacier database. Complete scanning of the Dehn charts, and develop an on-line interface to them.

ACCOMPLISHMENTS FOR NSIDC01.1:
Approximately 1000 photos were added to the database, including the Glacier Pairs Special Collection, a series of photos showing glaciers "now" and "then." These have been extremely popular, and were featured in the New York Times among other press outlets. Scanning of the Dehn charts was completed and an on-line interface developed.

Muir Glacier, Alaska, photographed by William O. Field on 13 August 1941 (left) and by Bruce F. Molnia on 31 August 2004 (right)

NSIDC02: 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 (ASR). Note that this work is funded through Task III, rather than Task II.

> ***MILESTONE NSIDC02.1:***
> In this year, our focus will be on completing the arctic change "indicator" algorithms, data streams, and Web pages. We will complete Onset of Melt indicator algorithm validation, and corresponding Web pages.

ACCOMPLISHMENTS FOR NSIDC02.1:

Following the example of the Sea Ice Index, "indicator" pages were developed for other cryospheric products. Ideally, climate indicators are long records that are kept up to date. They combine characteristics of climate data records, from which trends can be derived, and operational products. This combination is difficult to achieve. The team at NSIDC hopes to continue working on the Cryospheric Indicators until this ideal is realized. The best indicator products take little effort to understand. Graphics from the Sea Ice Index have been very successful, appearing in numerous reports, presentations, news articles, and at least one book (*Field Notes from a Catastrophe*, by E. Kolbert).

Another aspect of this milestone is the Reanalysis effort. This involves evaluating the Arctic performance of existing atmospheric reanalyses and identifying potential model improvements that bear on development of a dedicated Arctic System Reanalysis (ASR). The two existing reanalyses are the NCEP/NCAR effort (National Centers for Environmental Prediction/National Center for Atmospheric Research) and the ERA-40 reanalysis of the European Center for Medium Range Weather Forecasts.

Forecasts of Arctic precipitation in ERA-40 are of considerably higher quality compared to those from NCEP/NCAR. Squared correlations between monthly time series of observed and forecast precipitation over the major Arctic watersheds typically range from 0.60 to 0.90. After applying appropriate mass corrections, vertically-integrated horizontal atmospheric energy fluxes into the Arctic from ERA-40 appear to be very realistic, and compare favorably with those from the NCEP/NCAR reanalysis. The largest discrepancies are with respect to the meridional flux of potential energy, which in ERA-40 shows a downward trend over the last five years of the record. This may relate to problems in the assimilation of ATOVS satellite data. Even with mass corrections to the horizontal fluxes, the atmospheric energy budget in ERA-40 over the Arctic is not well closed. Ongoing analyses point especially to problems with the top of atmosphere radiation budget related to modeled cloud radiative properties, although terms of the surface energy budget are likely also involved.

The ASR will likely make use of the NoaH land surface model. Excessive snow evaporation was diagnosed and a solution proposed to the original model developers. The problem involved (1) excessive turbulent transfer under stable atmospheric conditions (2) a violation of the assumptions in the Penman evaporation approximation under cases of negative available energy.

NSIDC03: World Data Center for Glaciology, Boulder–Current Programs

GOAL:

Improve our 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 NSIDC03.1:

Maintain and update and existing research data sets (e.g. Former Soviet Union Hydrological Snow Surveys; The World Glacier Inventory). Publish new data sets such as the Dehn ice chart collection. Improve access to existing data sets, such snow model output archived for NWS NOHRSC.

ACCOMPLISHMENTS FOR NSIDC03.1:

Numerous data sets were published or updated in June 2005-July 2006. The most significant are:

Timing and Statistics of Autumn and Spring Annual Snow Cover for the Northern Hemisphere
http://nsidc.org/data/g02168.html.
Based on a NOAA snow cover product, this data set includes the timing of snow cover onset in the fall, the timing of last observed snow cover in the spring and the snow-free duration from 1972 to 2000.

The Dehn Collection of Arctic Sea Ice Charts, 1953-1986
http://nsidc.org/data/g01111.html
Many charts predate satellite observations and the regular ice charting activities of the U.S. National Ice Center, and are believed to contain information on location and extent of sea ice cover that is not available elsewhere.

AWI Moored ULS Data, Greenland Sea and Fram Strait, 1991-2002
http://nsidc.org/data/g02139.html
Upward Looking Sonar (ULS) data from 11 moorings provide ice draft, water pressure, and water temperature. These data were contributed to NSIDC by the Alfred Wegener Institute for Polar and Marine Research, Bremerhaven, Germany, in 2002 and 2004, as a contribution to the World Climate Research Programme's Arctic Climate System Study/Climate and Cryosphere (ACSYS/CliC) Project.

IMS Daily Northern Hemisphere Snow and Ice Analysis at 4 KM and 24 KM Resolution
http://nsidc.org/data/g02156.html
In cooperation with NOAA's OSDPD, NSIDC archives and distributes IMS products and image browse files. Manual analysis of satellite imagery produces the most accurate snow cover products available on a hemisphere wide scale.

Snow Data Assimilation System (SNODAS) Data Products at NSIDC
http://nsidc.org/data/g02158.html
In cooperation with the NOAA National Weather Service (NWS) National Operational Hydrologic Remote Sensing Center (NOHRSC), NSIDC is providing archive, access and user support for eight selected snow cover fields. This product is unique in terms of its utility for hydrological modeling.

MILESTONE NSIDC03.2:

Make research information available through the NSIDC Information Center, acquire and catalog cryospheric materials in the NSIDC library, and maintain NSIDC's analog data sets.

ACCOMPLISHMENTS FOR NSIDC03.2:

The NSIDC WDC for Glaciology, Boulder, Information Center librarians continue to maintain and add to a high quality collection of cryospheric reference material, as well as improving the stability of the analog collection, as resources allow. The NOAA Climate Database Modernization Program has provided funds for scanning some analog material by a contractor at an off site location.

CSV-06: Regional Climate Systems

PSD10 (*formerly ETL03*): 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 PSD10.1:***
> Participate in Stratus VAMOS Ocean Cloud Atmospheric Land Study (VOCALS) research cruises and deploy cloud radar, radiometer, and flux systems to measure key surface marine boundary layer parameters, low cloud macrophysical, microphysical, and radiative properties.

ACCOMPLISHMENTS FOR PSD10.1:
The systems were deployed on the NOAA Ship *Ronald H. Brown* for three weeks in October 2005. All systems obtained data on the cruise. Data products are available at the PSD FTP site for this project *ftp://ftp.etl.noaa.gov/et6/archive/STRATUS_2005*.

> ***MILESTONE PSD10.2:***
> Examine vertical transport of aerosol and trace gases by clouds, a process commonly known as "cloud venting."

ACCOMPLISHMENTS FOR PSD10.2:
Cloud venting is the process of transporting gases and aerosol particles vertically in the atmosphere, from the boundary layer to the free troposphere, through convective and frontal systems. Because cloud venting can affect ozone production as well as the radiative balance of the atmosphere, it has potential significance in climate processes and is a factor that is considered in climate models.

This CIRES research involved an extensive survey on what has been done on "convective pumping" or vertical transport of aerosol by clouds. Several programming applications were developed to visualize and analyze the large eddy simulations model output data.

Time-height cross sections and 10-min vertical profiles of updraft and downdraft cloud and aerosol mass fluxes were obtained for the mixed and "cloudy" regions, defined by a threshold in the liquid water amount. Preliminary results received on a 1-hour dataset will help to improve analysis of larger datasets for better understanding of the transport from the boundary layer to the free atmosphere and the possibility of cloud venting parameterization. Ultimately, work on this topic will help global modelers develop and refine cloud transport parameterization schemes.

CSV-07: Climate Services

PSD05 (CDC05a): 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 on hydrological variables of relevance to society.

> ***MILESTONE PSD05.1:***
> Monitor daily, seasonal, and longer-term precipitation variability over the western U.S. Explore ways to reclassify U.S. climate divisions based on coherent regional precipitation variability. Downscale NCEP Week Two ensemble forecasts for Colorado water resource managers. Continue developing seasonal forecast guidance tools for the U.S. based on the predictability of

tropical SSTs several seasons in advance, training these tools on the atmospheric responses to different types of anomalous tropical SSTs in large new sets of seasonal integrations made with the NCAR, GFDL, and NCEP GCMs.

ACCOMPLISHMENTS FOR PSD05.1:

A website has been created presenting an experimental reclassification of US Climate Divisions based on coherent regional precipitation variability (*http://www.cdc.noaa.gov/people/klaus.wolter/ClimateDivisions/*).

The experimental climate divisions were computed based on the following statistical approach: Multivariate cluster analyses were performed based on the seasonal correlation matrices among all U.S. stations. Rotated Principal Component Analysis (RPCA) was tried as well, but performed poorly on the national scale. The two cluster analysis techniques applied here were (1) "Average Linkage," and (2) "Ward's" method. Both techniques are well established, and superior to other clustering methods, such as "Complete" or "Single" linkage approaches. Results from both clustering methods were compared against each other, and used to create "core clusters" from the intersection of both analyses. Out of a possible 4370 stations with good temperature and precipitation data, the first core map classified 3310 stations as being within these most robust clusters. Core time series were computed based on normalized temperature and precipitation time series at the station level. These were used to compute the correlation coefficients between all 4370 stations and all 120 cores. If a station was not classified inside a core region, but correlated highly with a core in the region, it was allowed to be inserted into that core region. On the other hand, if a station had been classified as being inside a core region, but did not correlate highly with the core time series, it was eliminated from same core. A third scenario involved the swap of stations from one core to another, as long as its correlation with the new core was substantially higher than with the old core. In this iterative fashion, more and more of the remaining stations were gathered into the core regions, resulting in a total tally of 4139, or more than 95%. For comparison, the station total for precipitation-only cores was 7352 out of 7660, or 96%.

The other activities listed in the milestone were completed prior to Oct 1, 2005:

- Monitoring precip *http://www.cdc.noaa.gov/Drought/*
- Week 2 ensemble forecasts *http://www.cdc.noaa.gov/reforecast/narr/*
- Seasonal forecast tools for the US *http://www.cdc.noaa.gov/seasonalfcsts/1tier.html*

MILESTONE PSD05.2:

Conduct studies of recent climate change in the hydroclimatology of the western U.S., partly resulting from changes in tropical teleconnections, with emphasis on changes in streamflow and watershed health.

ACCOMPLISHMENTS FOR PSD05.2:

In an article appearing in the March 2005 issue of the *Journal of Climate*, Climate Diagnostics Center (CDC) researchers Shaleen Jain and Marty Hoerling have shown an increase in the synchronization of streamflows in four western North America river basins. The article, entitled "Decreasing Reliability and Increasing Synchroneity of Western North American Streamflow," demonstrates the resulting expanded stress placed on regional water resources. Climatic variations and change have affected the annual snowpack—and water source—of the Fraser, Columbia, Sacramento-San Joaquin, and Upper Colorado river basins. If these river basins experience in unison extreme high or low flow during the same year, adequate drought relief or flood mitigation may not be available. Water managers have relied on historical streamflow data for critical decisions such as ensuring sufficient water supplies and flood control. Because of these potentially long-term changes, the article calls into question the reliability of historical statistics for present and future flow management.

We discovered an emerging late-twentieth-century trend toward increasing year-to-year variance of streamflow in all four major river basins in western North America - Fraser, Columbia, Sacramento-San Joaquin, and Upper Colorado. A concurrent disproportionate increase in the incidence of synchronous flows (simultaneous high or low flows across all four river basins) has resulted in expansive water resources stress. The observed trends have analogs in wintertime atmospheric circulation regimes and ocean temperatures, raising new questions on the detection, attribution, and projection of regional hydrologic change induced by climate. This work was presented at several venues and also published in a peer-reviewed journal.

MILESTONE PSD05.3:

Continue research into assessments of climate impacts and programmatic development of climate, weather, and water services. Publish a study illustrating the use of uncertain tropical ENSO forecasts in reservoir management in the U.S. Take a lead in preparing the U.N. Millennium Ecosystem Assessment chapter on Extremes and Natural Hazards, and the IPCC Working Group II (Adaptation and Vulnerability) chapter on Assessing Adaptation Practices in response to global change.

ACCOMPLISHMENTS FOR PSD05.3:

***Frequency, Timeliness, and Density of Key Observations*:**

This report is an assessment to date of State Drought Task Forces, Regional Climate Centers, and RISA activities providing other task forces (e.g. Municipal Water, Wildfire Protection, Agriculture, Economic Impact, Tourism, Wildlife) with the drought forecasts and climatic conditions garnered from a combination of federal, local and state agencies. Information needs include projections of the following variables and indices at both small-watershed and large-basin scales for reservoir management: snowpack, soil moisture, streamflow reservoir levels, ground water levels, precipitation timing, surface Water Supply Index, Standardized Pressure Index and the Palmer Indexes.

The mechanisms for responding to drought usually entail (1) efficiency requirements and mandatory cutbacks, (2) supplementing surface with ground water, (3) increasing interbasin withdrawals, and (4) increasing storage facilities. Interbasin relations form part of an exceedingly complex legal and political environment.

Government agencies have developed and deployed a variety of observing networks over the past several decades to meet agency missions and measure drought-related parameters. Among their many uses, the data provided via these networks are useful in retrospective analysis of drought. However, many stations do not have near real-time reporting capabilities, and as such, the reporting frequency and timeliness for a large number of stations are not sufficient to support county-level and weekly drought monitoring and forecasting requirements in the 21st century. In addition, the density of some observing networks, most notably soil moisture, is inadequate for drought monitoring purposes.

Deficiencies created by these legacy systems include (but are not limited to):

- Ground water data are reported as infrequently as once every six weeks.
- Daily precipitation and temperature data are reported only at the end of each month.
- Reservoir water levels are made available only once per month.
- Soil moisture data are routinely available but from a sparse national network.

A highly visible example of the kind of problems this leads to can be illustrated in a critical application of the NOAA U.S. Cooperative Observer Network (COOP) temperature and precipitation data. The vast majority of observations from this network are available from NOAA only after a 45-day delay because the data are forwarded from observers to NOAA for processing once a month via the U.S. Mail. This makes their use impractical for operational drought response.

- There are a number of early opportunities that can make an important difference in our ability to mitigate and anticipate drought severity across the United States. The activities we have identified are all dependent on a substantial infrastructure of observing, data management and analysis systems already put in place by the USGEO agencies.

The report (to be completed in October 2006) will also describe the requested information formats and knowledge transfer mechanisms needed in support of the National Integrated Drought Information System (jointly with RISA Programs especially the Southwestern Climate Assessment). These include:

- Development of a “Drought Portal” “one-stop shopping” for drought information:
- Consistent formats, terms, and scales of information, compatible with the standards of the reservoir management community

Types of Information Needed – Including Tools, Products, Decision Support

- Key drought indices, drought threshold levels, drought triggers.
- Paleoclimate and modeled data. Modeled output or reconstructed values are often as important as historical data for driving water management models (risk *scenarios*).
- Multiyear drought (and climate) forecasts including drought retreat

- Climate forecasts are needed for conjunctive use water-resource management anywhere from 6 months to a year in advance for *operational decisions*, to a decade or more in advance for *policy and capital improvement projects*.
- Additional and alternative data: soil moisture data, groundwater data, derived variables (e.g., precipitation frequency), monsoon onset and demise, better estimates of high elevation snow and precipitation, information on forecast skill (in general) and forecast verification (for individual forecasts).
- Climate history is as valuable as forecasts in many situations. Past climate data serve as a basis for *scenario development, including regional comparisons:* historical climate differences between western vs eastern sides of the Rockies? How does this drought compare with previous droughts?
- Downscaled climate information. Many products are not readily available at spatial and temporal scales useful to decision makers.
- More *detailed* monitoring, and better assimilation of what information (see above) is available. This includes needs for *rapid assessment* of the entire suite of water supply variables including methods of addressing the fundamental spatial scale of the topography that controls snow and precipitation, at approximately 0.5 to 1 kilometer.

Our emphasis on "adaptive management" in climate services draws on a large body of work showing that long-term environmental problems are seldom dealt with effectively by a rigid set of "one-way" actions or policies but respond better to continued learning and steady public attention and visibility. We are pursuing this approach in the context of climatic and other uncertainties, but grounding the discussion in the implementation of actual adaptive management programs. To us, adaptive management has three key tenets (1) Policies are experiments that should be designed to produce usable lessons; (2) It should operate on scales compatible with natural processes, recognizing social and economic viability within functioning ecosystems; and (3) Is realized through effective partnerships among private, local, state, tribal and federal interests. In a watershed setting, this can mean balancing hydropower production, habitat management, conservation, endangered species recovery, and cultural resources in order to experiment, learn, and adapt. In a recent study, we focused on the experience of the Columbia and Colorado River Basins. One goal was to identify the strengths and weaknesses of an adaptive management approach in a changing climate. Our approach was based on the premise that understanding how effectively society might identify common goals, best use climate and other information, and prepare for the consequences of future variations and surprises, requires identification and evaluation of present systematic efforts (i.e. field-tested alternatives) to experiment, characterize uncertainties, make decisions, and cope with environmental variability across temporal and spatial scales. We also illustrated how an evolutionary or learning-based approach to "assessment" enters into regional and local activities in support of the U.S. Climate Change Science Program and the IPCC. This work was presented at several venues.

We completed a separate study illustrating the use of uncertain ENSO forecasts in reservoir management. The water management sector is often thought of as a primary beneficiary of improved climate forecasts. Given the probabilistic nature of climate forecasts, however, the potential impacts of uncertain climate information on reservoir decisions are unclear. In this study, we developed a conceptual statistical framework to understand the conditional forecast distribution of runoff volume based on a climate forecast. Two contributing factors were examined: (1) the correlation between the climate precursor (such as an ENSO event) and the target variable (here, runoff volume), and (2) the uncertainty in predicting the climate precursor itself, measured by the forecast distribution variance, which can be strongly case-dependent. The potential impacts of using forecast types (long-term mean or climatology, climate information with no uncertainty, and climate information with uncertainty) on the runoff volume distribution were quantified for a simple one-reservoir system. We illustrated how knowledge of the forecast uncertainty in runoff volumes, together with reservoir operation constraints, can enable an *a priori* identification of cases when a probabilistic forecast is likely to be most or least useful for a particular reservoir system. This work was presented at several conferences. A journal article is in preparation.

PSD07 (*formerly CDC05b*): 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 PSD07.1:

Continue updating the extensive publicly accessible climate data holdings on the CIRES/CDC website. Develop and install on local platforms netCDF versions of the ECMWF ERA-40 and other reanalysis datasets of the global and North American atmospheric circulation. Acquire new precipitation and soil moisture datasets.

ACCOMPLISHMENTS FOR PSD07.1:

CDC continued serving as a primary redistribution point for the NCEP Reanalysis data set, providing netCDF versions of the reanalysis fields via the web or via tape (for larger requests) to users throughout the world. CDC is a core NOAA partner, with NCEP, NCDC, GFDL, and PMEL, in the NOAA Operational Model Archive and Distribution System (NOMADS) being developed to provide seamless access to geographically distributed climate model outputs.

CDC continued updating and improving the recently re-named International Comprehensive Ocean-Atmosphere Data Set (I-COADS) under a cooperative project with NCAR and NOAA/NCDC. The new name recognizes the multinational input to the database while maintaining continuity of identity with COADS, which has been widely used. The recently released ICOADS-2.1 version of the dataset is the largest available set of *in situ* marine observations taken over the period 1784-2002. The ship observations include instrument measurements and visual estimates, whereas data from moored and drifting buoys are exclusively instrumental. The collection integrates data from many diverse sources that are inhomogeneous due to changes in observing systems and recording practices throughout the observing period of over two centuries. It is expected to be a key reference dataset for documenting long-term environmental changes, providing input to a variety of critical climate and other research applications, and as a basis for many derived products and analyses.

CDC has created a NetCDF version of pressure-level gridded data in the North American Regional Reanalysis (NARR) dataset that conforms to the CF metadata standard. CDC has also configured and deployed Live Access Server (LAS) software from NOAA's PMEL group in Seattle. The server, called ICOADS-LAS, serves the ICOADS data set via a graphical user interface.

MILESTONE PSD07.2:

Continue developing the CIRES/NOAA website dedicated to real-time predictions of tropical convection variations associated with the MJO and their remote impacts. Display various experimental and operational ensemble predictions in a uniform format to enable intercomparisons and skill evaluation.

ACCOMPLISHMENTS FOR PSD07.2:

Improved tropical MJO predictions offer the possibility of increasing tropical and extratropical forecast skill at lead times of 1-4 weeks. Unfortunately, current GCMs have difficulty in representing the MJO and its associated multi-scale interactions of convection and circulation. CDC hosts a website where real-time and experimental MJO forecasts are objectively evaluated, and feedback provided to forecasters. Forecast contributions now number five statistical models, two GCM ensembles and a coupled ocean-atmosphere model, with more contributions pending. Forecasts of five different variables are displayed in a common graphical format for easy comparison. Results confirm that both the statistical and numerical prediction models have only marginal skill at Week 2, even for planetary scale variables like 200 mb velocity potential. The forecast skill of tropical precipitation is poor for all the available GCMs.

CDC has been posting weather-climate forecast discussions on its website on a quasi-regular basis for the past several years. The discussions evaluate the real-time global atmospheric circulation anomalies, utilize forecasts of the MJO available on the website, and make experimental subjective predictions of US temperature and precipitation for weeks 1 through 3. They also seek to link midlatitude synoptic events with the more slowly evolving MJO and teleconnection patterns with an emphasis on extreme events and circulation transitions. A subseasonal synoptic-dynamic model provides a framework for evaluating the prediction models and for forecasting circulation and USA temperature/precipitation anomalies.

MILESTONE PSD07.3:
Develop new web pages on the CIRES/CDC website explaining basic and applied CIRES/CDC climate research in laymen's terms.

ACCOMPLISHMENTS FOR PSD07.3:
CDC staff continued their strong tradition of public outreach and service to the broader scientific community. They continued to provide numerous media interviews and specialized climate briefings, and continued to develop new webpages on its website explaining basic and applied CDC climate research in laymen's terms. The CDC web site contains links to many experimental and applied climate products that were developed at CDC under support from the CDEP/ARC program. Examples include prototype global risk assessments; climate probability distributions; interactive pages for calculating and displaying composite fields and correlations from NCEP Reanalysis data; operational analyses, US climate division data, ENSO climate risk pages, and a climate products information page that includes a broad range of operational and experimental climate products, particularly those developed by NOAA and its partners. CDC continues to serve as a primary redistribution point for the NCEP Reanalysis data set, providing netCDF versions of the reanalysis fields via the web or via tape (for larger requests) to users throughout the world.

Scientific Theme: GEODYNAMICS

GEO-01: Geophysical Data Systems

NGDC05: Instrumentation Design, Prototyping and Analysis

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 NGDC05.1:

Produce a global high-resolution model of the crustal field at the Earth's surface.

ACCOMPLISHMENTS FOR NGDC05.1:

Scientific output includes:

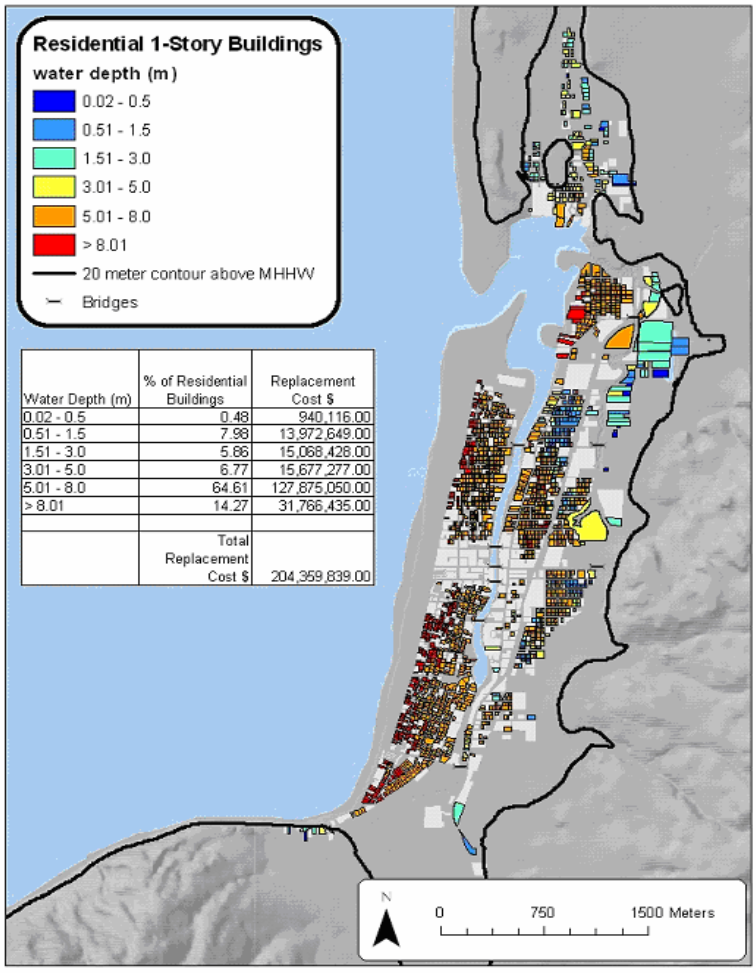
- 12 papers published (with 9 more in print or submitted for print)
- Initiated a weekly geomagnetism scientific seminar series at NGDC
- Crafted a draft Memorandum of Understanding with the European Space Agency for NOAA participation in the 2009 Swarm magnetic satellite mission
- Represented NOAA on the Swarm Mission Advisory Group
- Developed a greatly improved magnetic model of the lithosphere, updated software, both desktop and web-based, for all of the magnetic field models
- Developed a geomagnetism science web site through CIRES (*http://geomag.colorado.edu/*)

MILESTONE NGDC05.2:

Develop framework for analyzing the socio-economic impact from tsunamis.

ACCOMPLISHMENTS FOR NGDC05.2:

- Updated and reviewed quality of all US Coastal tsunami event data
- Developed a tsunami vulnerability assessment methodology based on an approach designed by Dr. Maria Papathoma and Dr. Dale Dominey-Howes
- Implemented Windows desktop version of Tsunami Travel Time software (P. Wessel) and provided TTT map products for the Pacific Region Tsunami Exercise (spring 2006)



Water Depth (m)	% of Residential Buildings	Replacement Cost $
0.02 - 0.5	0.48	940,116.00
0.51 - 1.5	7.98	13,972,649.00
1.51 - 3.0	5.86	15,068,428.00
3.01 - 5.0	6.77	15,677,277.00
5.01 - 8.0	64.61	127,875,050.00
> 8.01	14.27	31,766,435.00
	Total Replacement Cost $	204,359,839.00

MILESTONE NGDC05.3:
Improved modeling of Earth's main magnetic field.

ACCOMPLISHMENTS FOR NGDC05.3:

- Acquired, processed and managed global data for modeling the main magnetic field,
- Developed a revised geomagnetic field model (POMME-3),
- Updated models and on-line magnetic field calculators for estimating magnetic field values globally for specified date and location (*http://www.ngdc.noaa.gov/seg/geomag/magfield.shtml*)

Scientific Theme: INTEGRATING ACTIVITIES

IA-01: Science and Society
CSD10 (AL10): Scientific Assessments for Decision Makers
Policy01 (same): Science Policy Lecture Series

IA-02: Western Water Assessment
WWA01 (same): Scientific Assessments
WWA02 (same): Climate Products
WWA03 (same): Climate and Water Affairs

IA-03: Education and Outreach
No NOAA-funded projects

IA-04: Resource Development for Educators and Decision Makers
NGDC06 (same): Integrated Science and Ecosystem Informatics
Policy02 (same): Outreach to Decision Makers through the Internet
Policy03 (same): Outreach to Decision Makers through Newsletters

IA-01: Science and Society

CSD10 (*formerly AL10*): 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 CSD10.1***
> Lead and coordinate the drafting and international review of chapters for the WMO/UNEP 2006 scientific state-of-understanding assessment of the ozone layer.

ACCOMPLISHMENTS FOR CSD10.1
In the Scientific Assessment of Ozone Depletion: 2006, the world's leading scientists define the current scientific understanding of the ozone layer and the phenomenon of stratospheric ozone depletion, updating the 2002 Assessment as required by Article 6 of the United Nations Montreal Protocol on Substances that Deplete the Ozone Layer. This is a highly coordinated multi-agency effort involving NOAA, the United Nations Environment Programme (UNEP), the World Meteorological Organization (WMO), the National Aeronautics and Space Administration (NASA), and the European Commission (EC). The report is truly global in its importance, serving as the centerpiece of all national and international discussions related to ozone depletion. It is relied upon by scientists in the international community in its assessment of the current state of scientific understanding on the topic. By summarizing scientific findings in policy-relevant terms, the Assessment plays a particularly unique role as a "bridge" between the scientific community and decision makers. Specifically, the science in the Assessment will underpin future international decisions regarding ozone-depleting substances and the protection of the ozone layer. Findings of the 2006 Assessment include an update on atmospheric processes underlying ozone abundance at the poles and globally, observations of both short-lived and long-lived ozone-depleting substances in the atmosphere, expectations for recovery of the ozone layer, and discussion of the current state of understanding regarding the interactions between climate and the ozone layer.

CIRES scientists have made many contributions to the 2006 Ozone Assessment, including serving as Coauthors, Reviewers, and Coordinating Editor of the entire report. In 2005/6, the major milestones in the drafting and review of the document were completed, and all major international meetings associated with the review of the report were successfully held. The Executive Summary of the report will be released in August 2006, and the final printed copies of the report will be available in April 2007.

IA-02: Western Water Assessment

WWA01: Scientific Assessments

GOAL:
Identify and characterize regional vulnerabilities to climate variability and change for use by Intermountain water-resource decision makers.

MILESTONE WWA01.1:
Evaluate Front Range water needs to 2040.

ACCOMPLISHMENTS FOR WWA01.1:
Over the past year significant progress has been made in our efforts to model and evaluate the future water needs of Front Range water users. The SPRAT workgroup continued existing efforts with the Northern Colorado Water Conservancy District aimed at improving and applying the model to questions outside of those at the center of WWA's research focus. Recently a limited version of the model was distributed so that the NCWCD could begin exploring and utilizing the model on their own. In addition to our work with the NCWCD, model results, together with newly revised model documentation, were presented to numerous user groups throughout the Front Range. Output from the model suggests that significant water shortages can be expected without additional infrastructure/policy changes beyond those already being developed. Moreover, they demonstrate that the impact of future growth will vary largely by region and user type (e.g. agricultural users versus M&I users). These results, and others, were distributed to water managers throughout the Southwest via a written report published in Intermountain West Climate Summary and represented a chapter in the completed dissertation of Dr. Christopher Goemans.

MILESTONE WWA01.2:
Analyze Municipal Response to 2002 drought.

ACCOMPLISHMENTS FOR WWA01.2:
Three WWA researchers wrote a paper entitled "Use and effectiveness of municipal water restrictions during drought in Colorado." This paper studied how eight different municipal water providers handled the drought during 2002. Different strategies from voluntary to mandatory restrictions were utilized. Mandatory restrictions were found to reduce demand from 18 to 56% while voluntary restrictions reduced demand from 4 to 12%. The paper may be viewed at: *http://sciencepolicy.colorado.edu/admin/publication_files/resource-296-water_restrictions_jawra.pdf*

WWA also produced a white paper, "Use of Climate Information in Municipal Drought Planning in Colorado." Twenty-nine Colorado water providers were surveyed to understand how they use climate information in their planning efforts. The reports list the historical/current (streamflows, snowpack, etc) and forecasted (temperature and preciptation) indicators used by all providers. The types and methods of using various drought triggers are also discussed. The report was provided to all 29 entities and is available on the WWA website.

MILESTONE WWA01.3:
Investigate large water providers' vulnerabilities and climate products needs.

ACCOMPLISHMENTS FOR WWA01.3:
The purpose of this project is to identify water user needs for climate products (information and forecasts); to match these needs to WWA and NOAA climate research or identify new research areas; and to continue dialogue between these managers and WWA researchers. This year we have collected information about the uses and climate needs of six water providers which supply water to about 63% of the population on the Colorado Front Range and have completed interviews and draft report chapters for three of the six. We have been coordinating this work with studies on the South Platte Basin. Based on work in progress, Eric Ray gave a talk co-authored by Jessica Lowrey at the NOAA Climate Prediction Assessment workshop in Tucson, AZ in March 2006. Preliminary findings include: 1) There is little use of seasonal forecasts, but climate variability is reflected in annual and longer-term planning through the use of historic records; 2) the cities studied have over their history adopted strategies to meet water needs, including increasing efficiency, and these practices show continual innovation and adoption of new technologies and practices; 3) the project has identified needs for climate products in annual operations, but also finds significant needs for climate knowledge in longer-term planning, for example to assess the potential for

systems to cope in the future with drought, and interest in a range of potential climate change scenarios, droughts that have occurred outside the instrumental record. The research team plans to complete interviews this fall and have a full draft report by the end of the year.

MILESTONE WWA01.4:
Evaluate agricultural to drought.

ACCOMPLISHMENTS FOR WWA01.4:
Preliminary analysis of the quantity of agricultural water available for transfer to municipal uses was completed during the last year. Results were presented at the 2005 University Council on Water Resources annual conference, and suggest that much less agricultural water is available to meet future municipal demands than previously anticipated.

MILESTONE WWA01.5:
Evaluate agricultural use of climate forecasts.

ACCOMPLISHMENTS FOR WWA01.5:
This project was cancelled before inception due to concerns about NOAA involvement with agricultural use of climate products.

MILESTONE WWA01.6:
Investigate temperature and snow melt relationship in Colorado's front range.

ACCOMPLISHMENTS FOR WWA01.6:
Using the PRISM precipitation and temperature dataset, researchers investigated how temperature and precipitation have changed during the last 50 years in the Upper Colorado River Basin. Annual precipitation was shown to have increased during the entire 50-year period both in winter and summer. Temperatures, both minimum and maximum, have increased over the last 50 years, with minimums showing larger increases. Over the last 25 years the warming trend has increased in all seasons and at all elevations. Results of this research were presented at the MtnClim conference in the fall of 2005.

In the fall of 2005 a number of temperature sensors were placed in the University of Colorado Niwot Ridge Research area from approximately 10,000 feet to 12,000 feet to understand snow melt and temperature dynamics. The sensors were collected in June of 2006 and the data in now undergoing analysis.

WWA02: Climate Products

GOAL:
Develop information, products and processes to assist water resource decision makers throughout the Intermountain West.

MILESTONE WWA02.1
Improve Climate Services Clearinghouse Website.

ACCOMPLISHMENTS FOR WWA02.1:
The Climate Services Clearinghouse is an online, searchable database of all web-based products relating to climate. The website was updated and improved during the last year and is now at Version 2. It now contains 355 'temporal' resources, 429 'spatial resources,' 429 'organizational resources,' 419 resources by climate trend or characteristic, and 430 resources sorted by 'type of product.'

The PI on this project has been in discussion with several operational NOAA entities about product turnover.

MILESTONE WWA02.2:
Improve NWS Colorado Basin River Forecast Center forecasts

ACCOMPLISHMENTS FOR WWA02.2:
WWA researchers working with Colorado Basin River Forecast Center personnel jointly authored several publications that appeared in 2005:

MILESTONE WWA02.3:
Produce monthly intermountain climate summary.

ACCOMPLISHMENTS FOR WWA02.3:
The Western Water Assessment continues to produce our Intermountain West Climate Summary.

MILESTONE WWA02.4:
Provide Web-based seasonal forecasts for Colorado Drought Task Force.

ACCOMPLISHMENTS FOR WWA02.4:
The "Colorado and Interior Southwest Forecasts" are seasonal forecasts designed to complement the official CPC temperature and precipation forecasts. New for this year is the publication of the skill of these forecasts. The principal investigator on this effort collaborates with CPC to add his knowledge to the official NOAA forecasts. This forecast is used by the Colorado Drought Task Force.

A map of a sites used in reconstructions is here:
http://www.ncdc.noaa.gov/paleo/streamflow/chronologies.html#bigmap

Selected chronologies are available at the International Tree-Ring data bank here:
http://www.ncdc.noaa.gov/paleo/treering.html

MILESTONE WWA02.5:
Provide dendrohydrological datasets.

ACCOMPLISHMENTS FOR WWA02.5:
Several new chronologies were collected, adding to the International Tree-Ring Data Bank, a publicly available collection of tree-ring information. These chronologies included those collected for the purpose of reconstructing Colorado River streamflow at Lee's Ferry.

WWA03: 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 WWA03.1:
Sponsor Conference on Colorado River Compact.

ACCOMPLISHMENTS FOR WWA03.1:
Along with the University of Colorado Law School, the Western Water Assessment sponsored a three-day conference on Climate Change. This conference was attended by approximately 200 people from thoughout the country, and featured numerous internationally recognized speakers on the topic. WWA personnel made presentations at the conference.

MILESTONE WWA03.2:
Sponsor Climate and Water Affairs seminar series.

ACCOMPLISHMENTS FOR WWA03.2:
WWA sponsored a seminar series on key water and climate issues in the West. Attorney Larry MacDonnell gave a presentation on Colorado River policy issues, Margaret Matter on Colorado River gages, Bill Karsell of the USBR on the Water - Energy Nexus, Steve Hunter of the USBR on Weather Modification in the Colorado River Basin, and Ric Brown of the CWCB on the State Water Supply Initiative.

MILESTONE WWA03.3:
Maintain dendrohydrological website.

ACCOMPLISHMENTS FOR WWA03.3:
The TreeFlow website is designed to be a resource for water managers. In addition to providing access to data, there is also a significant education component to the site. Site visitors can receive a tutorial on how streamflow reconstructions are made from tree rings, issues surrounding the quality of the reconstructions, and are shown several reconstructions.

MILESTONE WWA03.4:
Maintain Western Water Assessment website.

ACCOMPLISHMENTS FOR WWA03.4:
The Western Water Assessment website was enhanced during the last year by the additional of a Colorado River specific series of pages on law, policy, river management and use, climate and drought, climate change, and environment and endangered species. In addition, the site is home to the proceedings of our 2005 conference on the Colorado River Compact. Several historically important documents were scanned for the site, including the minutes of the 1922 Compact negotiations. Material from the WWA symposium of Decision Support Activities for Climate Change is also now on the site.

IA-04: Resource Development for Educators and Decision Makers

NGDC06: Integrated Science and Ecosystem Informatics

GOAL:
Evaluate data and informatics needs to support integrated regional ecosystem assessments and improve the empirical basis for ecosystem assessment and communication to policy and decision makers.

MILESTONE NGDC06.1:
Continue to develop and support the World Deltas Network (WDN) as part of the Global Terrestrial Observing System (GTOS) and White Water to Blue Water (WW2BW) International Program; integrating with the NOAA Marine Sciences Committee regarding the WW2BW Partnership for the Mississippi River and Gulf of Mexico.

ACCOMPLISHMENTS FOR NGDC06.1:
The World Deltas Network (WDN) website was completed. A secretariat was established at the UN Food and Agriculture Organization (FAO) Rome. Related CIRES research continues.
See: *http://cires.colorado.edu/science/groups/wessman/projects/wdn*

MILESTONE NGDC06.2:
Transfer spatial modeling capabilities developed for the WDN, to the NOAA PRIDE initiative.

ACCOMPLISHMENTS FOR NGDC06.2:
NOAA funded a one-year experiment to test a geospatial modeling technique for mapping invasive species potentials in the Hawaiian Islands. Implementation proposal is in development. Pilot Study/Project "Architecture for Modeling Ecological Functions" (AMEF) was completed and is we are testing the application of modeling concepts in the Pacific Basin (PRIDE) region. An implementation proposal is in development.
See: *http://cires.colorado.edu/science/groups/wessman/projects/amef*

MILESTONE NGDC06.3:
Plan and conduct planning and review workshops related to current projects.

ACCOMPLISHMENTS FOR NGDC06.3:
Development of a US Regional Node for the Ocean Biogeographic Information System (OBIS), which is the data arm of the Census of Marine Life (CoML). This 12-18-mo project will involve collaboration with all CoML data

providers, including NOAA. The project began July 14, 2006. OBIS will provide the context for further development of ecoinformatics and modeling capabilities. See: *http://169.237.62.40:11000*

Policy02: 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 Policy02.1:***
> Continue upgrading the Center's websites in terms of appearance, quality and quantity of content, reliability, and ease of maintenance. Finish version 3 of the Publications System for the Climate Services Clearinghouse and Science Policy Assessment and Research on Climate, as well as other Center projects. Reprogram announcement system. Share systems developed by webmaster with other web professionals.

ACCOMPLISHMENTS FOR Policy02.1:
Version 3 of the publications system was not completed because we did not receive funding for the Climate Services Clearinghouse and that project was terminated. Otherwise, progress was made toward these goals. The home page of the Center's main site was completely overhauled to improve its appearance and ease of use. A database was instituted that included all employees, students, visitors, and collaborators at the Center, which automated several pages on the website displaying this information. Upgrades were made to increase the functionality of our publications database.

Policy03: 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 Policy03.1:***
> 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.

ACCOMPLISHMENTS FOR Policy03.1:
We have strived to improve the content of our newsletter over the past year to make it more interesting to science and technology policy decision makers. We included two pieces by prominent current and former congressional staffers commenting on the state of science policy in the U.S. Congress. We are going to be advertising *Ogmius* content more widely through our recently created "science policy briefings" which are emailed to a list of approximately 2,000 science policy decision makers in Washington, D.C. and elsewhere.

Scientific Theme: PLANETARY METABOLISM

PM-01: Biogeochemical Cycling
No NOAA-funded projects

PM-02: Biosphere-Atmosphere Interactions
CSD07 (AL07): Biosphere-Atmosphere Exchange

PM-03: Response of Natural Systems to Perturbations
NGDC07 (same): Anthropogenic Remote Sensing

PM-04: Transport and Fate of Chemicals in the Biosphere
No NOAA-funded projects

PM-02: Biosphere-Atmosphere Interactions

CSD07 (*formerly AL07*): Biosphere-Atmosphere Exchange

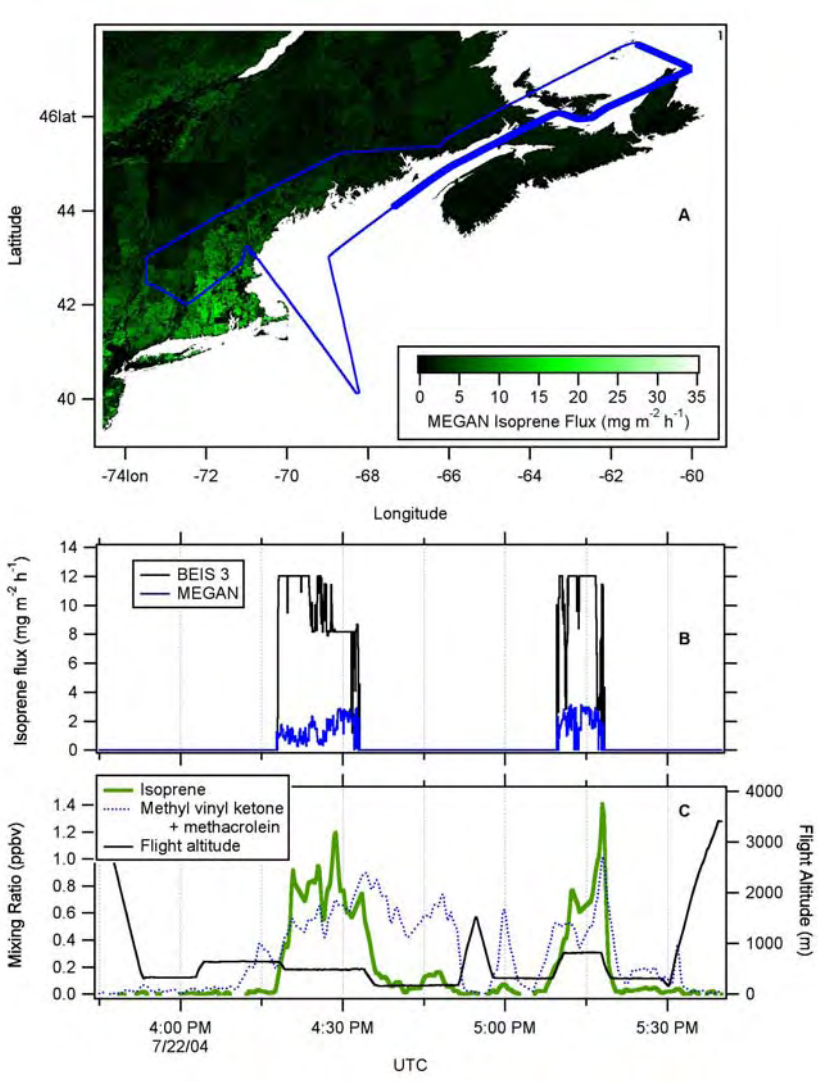
GOAL:
Gain an improved understanding of the role that the exchange of gases between the surface and the atmosphere plays in shaping regional climate and air quality.

> ***MILESTONE CSD07.1:***
> Analyze New England Air Quality Study-2004 field observations of the natural biogenic sources of emissions, such as isoprene, that could influence air quality in New England.

ACCOMPLISHMENTS FOR CSD07.1:
During the New England Air Quality Study in 2004, isoprene was measured with a fast time response using PTR-MS onboard the NOAA WP-3D aircraft. The results are compared with the expected mixing ratios based on (1) isoprene emission inventories, (2) isoprene lifetimes, and (3) meteorological parameters (boundary layer height, temperature and photoactive radiation).

Two emission inventories are compared in this work: BEIS 3 (Biogenic Emission Inventory System 3) and MEGAN (Model for Emissions of Gases and Aerosol from Nature). Relatively large discrepancies between BEIS3 and MEGAN occur in Nova Scotia, which region was probed by the NOAA WP-3D during a flight on July 22, 2004. Figure 1A (next page) shows the flight track on that day, along with the MEGAN inventory. The isoprene emissions according to BEIS3 and MEGAN are extracted along the thicker part of the flight track in Fig. 1A and shown in Fig. 1B. Naturally, both inventories show the sharp contrast between land and sea, but the BEIS3 estimate for land emissions in this region is approximately 6 times higher. The measurements of isoprene during this flight interval are shown in Fig. 1C. The observation of isoprene is mostly limited to the parts of the flight over land, but do extend over the sea due to its non-zero lifetime. Also measured during the flight were methyl vinyl ketone and methacrolein (Fig. 1C), two atmospheric oxidation products of isoprene. It is clearly seen that isoprene is higher than its products over land, whereas the products are higher than isoprene over sea. This shows that isoprene is less oxidized over land, which is expected since it is closer to its sources.

The expected isoprene can be calculated based on measured boundary layer heights (700-1200 m), measured concentrations of OH ($0.7\text{-}1.4\times10^6$ cm^{-3}), which is the main radical in the atmosphere that removes isoprene chemically, and other meteorological parameters. Using the BEIS3 emission flux we estimate an isoprene mixing ratios of ~10 ppbv over land, whereas the value obtained using MEGAN is ~1.5 ppbv. The latter is much closer to the observed mixing ratio of ~1.0 ppbv, and we conclude that MEGAN is more accurate for this region of North America. We intend to extend this work by including an analysis of data from the upcoming Texas Air Quality Study in the summer of 2006. The results are helpful to assess the accuracy of isoprene emissions inventories. In the polluted atmosphere, isoprene is an important precursor of ozone and aerosol, which are both important factors in



determining regional air quality and climate. Accurate emissions inventories will help to improve the (forecast) models describing ozone and aerosol, and thus illuminate their importance in the atmosphere.

***Panel A** shows the isoprene emission flux in the northeastern U.S. and Nova Scotia estimated in the MEGAN inventory. The blue line is the flight track of the NOAA WP-3D on July 22, 2004.*

***Panel B** shows the emission flux according to the BEIS3 and MEGAN models, extracted along the thicker part of the flight track in panel A.*

***Panel C** shows the measured mixing ratios of isoprene and its photoproducts along that same part of the flight.*

PM-03: Response of Natural Systems to Perturbations

NGDC07: 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:***
> Produce a global nighttime lights time series spanning a fourteen year-time period from 1992 to 2005.

ACCOMPLISHMENTS:

Time series was completed from 1992-2004.

Scientific Theme: REGIONAL PROCESSES

RP-01: Region-Specific Impacts of Climate Variability and Extreme Events
No NOAA-funded projects

RP-02: Regional Hydrological Cycles in Weather and Climate
PSD11 (ETL05): Water Cycle
PSD14 (ETL08): Energy

RP-03: Surface/Atmosphere Exchange
PSD12 (ETL06): Air-Sea Interaction

RP-04: Regional Air Quality
CSD08 (AL08): Regional Air Quality
GMD06 (CMDL03): Baseline Air Quality
PSD13 (ETL07): Air Quality
GSD02 (FSL02): Regional Air Quality Prediction

RP-05 Intercontinental Transport and Chemical Transformation
CSD05 (AL04b): Tropospheric and Stratospheric Transport and Chemical Transformation

RP-06 Atmospheric Chemical Forecasting
CSD09 (AL09): Aerosol Formation, Chemical Composition, and Radiative Properties

RP-07 High Latitude/High Altitude Regional Processes
No NOAA-funded projects

RP-02: Regional Hydrological Cycles in Weather and Climate

PSD11 (*formerly ETL05*): Water Cycle

GOAL:
Improve weather and climate predictions through an increased knowledge of regional and global water cycle processes.

> ***MILESTONE PSD11.1:***
> Study the boundary-layer processes and precipitation microphysics associated with the North American Monsoon using measurements collected during the summer of 2004 at the boundary-layer and microphysics super site in Mexico.

ACCOMPLISHMENTS FOR PSD11.1:
CIRES investigators published (in press) an article summarizing results obtained from their participation in the North American Monsoon Experiment. Their project deployed an S-band precipitation profiler, a 449-MHz Doppler wind profiler, and a raindrop disdrometer at Estacion Obispo, Mexico for a two-month period during the summer of 2004. The paper provided a climatological context for the profiler observations at the field site. The S-band profiler reflectivity distributions were compared with TRMM Precipitation Radar (PR) reflectivity distributions from the 2004 season over the NAME domain as well as from the 1998-2005 seasons. This analysis placed the NAME 2004 observations into context with previous and future monsoon seasons and provided a geographical perspective on the representativeness of the precipitation sampled at the profiler location.

MILESTONE PSD11.2:

A CIRES investigator will contribute on a project to implement, test and evaluate the ETL sea-spray parameterization scheme in NCEP's operational hurricane model. Numerical experiments using the operational model will be carried out for several historical hurricane cases to assess the impact of the ETL scheme on operational hurricane intensity forecasts. A report of the assessment will be submitted to NCEP at the end of the project.

ACCOMPLISHMENTS FOR PSD11.2:

The1-D Kepert-Fairall-Bao explicit sea-spray model was used to investigate thermodynamic feedback effects of sea-spray in the droplet evaporation layer under hurricane conditions. The PSD sea-spray parameterization scheme was implemented into the MM5 model, the WRF-ARW model and an operational hurricane model (i.e., NCEP's operational hurricane model). Numerical experiments using the operational model were carried out for several historical hurricane cases to assess the impact of the PSD sea-spray parameterization scheme on operational hurricane intensity forecasts. The results of assessment were reported to NCEP as well as presented at the International Conference of Ocean Research 2005 and the Interdepartmental Hurricane Conference 2006.

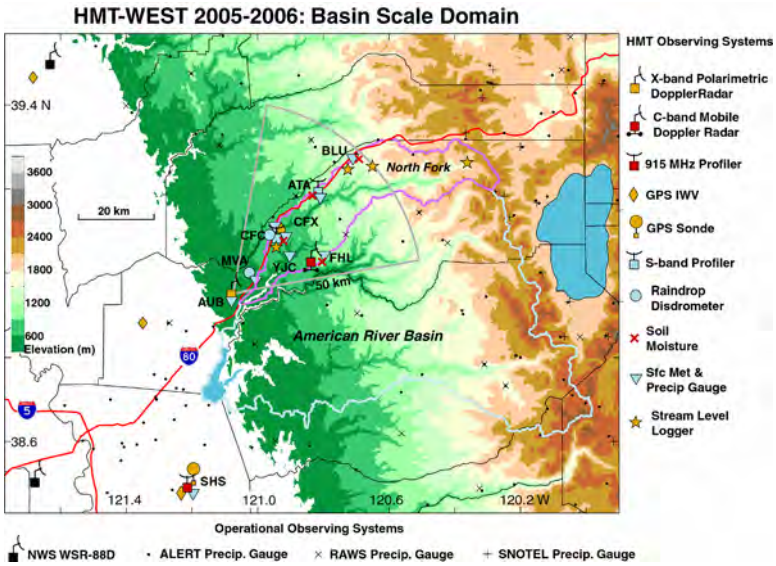
MILESTONE PSD11.3

Plan and execute the 2006 HMT (Hydrometeorology Testbed) field campaign in the northern California American River basin, located in the Sierra Nevada Mountains west of Lake Tahoe and east of Sacramento. This effort will involve deployment of several instrument systems utilized in earlier HMT's conducted in the Russian River basin of northern California but will yield critical new understanding of orographic influences on airflow and precipitation growth over the Sierra Nevada mountains, a barrier that is substantially wider and taller than the coastal mountains. CIRES investigators will be key participants and contributors to this activity.

ACCOMPLISHMENTS FOR PSD11.3

The first season of full-scale HMT operations took place in California's American River Basin (ARB) from December 2005 through March 2006. Water supplies from this basin are immensely important to California's economy and natural habitats, and the threat of catastrophic floods to the downstream Sacramento area is extremely serious. In accord with recommendations of the HMT Advisory panel, the field observations focus on the unregulated North Fork of the American River. Several remote and *in situ* instument systems were deployed to this area (figure below). These measurements occurred within the context of existing operational observing sites of the NWS and other agencies. Together, the arrays of instruments provide a comprehensive view of weather in and approaching the ARB.

The HMT instruments performed well this winter and the data from most were displayed in realtime on the project web page. Weather conditions in northern California were very favorable for the HMT operations this past winter. Precipitation in the ARB in December 2005 was more than a factor of three above the climatological normal values for December. December 2005 was the 8th wettest December in California in the last 111 years, according to NOAA's National Climatic Data Center.



Basin scale map of instruments deployed to the American River Basin during HMT-West 2006.

MILESTONE PSD11.4

Create a multi-year global oceanic data set of near-surface temperature and humidity using a multi-sensor satellite retrieval method recently developed at the Physical Sciences Division (PSD).

ACCOMPLISHMENTS FOR PSD11.4

Researchers developed daily averaged near-surface temperature and humidity data set for 1999-2000 and 2003-2004.

PSD14 (*formerly ETL08*): Energy

GOAL:

Improve the performance of temperature forecasts provided by operational numerical models to allow better prediction of energy loads for the power generation and distribution industry.

MILESTONE PSD14.1:

Data taken at the New England boundary-layer super site will be used to evaluate several PBL parameterization schemes, including 1-D versions of NCEP's GFS and PSD PBL schemes and a new PBL scheme that CIRES investigators have helped to develop along with colleagues at NOAA/PSD. A paper describing and evaluating this new PBL scheme will be submitted for publication.

ACCOMPLISHMENTS FOR PSD14.1:

Two CIRES investigators contributed to a journal article summarizing the goals and results of the New England High Resolution Temperature Program that was published in the *Bulletin of the American Meteorological Society* (*Stensrud et al.,* 2006). The New England High Resolution Temperature Program was funded by a congressional earmark that was discontinued in NOAA's FY06 budget. The 1-D WRF model has been streamlined and fully tested with the permutation of various PBL, surface layer and land-surface schemes (including both GFS and ETA PBL schemes, and the operational land-surface scheme). The evaluation of the model against the New England observations has begun, and preliminary results have been shown at several meetings.

RP-03: Surface/Atmosphere Exchange

PSD12 (*formerly ETL06*): Air-Sea Interaction

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 PSD12.1:

Process Eastern Pacific Investigations of Climate (EPIC) and Pan-American Climate Study (PACS) data sets, provide a detailed analysis of these air-sea interaction data products, and make the final data set publicly available. Deployment on new excursions within the PACS and EPIC regions are imminent, as are cruises in the North American Monsoon Experiment (NAME) and New England Air Quality Studies (NEAQS) regions.

ACCOMPLISHMENTS FOR PSD12.1:

Scientists participated in Stratus 2005 and AMMA2006 cruises. Data from 23 cruises is now on ESRL/PSD archive (*ftp://ftp.etl.noaa.gov/et6/archive*).

MILESTONE PSD12.2:

Measurements of sea spray will continue as part of the Coupled Boundary Layers Air-Sea Transfer (CBLAST) experiment.

ACCOMPLISHMENTS FOR PSD12.2:
Funding for this project was terminated so nothing was done.

> ***MILESTONE PSD12.3:***
> Further quantify the air-sea transfer of gases and use a detailed physical analysis of data obtained from the Post-GasEx surface processes experiments to evaluate and improve gas transfer parameterizations.

ACCOMPLISHMENTS FOR PSD12.3:
Work continued with parameterizations for ozone and DMS. Two papers appeared in print and a third was submitted.

> ***MILESTONE PSD12.4:***
> Create a multi-year global oceanic data set of near-surface temperature and humidity using a multi-sensor satellite retrieval method recently developed at the Physical Sciences Division (PSD).

ACCOMPLISHMENTS FOR PSD12.4:
A new method for retrieving near-surface temperature and humidity was developed using multiple satellite microwave sensors (AMSU-A and SSM/I). Four years of daily averaged data (1999-2000, 2003-2004) were constructed and used as a stability index for examining biases between infrared and microwave SST products. The retrieved temperature and humidity data were also used as inputs for construction of daily sensible and latent heat flux data. An ongoing study is comparing the heat flux data derived using these retrieved temperature and humidity data with other satellite-derived heat flux products.

RP-04: Surface/Atmosphere Exchange

CSD08 (*formerly AL08*): 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 CSD08.1:***
> Analyze the sources and meteorological and chemical processes that determine air quality in New England, using the data gathered during the summer-2004 New England Air Quality Study (NEAQS 2004).

ACCOMPLISHMENTS FOR CSD08.1:
The preliminary findings from the 2004 New England Air Quality Study that was carried out during the summer of 2004 in the Northeastern United States were reported at the 2005 Fall Meeting of the American Geophysical Union. The results obtained by CIRES scientists and their colleagues were presented in five oral sessions and three poster sessions at the meeting. Additional interpretation of these results has led to the submission of nine articles to the *Journal of Geophysical Research* and will be contained in special journal sections that will be devoted to this study. Significant finding from these results include:

- Nighttime processing of NO_X and VOC can significantly affect next-day ozone formation.
- Aerosol composition influences N_2O_5 reactions on aerosol particles. This suggests that factors not normally considered to affect regional ozone (e.g., sulfur and ammonia emissions) may in fact have an influence.
- Air quality models must be modified to account for this newly understood nighttime chemistry.
- Pollution controls at fossil-fueled power plants, though costly to implement, have resulted in verifiable reductions in nitrogen oxide emissions and atmospheric nitrogen oxide levels.

- Under typical summertime conditions, the nitrogen oxide emission reductions by these plants have lowered ozone levels in the Northeastern U.S., improving air quality in the region.

MILESTONE CSD08.2:
Plan for the Texas Air Quality Study in 2006, specifically investigating the role of industrial emissions on ozone formation in Houston.

ACCOMPLISHMENTS FOR CSD08.2:
Several major planning meetings took place this past year for the 2005-2006 Texas Air Quality Study/Gulf of Mexico Atmospheric Composition and Climate Study (TexAQS/GoMACCS), and the mission is poised for its start in August 2006. Several CIRES scientists and their colleagues from NOAA and across the U.S. will be participating in this major field mission.

The 2006 TexAQS/GoMACCS study is a major multi-institutional intensive field program that will focus on investigating important scientific questions that are common to both climate and air quality. This intensive field study will focus on providing a better understanding of the sources and atmospheric processes responsible for the formation and distribution of ozone and aerosols in the atmosphere and the influence that these species have on the radiative forcing of climate regionally and globally, as well as their impact on air quality, human health, and regional haze. The study area will be Texas and the northwestern Gulf of Mexico. The intensive work in August/September 2006 is superimposed on a longer study period that commenced in May 2005, in which state and university scientists in Texas are gathering data from ground stations to characterize atmospheric composition in a broad region of southeastern Texas.

The air quality component of this field experiment will investigate the sources and processes that are responsible for photochemical pollution (ozone) and regional haze during the summertime in Texas. Several counties in Texas are experiencing air quality problems associated with this ozone. In addition, there is growing concern that additional counties in the state may be facing similar issues in the near future. The 2006 study will provide information on the sources of the ozone and aerosols precursors and processes responsible for the formation and distribution of ozone and aerosols in the state. The mission will also investigate the role of the region's ozone and aerosols in climate. By addressing both Climate and Air Quality objectives, the 2006 TexAQS/GoMACCS studies will be especially effective in leveraging resources and personnel in support of NOAA's mission.

MILESTONE CSD08.3:
Measure the rate coefficient for the reactions of hydroxyl radicals with various olefinic alcohols to better elucidate the role of oxygenated hydrocarbons in tropospheric ozone production.

ACCOMPLISHMENTS FOR CSD08.3:
Rate coefficients for reaction of the hydroxyl radical (OH) with several unsaturated alcohols including (Z-3-hexen-1-ol, E-2-hexen-1-ol, 1-penten-3-ol, Z-2-Penten-1-ol, and E-2-penten-1-ol) have been measured using the Pulsed Laser Photolysis – Laser Induced Fluorescence (PLP-LIF) technique between 235 and 375 K. Unsaturated alcohols, such as those included in this study, are emitted directly into the tropospheric boundary layer following the wounding (cutting or harvesting) of vegetation. The oxidation of these compounds therefore influences ozone production and regional air quality. Several of the compounds included in this study are not emitted but are similar in chemical structure and therefore provide data necessary to established reactivity relationships and therefore the ability to predict rate coefficients for other compounds. The laboratory measurements are being completed and a manuscript is currently in preparation.

GMD06 (*formerly CMDL03*): Baseline Air Quality

GOAL:

Study intercontinental transport events to improve our understanding of their importance in affecting overall air quality and its impacts on public health.

> ***MILESTONE GMD06.1:***
> Deploy an *in-situ* surface aerosol monitoring system as part of the Department of Energy's ARM (Aerosol Radiation Measurements) Mobile Facility. Cloud droplets will be sampled through a counterflow virtual impactor (CVI) and the physical, chemical and optical properties of the droplet kernels will be studied. The first deployment is at Pt. Reyes, California, a coastal site with frequent fog events. The second installment will be in Naimey, Niger where dust aerosol is prevalent in the dry season.

ACCOMPLISHMENTS FOR GMD06.1:

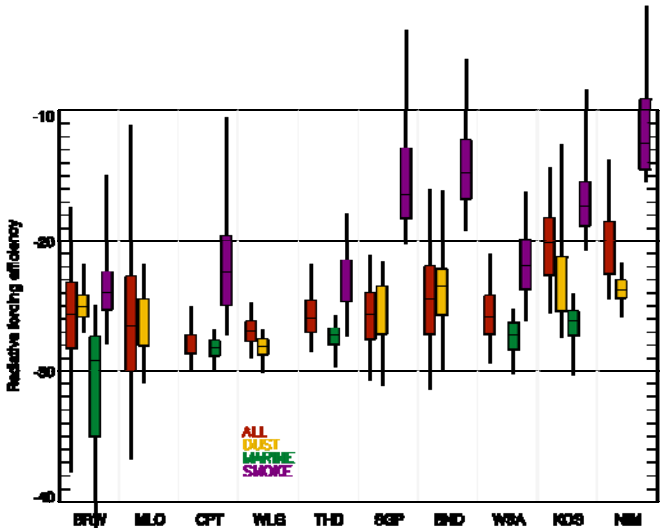
The NOAA/GMD Aerosol group built and deployed a mobile aerosol monitoring system as part of the DOE Atmospheric Radiation Measurement Program. The first deployment was from March to September 2005 in Pt. Reyes, CA. The second deployment from December 2005 to January 2007 was in Niamey, Niger. At Pt. Reyes, data was collected on the aerosol optical, hygroscopic and cloud-forming properties in and out of fog. In Niamey, Niger differences in these aerosol properties was observed for dust and smoke aerosol during the dry and wet seasons. The African deployment was part of a larger field intensive known as AMMA, African Monsoon Multidiscplinary Analysis.

> ***MILESTONE GMD06.2:***
> Deploy aerosol monitoring systems to sites in Mt. Waliguan, China and Cape Point, South Africa as part of the WHO Global Atmospheric Watch (GAW) program. The Mt. Waliguan observatory is a high altitude site in the Tibetan Plateau ideally situated to measure long-range transport of aerosol and pollutants in the free troposphere. The Cape Point, South Africa is a marine site on the southern tip of the African Continent.

ACCOMPLISHMENTS FOR GMD06.2:

Aerosol monitoring systems were deployed to Mount Waliguan, China and Cape Point, South Africa as part of the WMO Global Atmospheric Watch (GAW) program. The Mt. Waliguan observatory (WLG) (operational August, 2005) is a high altitude site in the Tibetan Plateau ideally situated to measure long range transport of aerosol and pollutants in the free troposphere. The Cape Point site (CPT) (operational November, 2005) provides an opportunity to measure pristine marine air as well as urban pollution and biomass burning aerosol from Capetown and its environs. Photos of the two observatories are shown below: Mt Waliguan on the left, Cape Point on the right.

Top-of-atmosphere aerosol radiative forcing efficiency (RFE) values from these sites have been calculated and put in context with results from other similar stations operated by GMD's aerosol group. The figure on the next page shows that a value of -25 W m^{-2} gives a useful first estimate (± 50%) of the RFE, although smoke aerosol is quite different. These ground-based measurements of RFE allow evaluation of aerosol direct climate forcing when combined with satellite measurements. Results from the first year of measurements for CPT and WLG will be presented at the IGAC conference in September 2006.

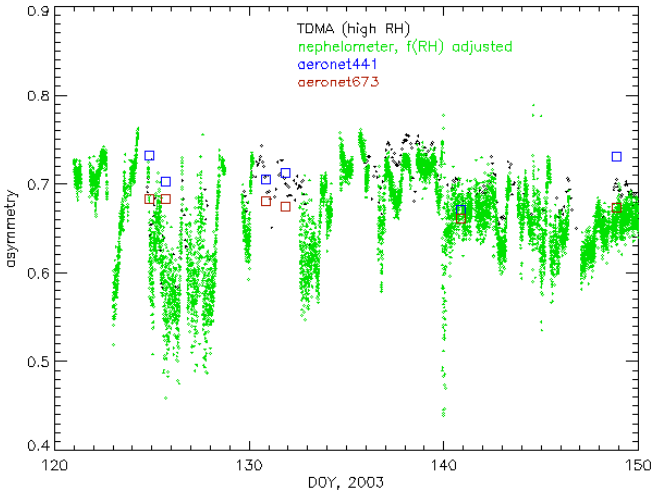


TOA radiative forcing efficiency (in W m^{-2} per unit optical depth) for different aerosol types for sites where GMD's aerosol group makes measurements of aerosol optical properties.
BRW=Barrow, AK
MLO=Mauna Loa, HI
CPT=Cape Point, S. Africa
WLG=Mt Waliguan, China
THD=Trinidad Head, CA
SGP=Lamont, OK
BND=Bondville, IL
WSA=Sable Island, Canada
KOS=Kosan, S. Korea
NIM=Niamey, Niger
(data for low relative humidity (RH<40%) conditions, wavelength=550 nm)

MILESTONE GMD06.3:
Publish in JGR a summary of results from a May 2003 field intensive where an array of instruments was used to measure the optical, physical, and chemical properties of aerosols at a mid-continental site. These measurements provided multiple methods for deriving a parameterization of the angular scattering properties of aerosol particles.

ACCOMPLISHMENTS FOR GMD06.3:
Several papers involving CIRES research scientists were published in *Journal of Geophysical Research* in 2006 presenting results from a May 2003 field intensive where an array of instruments was used to measure the optical, physical, and chemical properties of aerosols at a mid-continental site.

Andrews et al. (2006) (lead author is a CIRES scientist) presented results describing measurements which provide multiple methods for deriving a parameterization of the angular scattering properties of aerosol particles. Understanding the angular distribution of light scattered by particles is a key factor in better constraining radiative forcing calculations in models. The figure at left shows a time series comparison of asymmetry parameter (a representation of angular scattering) derived by three very different methods.



Time series comparison of asymmetry parameter for □=550 nm at ambient RH.

Method 1 uses scattering and backscattering measured by a nephelometer .

Method 2 uses size distributions from a TDMA and Mie scattering theory

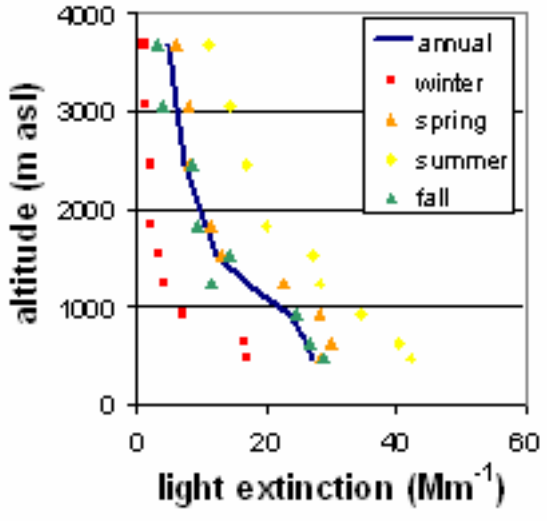
Method 3 inverts spectral aerosol optical depth data measured by the AERONET sunphotometer (for 441 and 673 nm wavelengths)

MILESTONE GMD06.4:
Publish a paper on the seasonal variations of the vertical profiles of optical properties of continental aerosols. This will employ measurements from a light aircraft of the aerosol properties affecting visibility and haze over a mid-continental site.

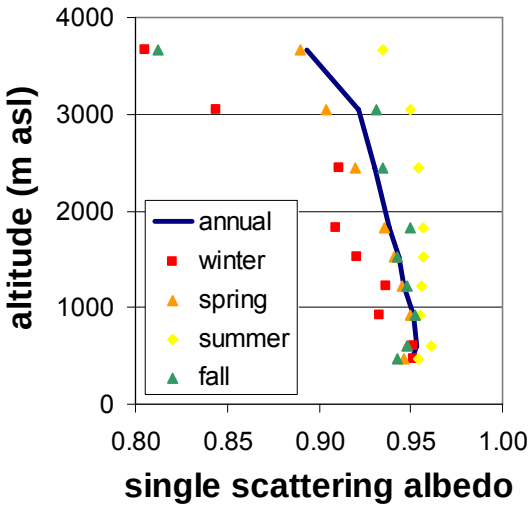
ACCOMPLISHMENTS FOR GMD06.4:

A paper on the seasonal variations of the vertical profiles of optical properties of continental aerosols is still in progress. This will employ measurements from a light aircraft of the aerosol properties affecting visibility and haze over a mid-continental site.

The data have been analyzed but the paper itself is still in draft form. The plots below show the median values for aerosol extinction and single scattering albedo as a function of season.



Left: There are significant differences in aerosol extinction profiles measured over the Lamont, OK site. There is more aerosol extinction in the summer and less in the winter. This appears to correspond with changes in source region: summer air masses tend to come from the polluted gulf coast, while winter air masses tend to be from the northwest or Arctic.



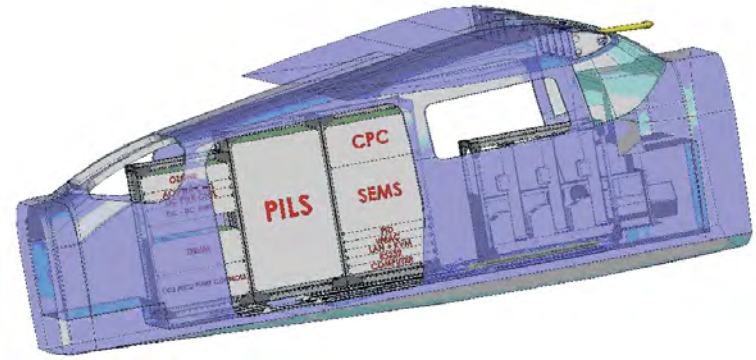
Right: Interestingly, while the summertime air masses tend to have more aerosol, the aerosol single scattering albedo is lower for the wintertime aerosol. This may be due to preferential scavenging leaving relatively more absorbing aerosol in the airmass.

MILESTONE GMD06.5:

Deploy a new instrumented aircraft for long-term monitoring of vertical profiles of aerosol chemical, radiative, and microphysical properties over the Midwest United States. The aircraft will make vertical measurements of aerosol chemical, optical and physical properties over a surface site several times a week.

ACCOMPLISHMENTS FOR GMD06.5:

A new instrumented aircraft (Cessna 206) for long-term monitoring of vertical profiles of aerosol chemical, radiative, and microphysical properties has been deployed over the central United States (near Champaign, IL). The aircraft has been making vertical profiling measurements of aerosol chemical, optical and physical properties over a surface site several times a week since June 2006. The figure below shows a schematic of the instrument payload.



Instruments on board the airplane include an ozone monitor, a PILS (particle into liquid sampler) for measuring aerosol chemistry, a CPC (condensation particle counter) to measure particle number concentrations, a SEMS (scanning electrical mobility sizer) to measure aerosol size distributions, and an optics rack to measure spectral aerosol light scattering, backscattering and aerosol absorption and f(RH) an indication of aerosol hygroscopicity.

PSD13 (*formerly ETL07*): 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 PSD13.1:***
> CIRES investigators will publish a paper describing the development and application of a web-based trajectory tool that uses measurements from a regional wind profiler network.

ACCOMPLISHMENTS FOR PSD13.1:
CIRES investigators submitted a paper to the ICARTT-NEAQS special issue in the *Journal of Geophysical Research* that describes the NOAA wind profiler trajectory tool and demonstrates how the tool captures changes in mesoscale and synoptic weather better than trajectory tools that have access only to upper-air winds measured by the twice-daily soundings from the operational rawinsonde network.

CIRES and NOAA investigators produced a web-based trajectory tool that scientists can use to calculate regional Langrangian particle trajectories using hourly wind profile observations collected by the network of boundary-layer wind profilers available for the 2004 New England Air Quality Study. The tool is available online at *http://www.etl.noaa.gov/programs/2004/neaqs/traj/*

> ***MILESTONE PSD13.2:***
> CIRES investigators will complete MM5 model runs for the Central California Ozone Study. Seasonal model runs with comparisons to observations will be used to assess the model's skill over the entire summer season. Publication of the seasonal modeling work will be started.

ACCOMPLISHMENTS FOR PSD13.2:
The MM5 season-long simulations have been carried out for the summer of 2000. Comparison of the results from the simulations with the CCOS observations is undergoing. The output of the MM5 simulations has also been sent to our partners in California for further evaluation using two off-line chemical models that are driven meteorologically by the MM5 output. One of the major findings from this project is that the MM5 simulated transport and dispersion processes in Central California are very sensitive to the uncertainties in the large-scale flow and the land-surface model initialization. The sensitivity shows a significant variability with various locations in Central California. A presentation on this finding was made at the annual WRF workshop, and a journal article based on the presentation has been written.

> ***MILESTONE PSD13.3:***
> Analyze measurements of air-sea fluxes and gas transfer in the New England experiment on the *Ron Brown* in August 2004.

ACCOMPLISHMENTS FOR PSD13.3:
The PSD flux system was deployed on the NOAA Ship *Ronald H. Brown* during the NEAQS cruise in 2004. A full set of fluxes was obtained. The direct covariance fluxes were computed and compared to the NOAA COARE bulk flux algorithm version 3.0. The algorithm yields higher fluxes than the measurements when the PBL depth is extremely shallow (generally when close to shore in stable conditions). A new ozone parameterization was used to determine ozone deposition velocities as a function of location and conditions. A paper on these results was submitted to the ICARTT special section in JGR.

> ***MILESTONE PSD13.4:***
> Document meteorological processes that contributed to high-ozone episodes in the New England area using data from the NEAQS 2002 and 2004 air quality studies. Compare model predictions of meteorological variables and ozone concentrations with observations from these air quality studies.

ACCOMPLISHMENTS FOR PSD13.4:
CIRES investigators submitted a manuscript to the ICARTT-NEAQS special issue in the *Journal of Geophysical Research* that examines the role of meteorology and climate in controlling the vast difference in the number of surface ozone violations experienced in New England during 2002 and 2004. While both years were synoptically active, the climate conditions were very dissimilar, with 2002 being very warm and dry and 2004 being very cool and wet. We conclude that these climate extremes were responsible for controlling the number of summertime pollution events experienced in New England.

> ***MILESTONE PSD13.5:***
> Participate in the 2006 TexAQS/GoMACCS Air Quality Study in the Houston, Texas vicinity by (i) deploying a network of integrated boundary-layer wind profiler observing stations and by (ii) operating lidars on an aircraft and a research ship.

ACCOMPLISHMENTS FOR PSD13.5:
CIRES investigators particpated in the design of a comprehensive wind proifler network in Eastern Texas for the 2006 Texas Air Quality Study. All of the profilers planned for the project are in place for the study, which begins Aug 1, 2006. CIRES researchers will deploy three lidar systems during the TexAQS/GoMACCS Air Quality Study in August and September 2006. An ozone and aerosol profiling lidar and a Doppler wind lidar will be operated continuously on the NOAA research vessel *Ronald H. Brown* and a recently developed compact airborne ozone and aerosol lidar will be flown on a NOAA Twin Otter aircraft. The data collected with these lidars will be used to address key science questions regarding the role of transport and mixing processes in the development of high-pollution episodes in southeastern Texas. The NOAA wind profiler trajectory tool has been developed for Texas. This tool uses observations from the profiler network to calculate Lagrangian particle trajectories. The interactive web-based tool is available at *http://www.etl.noaa.gov/programs/2006/texaqs/traj/*

GSD02 (*formerly FSL02*): Regional Air Quality Prediction

GOAL:
Perform research to develop and evaluate new techniques for improved transport and chemical evolution in fully coupled atmospheric/chemistry models capable of real-time forecasts. Engage in real-time air quality forecasts for ozone and particulate matter (PM2.5 and PM10). Evaluate forecasts using observations from special observing periods.

> ***MILESTONE GSD02.1:***
> Evaluate forecast accuracy and relative efficiency of off-line air-quality models (chemistry predicted using output from non-interactive previously run atmospheric forecast) versus on-line air quality models (full coupling between standard atmospheric and chemical processes in a single model).

ACCOMPLISHMENTS FOR GSD02.1:
First, a control online air quality simulation was conducted for one single forecast run, and the meteorology and chemical data were saved at a 60-s time interval. Analysis of the power spectrum of the vertical mass flux indicates that offline simulations with larger coupling intervals may be susceptible to significant errors in the vertical redistribution of mass since only a small amount of the variability of the vertical mass flux is captured. In a second step, the control online air quality simulation was extended over a 15-day period to simulate a forecast environment, and results were compared to observations in terms of RMS errors, biases, and correlation coefficients. Subsequently, several offline simulations were conducted with meteorological data updates at 10-, 30-, and 60-min time intervals.

Results showed that even when averaged over longer time periods and when looking at commonly used evaluation scores, significant errors are introduced when running the model in offline mode. Explicitly resolved convective systems are shown to have a particularly severe influence on the vertical redistribution of mass. Similar effects should be expected with other rapidly evolving circulation systems. This is of particular importance for unbalanced flow regimes, where the divergent component becomes important. The vertical redistribution of the constituents may well be determined more by the nature of these circulation systems than by the larger scale flow. As we go to even smaller scales this effect will be increased, since more and more of these types of circulation systems will be

resolved. The most noticeable influence will be seen in simulations that use large domains to prevent air from quickly flushing beyond their perimeters, or that feed on themselves (e.g. air quality forecasts that are reinitialized with forecasts). As another consequence–and because of the importance of quantitative estimates of vertical transport–it may also be critical to use very high time resolution meteorological output (or online simulations) when performing dispersion simulations in the case of the release of toxic substances.

MILESTONE GSD02.2:
Use data from real-time air-quality forecasts during field experiment (NEAQS 2004) for further evaluation of a coupled model with a focus on aerosols (particulate matter), and interaction of aerosols and radiation.

ACCOMPLISHMENTS FOR GSD02.2:
The study of the aerosol/radiation interaction is an ongoing project (three-year project). Detailed results of model evaluations are summarized in a progress report submitted to NOAA/OAR.

Initial results, looking at one single day in a little bit more detail, show that the aerosol feedback may cause large difference in the prediction of the near-surface temperature fields. Most of these appear to be related to differences in the cloud fields. The convective parameterization appears sensitive to differential heating and cooling in the lower levels. This in turn influences the explicit microphysics scheme through differing detrainment of cloud water and ice. In addition, warming through additional absorption appears to evaporate some otherwise present low-level clouds. A detailed analysis of the results will be part of the second-year work which is funded and is in progress. It is clear that not only a look at statistical averages is necessary, but also a careful look at one particular case.

RP-05: Intercontinental Transport and Chemical Transformation

CSD05 (*formerly AL04b*): 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 CSD05.1:
Report the preliminary findings from the 2004 Intercontinental Transport and Chemical Transformation (ITCT) field mission that was carried out during the summer of 2004 off the east coast of North America.

ACCOMPLISHMENTS FOR CSD05.1:
The preliminary findings from the 2004 Intercontinental Transport and Chemical Transformation (ITCT) field mission that was carried out during the summer of 2004 off the east coast of North America were reported at the 2005 Fall Meeting of the American Geophysical Union. The results obtained by CIRES scientists and their colleagues were presented in five oral sessions and four poster sessions at the meeting. Additional interpretation of these results has led to the submission of four articles to the Journal of Geophysical Research and will be contained in special journal sections that will be devoted to this study. Significant finding from these results include:

- Ozone-related pollutants can survive longer in the atmosphere when they are transported in layers above the ocean. Consequently, urban areas can affect air quality far from the source and even over remote regions of the globe.
- Nitric acid is not always a terminating step in ozone formation. Nitric acid abundance was sufficiently elevated to make a substantial contribution to NO_x levels in remote regions. These elevated NO_x levels allow for continuing O_3 production.
- Some pollutants (such as nitric acid) will be eventually removed from the air when storm passage occurs, causing high levels of nitrate to be episodically deposited to the remote oceans. Ocean life in remote regions can be especially sensitive to these large nutrient inputs.

- Forest fires are a very large source of trace gases and particles in the Earth's atmosphere that can have significant episodic effects on air quality thousands of miles away from the sources.
- Lightning has a strong influence on ozone production in the upper troposphere above eastern North America producing a strong enhancement in the concentration of ozone over North America that can have a significant effect on climate and air-quality.

MILESTONE CSD05.2:
Plan for the Gulf of Mexico Atmospheric Composition and Climate Study in 2006, specifically investigating the role of emissions from the southern United States on regional atmospheric radiative forcing by ozone and aerosols.

ACCOMPLISHMENTS FOR CSD05.2:
Several major planning meetings took place this past year for the 2005-2006 Texas Air Quality Study/Gulf of Mexico Atmospheric Composition and Climate Study (TexAQS/GoMACCS), and the mission is poised for its start in August 2006. Several CIRES scientists and their colleagues from NOAA and across the U.S. will be participating in this major field mission.

The 2006 TexAQS/GoMACCS study is a major multi-institutional intensive field program that will focus on investigating important scientific questions that are common to both climate and air quality. This intensive field study will ultimately provide a better understanding of the sources and atmospheric processes responsible for the formation and distribution of ozone and aerosols in the atmosphere and the influence that these species have on the radiative forcing of climate regionally and globally, as well as their impact on air quality, human health, and regional haze. The study area will be Texas and the northwestern Gulf of Mexico. The intensive work in August/September 2006 is superimposed on a longer study period that commenced in May 2005, in which state and university scientists in Texas are gathering data from ground stations to characterize atmospheric composition in a broad region of southeastern Texas.

GoMACCS, the climate component of this field program, will characterize marine/continental chemical and meteorological processes over Texas and the Gulf of Mexico in order to improve the simulation of the radiative forcing of climate change by lower-atmosphere ozone and aerosols. In addition to clear-sky radiative effects, GoMACCS will investigate the influence of aerosols on cloud properties and the role of clouds in chemical transformation. The mission will also investigate the role of the region's ozone and aerosols in air quality. By addressing both Climate and Air Quality objectives, the 2006 TexAQS/GoMACCS studies will be especially effective in leveraging resources and personnel in support of NOAA's mission.

RP-06: Atmospheric Chemical Forecasting

CSD09 (AL09): 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 CSD09.1:
Analyze results of the organic content of aerosols in the context of their role in cloud physics.

ACCOMPLISHMENTS FOR CSD09.1:
Work has progressed first on the continued development of a lab-based prototype instrument and then on construction of a field-deployable instrument with the goal of measuring the speciated organic composition of atmospheric aerosols. This measurement will yield information about the individual organic compounds present in aerosols that may influence their hygroscopic properties. The first field deployment of this instrument will take place during late summer 2006. Laboratory studies on secondary organic aerosol formation using the developed instrument are planned following the field mission.

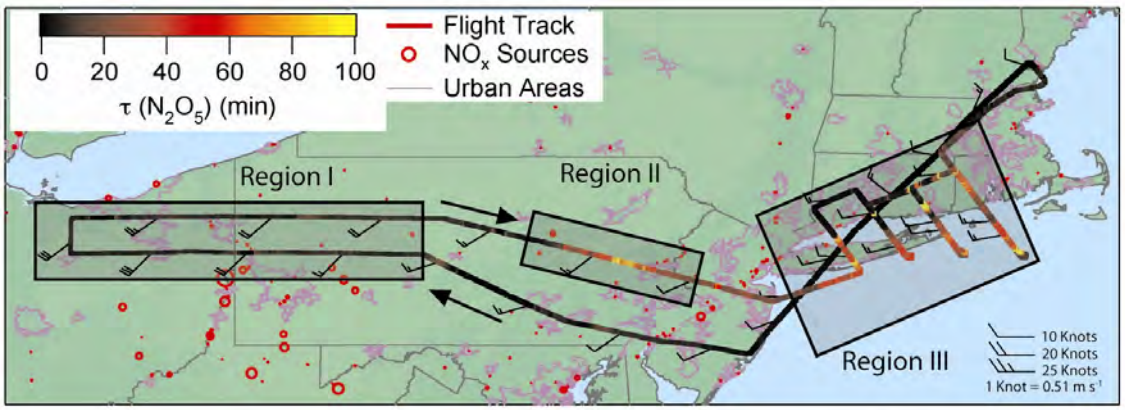
MILESTONE CSD09.2:

Analyze the data from the two cavity ring down spectrometers fielded in FY2004, one aboard NOAA WP-3 aircraft and another aboard R/V *Ronald H. Brown*, to evaluate the role of nighttime chemistry in regional air quality and climate.

ACCOMPLISHMENTS FOR CSD09.2:

During the 2004 New England Air Quality Study/Intercontinental Transport and Chemical Transformation (NEAQS-ITCT 2004) campaign, a pair of instruments was deployed to measure the concentrations of the nocturnal nitrogen oxides, NO_3 and N_2O_5, on the NOAA P-3 aircraft and the NOAA research vessel *Ronald H. Brown*. Analysis of these results in 2005-2006 yielded several important results that furthered the understanding of the role of nitrogen oxides in ozone formation and loss in polluted regions. These results appeared in four separate publications in 2005-2006. Additional publications from this data analysis are anticipated in 2006-2007.

The most significant of the new findings was the variability in the heterogeneous hydrolysis of N_2O_5 as observed from data taken on the NOAA P-3. These results were published in the January 6, 2006 issue of *Science* (*Brown et al. Science*, 311 67-70 (2006)). The analysis showed that N_2O_5 can act either as a nocturnal reservoir or a sink for nitrogen oxides, that such differences are regional in nature, and that the composition of aerosol is a determining factor. A figure from this manuscript appears below. Additional publications included an analysis of the role of NO_3 and N_2O_5 during the daytime, analysis of the nocturnal loss and/or transport of ozone in regionally polluted environments and a description of the performance of a novel instrument for measurement of NO_2.



P-3 flight track for August 9-10, 2004, color coded according to the N_2O_5 lifetime, $\tau(N_2O_5)$, showing large regional variability in the reactivity of N_2O_5 on aerosol. NO_x sources from power plants and urban areas are shown. This variability in N_2O_5 reactivity was shown to be correlated to aerosol composition.

MILESTONE CSD09.3:

Continue studies of how soot modifies nitrogen oxides species (NO_2, NO_3, N_2O_5, and HNO_3) in the troposphere and, in turn, how soot is modified by exposure to these atmospheric chemicals.

ACCOMPLISHMENTS FOR CSD09.3:

The uptake of HNO_3 on aviation kerosene (TC-1) soot was measured as a function of temperature (253 – 295 K) and the partial pressure of HNO_3 and on hexane soot was studied at 295 K and over a limited partial pressure of HNO_3. The HNO_3 uptake was mostly reversible and did not release measurable amounts of gas phase products such as HONO, NO_3, NO_2 or N_2O_5. The heat of adsorption of HNO_3 on soot was dependent on the surface coverage. The isosteric heats of adsorption, $\Delta^0H^{isosteric}$, were determined as a function of coverage. $\Delta^0H^{isosteric}$ values were in the range -16 to -13 kcal mol-1. The heats of adsorption decrease with increasing coverage. The adsorption data were fit to Freundlich and to Langmuir-Freundlich isotherms. The heterogeneity parameter values were close to 0.5, which suggested that a HNO_3 molecule can occupy two sites on the surface with or without being dissociated and that the soot surface could be non-uniform. Surface FTIR studies on the interaction of soot with HNO_3 did not reveal formation of any minor product such as organic nitrate or nitro compound on the soot surface. Using our measured coverage, we calculate that the partitioning of gas-phase nitric acid to black carbon aerosol is not a significant loss process of HNO_3 in the atmosphere.

Complementary Research

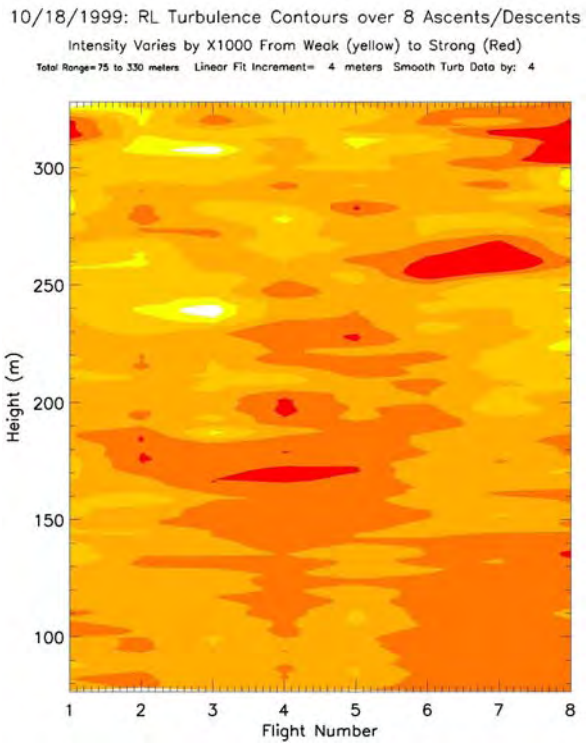
Faculty Fellows Research

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

Ben Balsley

We are currently examining a number of new 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, 1999. The RL lies between the stable boundary layer (the lowest region of the nighttime atmosphere that is tightly coupled to the earth's surface) and the steep temperature gradient that defines the bottom of the free atmosphere. Although the RL is a poorly studied region owing to its inaccessibility, it is important for studying the turbulent transport into the free atmosphere of pollutants generated at ground levels.

Our results show that the RL is not—as has has been generally portrayed in the literature—a passive, quiescent remnant of the previous afternoon's convective boundary layer. Rather it is a complex, rapidly changing, and dynamic arena harboring regions of intense turbulent variations with extremely sharp gradients. Our current studies show that RL turbulence: (1) is always present, (2) can exceed stable boundary turbulence levels by an order of magnitude, (3) can range in intensity over more than three orders of magnitude, (4) is generated locally on scales of a few tens of meters or less by velocity shears, and (5) can be entrained into the underlying stable boundary layer, particularly when the RL turbulence is intense and the stratification between the RL and SBL is relatively weak.



The figure at right is a contour plot of RL turbulence structure made from eight balloon flights between 75m and 330m over a 2-hour period on 10/18/99. The logarithmically shaded contours show more than a 3-order-of-magnitude range in the local turbulence intensity, with strong gradients occurring over a very few meters vertically. The larger-scale turbulent regions show some temporal coherence from flight to flight. Note that the stable boundary layer was located below 75 m during this entire period.

It appears that the RL is also developing into a useful region for studying fundamental turbulence processes in unbounded atmospheric regions.

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

Roger G. Barry and Florence Fetterer
Funding: NASA: Cryospheric Sciences

The primary objective of this work is to fill gaps in the Arctic sea ice data record by extending the record back and forward in time. A secondary objective is to provide summary statistics, and to assess the evidence for climate change in the Russian Arctic over the period 1930s-2005. The 1930-40s saw significant high latitude warming and therefore it is important to document accompanying changes in ice conditions for comparison with those of summers since 1990.

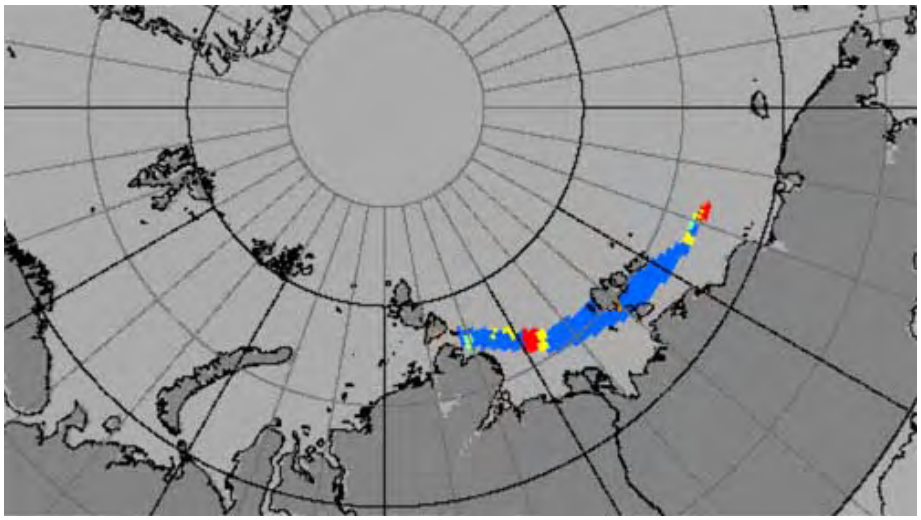
Two significant sources of historical sea ice chart data in digital form are the WMO Global Digital Sea Ice Data Bank (GDSIDB), and the Environmental Working Group Sea Ice Atlas. The sea ice atlas includes arctic-wide U.S. National Ice Center (NIC) seven-day sea ice charts, 1972-1994, and Russian Arctic ten-day sea ice charts, 1950-1992.

Sea ice charts for 1933–49 based on aerial reconnaissance, and recent data for 1993-2005 have been digitized at the Arctic and Antarctic Research Institute, St. Petersburg, Russia, and can be viewed using an interactive browser at *http://www.aari.nw.ru/gdsidb/sea_ice/real_sigrid/view.html*

Each chart was delivered in the World Meteorological Organization Sea Ice Grid (SIGRID) format with a corresponding gif image file. The 377 charts show total concentration. An example of a color-mapped (gif format) chart from the 1930s is shown in the Figure.

The next steps will be to

- Convert 1933-1949 data in SIGRID format to the Equal-Area Scalable Earth (EASE) grid.
- Acquire 1993-2005 data, and convert to EASE-Grid
- Construct climatological products (e.g. mean, median, maximum, and minimum concentration grids).
- Conduct analysis, through a post-doctoral fellow.



September 1, 1933

Other work included the completion and publication of *The Arctic Climate System*. Cambridge University Press, 385 pp., authors Mark C. Serreze and Roger G. Barry. This was awarded the best textbook of 2005 by the Atmospheric Science Libraries International.

Fault Creep in California

Roger Bilham
Funded by the U.S. Geological Survey

Parts of the San Andreas fault system in California slip aseismically near the Earth's surface at rates of 1-30 mm each year by a process known as creep. Usually this creep extends to depths of less than 3 km, but in rare cases it prevails throughout the Earth's crust. Over many decades this creep damages houses, roads and pipe-lines across the Hayward and San Andreas faults requiring frequent repairs, but each cm lost to creep effectively reduces the magnitude of a future earthquake at that location. A change in creep rate may also signify a change in the stress applied to the fault, and hence its measurement that may provide insight into future seismicity.

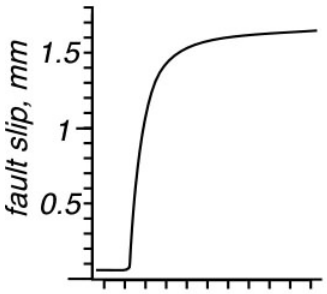
Offset fence and road on the San Andreas fault just north of San Juan Bautista, California. The horse stands on the Pacific plate and is looking closely at the fault trace that here causes the field behind her to move 3 μm each day to the NW relative to the foreground fence on the N. American Plate (>9 mm/year creep rate for the past 20 years).

We operate 14 creep-meters on the San Andreas Fault system between the Imperial Valley and the Bay Area to monitor this creep. The USGS operates a further 20 creep-meters. The creep-meters are 10-30-m long and consist of graphite, silica-fiber or invar rods buried obliquely across the faults at 0.5-2-m depth. A displacement sensor at the free end of the bar measures slip on the fault with a resolution of <10 μm (a human hair is typically >50 μm), over a range of 32-100 mm. Data from creep-meters in urban settings (Fremont, Oakland, Hayward and Berkeley) are transmitted at 10-minute intervals to USGS data banks. Two- to five-minute sampled data from rural areas are collected several times each year from buried low-power creepmeters (three years operation from AA batteries). In the Bay Area our creepmeters across the Hayward fault use helical piles to anchor the ends of sensors more than 10 m below the surface. Despite these precautions, seasonal noise sources (rain and temperature changes) introduce spurious signals exceeding ±1 mm.

Accomplishments

We find that in some locations the creep process is linear with time. In other locations, even on the same fault, it occurs in creep events with durations of a few days to a few months and with amplitudes of 1-5 mm. Data from the array 1994-2006 may be accessed by the public, graphically or numerically, via an interactive web page:
http://cires.colorado.edu/~bilham/creepmeter.file/creepmeters.htm

One of the most intriguing aspects of creep, that accelerated slip may precede large earthquakes, was refuted during the occurrence of the Mw=6 Parkfield earthquake of 2004. In contrast to the hoped-for precursory creep signal, no surface slip was manifest until several days after the mainshock. All the creepmeters monitored an increment in surface strain that later developed into localised surface cracks. Subsurface rupture on the fault at depth took several days to tunnel its way to the surface, but has now offset the fault more than 15 cm.



A typical creep 1.5-mm-amplitude, 2-day-duration creep event on the San Andreas fault at the northern end of the 1857 earthquake rupture.

Bilham, R, N. Suszek and S. Pinkney, California Creepmeters, *Seism. Res. Lett*. **75**(4), 481-492 (2004)
Bilham, R. Co-seismic Strain and the Transition to Surface Afterslip Recorded by Creep-Meters near the 2004 Parkfield Epicenter. *Seism. Res. Lett.* **76**(1), 49-57. 2005.

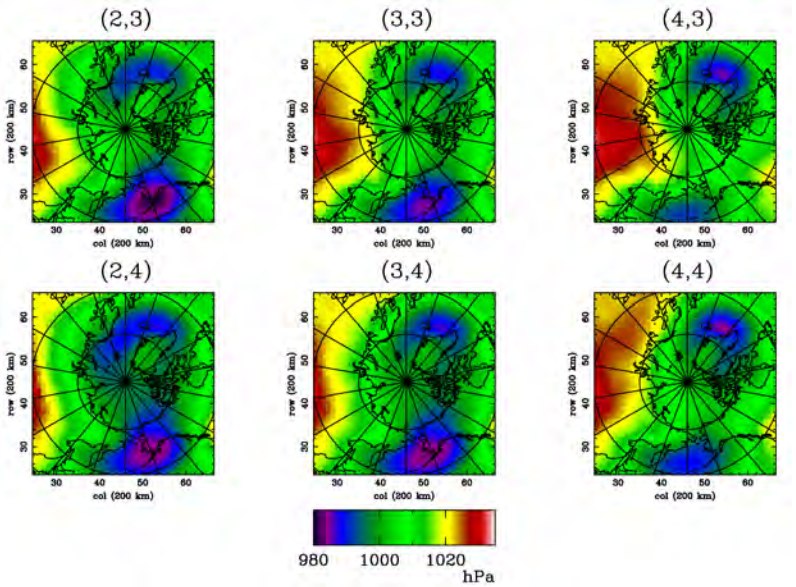
Use of Self-Organizing Maps for Climate and Weather Applications

John Cassano

Funding: National Science Foundation Office of Polar Programs

One avenue of current research in the Cassano Polar Climate and Meteorology group at the University of Colorado has involved the application of a technique known as self-organizing maps (SOMs) to create objective synoptic climatologies for the polar regions. These synoptic climatologies are based on multiple years to decades of sea-level pressure data and identify the key large-scale near-surface atmospheric circulation regimes in the area of study (e.g. figure this page). Once these circulation regimes are identified other aspects of the climate and weather can be related to the large scale circulation. The use of SOMs in this way is a relatively new technique and has proven useful for a number of our ongoing research projects.

We have used the SOM technique to evaluate regional changes predicted by global climate system model simulations of the 21st century in the Arctic and Antarctic. This research was a contribution to the Intergovernmental Panel on Climate Change Fourth Assessment Report (IPCC AR4). Further, we have used this method to assess the relative role of atmospheric warming and changes in atmospheric circulation on predicted changes in polar precipitation regimes over the 21st century. The results from this analysis vary by region, but in general the thermodynamic changes dominate the predicted change in polar precipitation over the 21st century. The results from this study are important for evaluating the atmospheric role in forcing changes in the Antarctic ice sheet mass balance and Arctic river discharge to the Arctic Ocean.



Six of the 35 synoptic weather patterns identified over a pan-Arctic domain using the SOM algorithm. Color shading indicates sea level pressure.

We have also used SOMs to evaluate real-time weather forecasts from the Antarctic Mesoscale Prediction System (AMPS). With the SOM technique we have evaluated model skill for each of the primary large-scale weather patterns in the Ross Sea sector of Antarctica. Results from this analysis provide weather forecasters for the United States Antarctic Program with additional guidance on model skill, and allow them to better assess the confidence that they can place in the numerical weather prediction forecasts produced by AMPS.

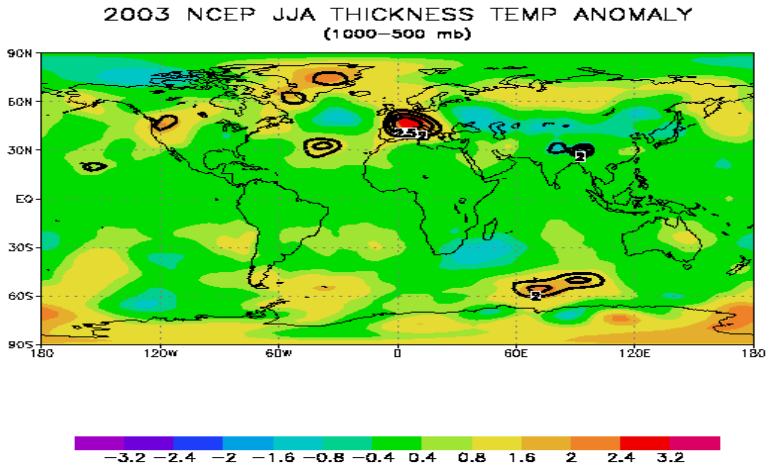
A third application of SOMs to our research has been in exploring the forcing for the near surface wind regime over the Ross Ice Shelf. The Ross Ice Shelf has been shown to be a key area for atmospheric mass transport from the Antarctic to lower latitudes of the Southern Hemisphere, with much of this transport accomplished by the low level wind regime. The surface winds in this region are influenced by katabatic drainage from the East and West Antarctic ice sheets, barrier winds along the Transantarctic mountains, mesoscale cyclones, and large-scale cyclones in the Ross Sea. The use of SOMs has allowed us to better define the regional pressure field responsible for each of these wind regimes.

Extreme Temperatures: Was the European Heat Wave Unusual?

Tom Chase
Funding: NSF and University of Alabama at Huntsville

We have been examining the natural variability of the atmosphere including large-scale circulation patterns and monsoons, usually in the context of changes in landcover. Here we give an example of this research and place the European summer heat wave of 2003 in the context of other extreme summer tropospheric temperature events from 22°N to 80°N since 1979. This work is in collaboration with Klaus Wolter and Roger Pielke Sr. also of CIRES. The analysis is performed in terms of standard deviations (SD) exceeded and correlations between regional extremes and temperatures at larger spatial scales.

The figure below shows the global thickness temperature anomaly relative to the 1979-2003 average for June, July, and August (JJA) 2003 for the 1000-500 mb layer average from the NCEP reanalysis. Contours are of standard deviation with 2.0, 2.5, and 3.0 SD shown. The 2003 warm anomaly over Europe was a deep atmospheric phenomenon and exceeded 3.0 SD above the mean for this period. By definition, exceeding 3.0 SD is an extremely unusual event statistically and would be expected in much less than 1% of observations.



1000-500 mb thickness temperature anomaly for June, July and August 2003. 2.0, 2.5, and 3.0 standard deviations from the 1979-2003 mean are contoured in thick lines for anomalies of both sign.

We then compared extreme tropospheric temperature events from 22°N to 80°N in JJA and globally using annual averages to the European summer heat wave of 2003 in terms of standard deviations exceeded and correlations between regional extremes and temperatures at larger spatial scales. As has been pointed out previously the European warm anomaly during the summer of 2003 at 3.0 standard deviations was statistically unusual and was a deep tropospheric phenomenon. In this analysis we found additionally that:

1) Extreme warm anomalies equally, or more, unusual than the 2003 heat wave occur regularly.
2) Extreme cold anomalies also occur regularly and can exceed the magnitude of the 2003 warm anomaly in terms of the value of SD. Cold anomalies are somewhat less extreme, on average, than warm anomalies during this period.
3) There is a correlation between global and hemispheric average temperature and the presence of warm or cold regional anomalies of the same sign. (i.e., warmer than average years have more regional heat waves and colder than average years have more cold waves). This correlation is stronger for warm anomalies than for cold anomalies and diminishes with more extreme anomalies. This relationship between warm years globally and regional heat waves is also reflected in the tendency for regional warm and cold anomalies to be anti-correlated with each other in a single year (i.e., years with strong regional warm anomalies do not generally also have strong cold anomalies and vice versa.
4) Natural variability in the form of El Niño and volcanism appears of much greater importance in causing extreme regional temperature anomalies as regional extremes during 1998 in particular are smaller than anomalies seen in summer 2003 both in area affected and SD extremes exceeded. Other natural modes of variability, such as the summer annular mode implicated in the 2003 heat wave, appear to have a smaller effect than ENSO.
5) Regression analyses do not provide strong support for the idea that regional heat or cold waves are significantly increasing or decreasing with time during the period considered here (1979-2003).

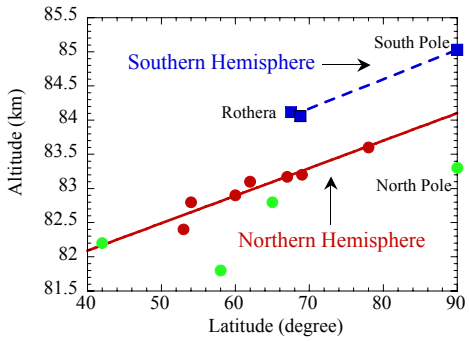
Lidar Investigation of Middle Atmosphere Composition, Temperature, and Dynamics in Polar and Tropical Regions

Xinzhao Chu

Funding: NSF Aeronomy and CEDAR Programs

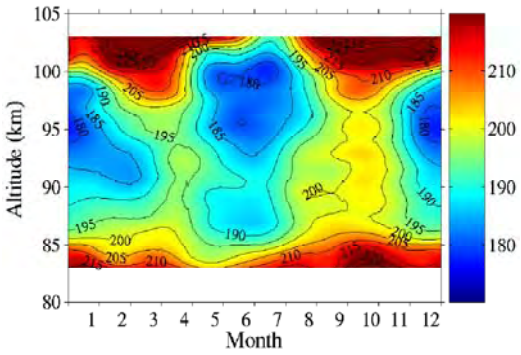
Human-induced changes in the Earth climate system represent one of the most challenging issues in this century. Doubling concentration of the greenhouse gas CO_2 is predicted to cool the stratopause (~50 km) by 10-12 K and the mesopause region (80-100 km) by 6-12 K. Middle atmosphere temperature and polar mesospheric clouds are excellent candidates for monitoring climate change. Knowledge of the composition, temperature and dynamics in the middle atmosphere is essential for developing accurate general circulation and chemical models of the atmosphere that are used to project the future state of our climate system.

Polar Middle Atmosphere Study at South Pole (90°S) and Rothera (67.5°S, 68.0°W), Antarctica: These projects are collaborations with the British Antarctic Survey and the University of Illinois. Our objectives are to collect data of polar mesospheric clouds (PMC), iron and atmospheric density, and temperature in the middle atmosphere using an iron (Fe) Boltzmann temperature lidar, and analyze these valuable data to characterize the polar middle atmosphere composition, temperature and dynamics in Antarctica. Several key scientific findings resulting from these studies have advanced our understanding in these areas: (1) Hemispheric difference and latitudinal dependence in the mean centroid altitude of polar mesospheric clouds (figure left), i.e., the southern PMC altitudes are ~1 km higher than corresponding northern PMC at similar latitudes, and higher PMC altitudes occur at higher latitudes; (2) Heterogeneous removal of mesospheric Fe atoms by PMC ice particles at South Pole and Rothera; (3) South Pole winter temperature being significantly colder than GCM model predictions; (4) Space-shuttle-formed polar mesospheric clouds at Rothera, Antarctica; (5) Large-scale dynamics test using year-round mesospheric Fe and Na density data and gas-phase mesosphere chemistry model. Data analyses also reveal seasonal variations of gravity wave strength and its anti-correlation to PMC brightness.



Mean centroid altitudes of polar mesospheric clouds (PMC) observed by lidar and triangulation measurements in both hemispheres.

Tropical Middle Atmosphere Study at Arecibo (18.35°N, 66.75°W), Puerto Rico and Maui (20.7°N, 156.3°W): This project is a collaboration with the Arecibo Observatory. Our objectives are to characterize the thermal structure and dynamics in the tropical mesosphere and lower thermosphere (MLT) using the Arecibo potassium (K) Doppler lidar data and make comparisons to measurements at Maui and other locations. A year-round climatology of temperatures at Arecibo has been formed using nighttime K lidar data (figure right) and this is the first one in the tropical area. The mesopause (the location of coldest temperature) remains around 100 km during summer while the mesopause temperature is cold in both solstices and warm around equinoxes. A significant semiannual oscillation is clearly shown in the figure. These features are significantly different from those at mid and high latitudes.



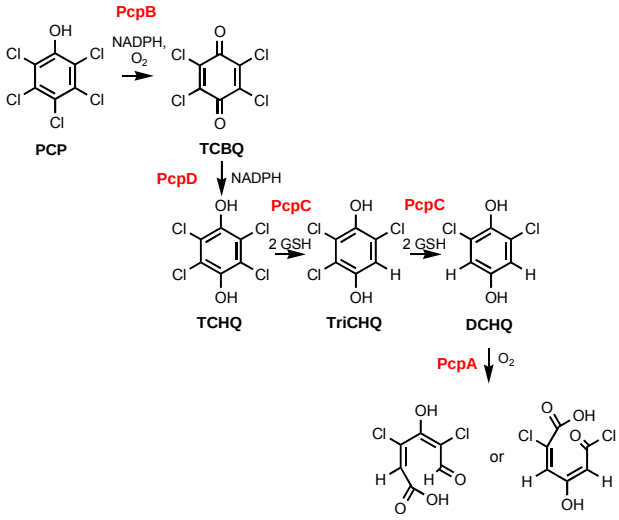
Seasonal climatology of temperature in the mesosphere and lower thermosphere (MLT) at Arecibo, Puerto Rico (18.35°N, 66.75°W).

Analysis of the Poor Catalytic Performance of Pentachlorophenol Hydroxylase

Shelley D. Copley

Funding: DOD Army Research Office

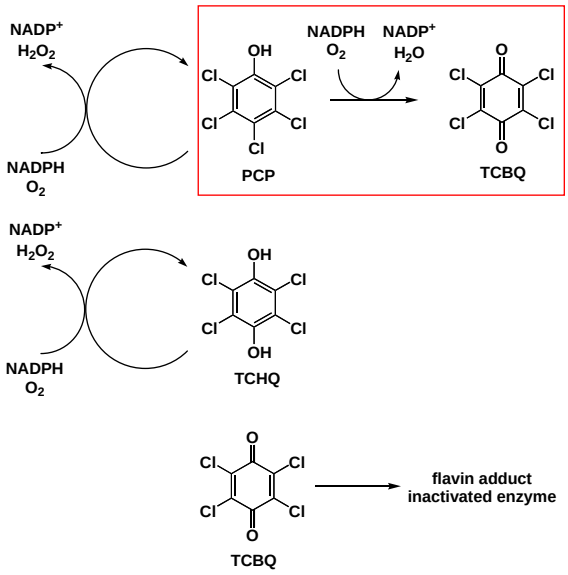
Pentachlorophenol (PCP) is a highly toxic pesticide that was first introduced into the environment in 1936. Biodegradation of PCP is challenging because it uncouples oxidative phosphorylation and alters membrane fluidity. Despite its toxicity and recent introduction into the environment, PCP can be completely 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.



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.

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 (see figure at left). None of these enzymes functions very well. The first enzyme in the pathway, PCP hydroxylase, is particularly important because it limits the flux through the pathway. We have identified the reasons for the poor function of this enzyme.

PCP hydroxylase converts PCP to tetrachloro-benzoquinone (TCBQ). The enzyme turns over substrate at a very slow rate – the reaction takes nearly 20 seconds to complete. (Most enzymes in this family complete 5-200 cycles per second.) Furthermore, the normal catalytic cycle is often subverted. Since hydroxylation of the substrate is slow, most of the time the hydroperoxy-flavin cofactor responsible for transferring the hydroxyl group to PCP decomposes to form H_2O_2. This process (which is called futile cycling) generates a toxic product and wastes the valuable metabolite, NADPH. Futile cycling also occurs in the presence of the downstream metabolite, tetrachlorohydroquinone (TCHQ). Finally, the TCBQ product can react with the active site flavin and inactivate the enzyme. The processes that occur at the active site of the enzyme are summarized in the Scheme at the right. (The desired reaction is shown in the red box. All of the other processes are wasteful.) These results help us to understand both why the current enzyme is a very poor catalyst, and the aspects of enzyme performance that need to be manipulated to evolve a better enzyme.



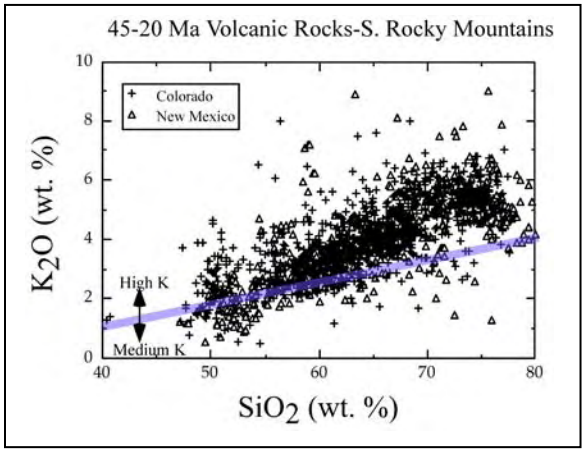
Regional Space-Time-Composition Patterns in Continental Magmatism

G. Lang Farmer
Funding: NSF Earth Sciences

In concert with collaborators at the University of Kansas, the Kansas Geological Survey, the University of North Carolina, the Carnegie Institution of Washington, and the Universidad Nacional Autónoma de México, an on-line geochronology and geochemistry database for igneous rocks in western North America has been established (*http://navdat.kgs.ku.edu/*). The North American volcanic and intrusive igneous rock database (NAVDAT) is one of three global initiatives to compile and serve terrestrial igneous rocks data. All three are cooperating as the "Earthchem" project (*http://www.earthchem.org/*) and share the same basic database schema. NAVDAT currently contains some 40,000 searchable samples from western North America, and includes a variety of on-line sample mapping and data visualization capabilities.

Accomplishments

Sufficient data is now available through NAVDAT to easily allow interrogation of regional space-time-composition patterns in Late Cretaceous and younger magmatism in western North America in unprecendented detail. Farmer's research group has concentrated on determining the origin of the mid-Tertiary "ignimbrite flareup" that affected much of western North America. This large-volume volcanic event likely affected global climate during this time period but its origin is enigmatic. Using NAVDAT as the primary research tool, Farmer's group used volcanic rock chemical, isotopic and eruptive volume data to assess models for the origin of this igneous activity. The results of this assessment suggest that if the magmas parental to the ignimbrite flareup in the southern Rocky Mountains were derived by conductive heating of the base of pre-existing mantle lithosphere, as the current data suggest, then the estimated mantle source volumes not only require that the lower 20 km of the mantle lithosphere beneath the entire southern Rocky Mountains have partially melted during the mid-Tertiary but also that mafic magmas were drawn laterally for distances of up to ~300 km into each center. Such widespread melting of lithospheric mantle melting requires that the lithospheric mantle has been uniformly fertile and primed for melting, a possibility if the lithospheric mantle had experienced widespread hydration and refrigeration during early Tertiary low angle subduction. Exposure of the mantle lithosphere to hot, upwelling sublithospheric mantle during subsequent slab roll back could then trigger the mantle melting.



Chemical data (wt. % K_2O and SiO_2) for mid-Tertiary (45-20 Ma) old volcanic rocks in Colorado and New Mexico, as delivered from the North American Volcanic and Intrusive Rock Database.

Significance

The work on the ignimbrite flareup demonstrates the power of interrogating hundreds of rock chemical analyses in addressing fundamental issues in assessing the origin continental volcanic activity. Prior to the advent of NAVDAT, consideration of large igneous rock datasets (large by igneous petrology standards, in any event) was rarely undertaken due to the large amount of work involved in compiling literature data. This issue has now been surmounted and it is anticipated that NAVDAT and EarthChem will become standard tools in the study of the continental lithosphere.

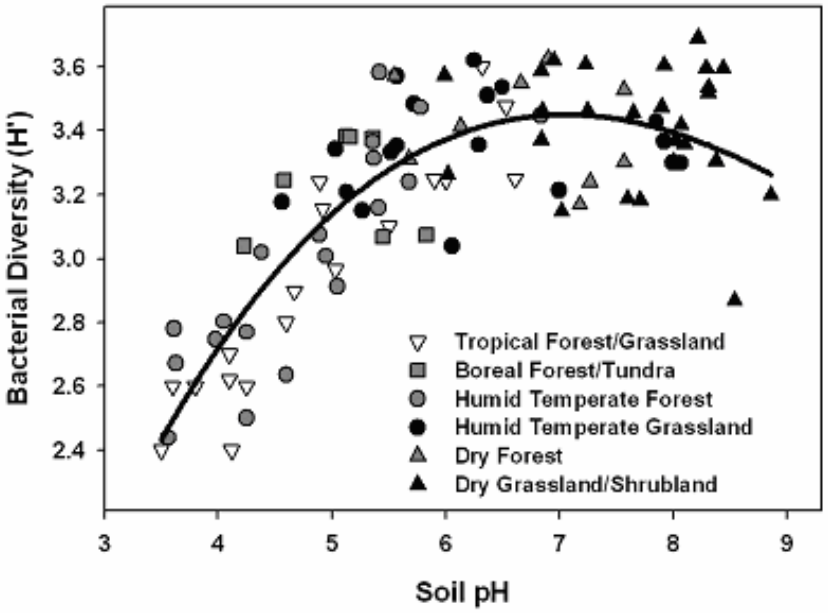
The Biogeography of Soil Microbial Communities

Noah Fierer

Funding: A.W. Mellon Foundation, National Science Foundation

Soil microorganisms represent a major portion of the living biomass on Earth and their activities play an integral role in terrestrial nutrient cycles and the maintenance of soil fertility. Despite their abundance and biogeochemical importance, we are only beginning to understand the patterns of diversity exhibited by soil microorganisms. Our objectives for this project were to characterize the diversity of soil microorganisms and describe the continental-scale distribution of soil microbial communities.

We collected 90 soils from across North and South America and used a range of molecular analyses (terminal restriction fragment length polymorphism analyses, clone libraries, and quantitative PCR assays) to examine the biogeographical patterns exhibited by soil bacterial communities. We found that bacterial diversity was unrelated to site temperature, latitude, and other variables that typically predict plant and animal diversity, and community composition was largely independent of geographic distance. The diversity and richness of soil bacterial communities differed by ecosystem type and these differences could be explained almost completely by soil pH (figure this page). To our knowledge, this project represents the first continental-scale description of soil bacterial communities and the environmental factors influencing their biodiversity.



In a related project, we compared the diversity and community structure of archaea, bacteria, fungi, and viruses in the surface soil from three very different ecosystems (desert, prairie, and tropical rainforest). We exhaustively characterized the full range of microscopic life in soil in order to quantitatively compare the diversity within these four distinct microbial groups. The key findings of this study are outlined below:

1) The number of species of soil microorganisms in a single $100m^2$ plot is likely to exceed the total number of microorganisms described to date.
2) Bacteria are not the most diverse group of microorganisms, the species richness of archaea, fungi, and viruses rivals or exceeds the richness of soil bacteria in rainforest, prairie, and desert soils.
3) Soil microorganisms are globally as well as locally diverse. The centuries-old speculation that the global diversity of the smallest organisms should be relatively low is apparently incorrect.

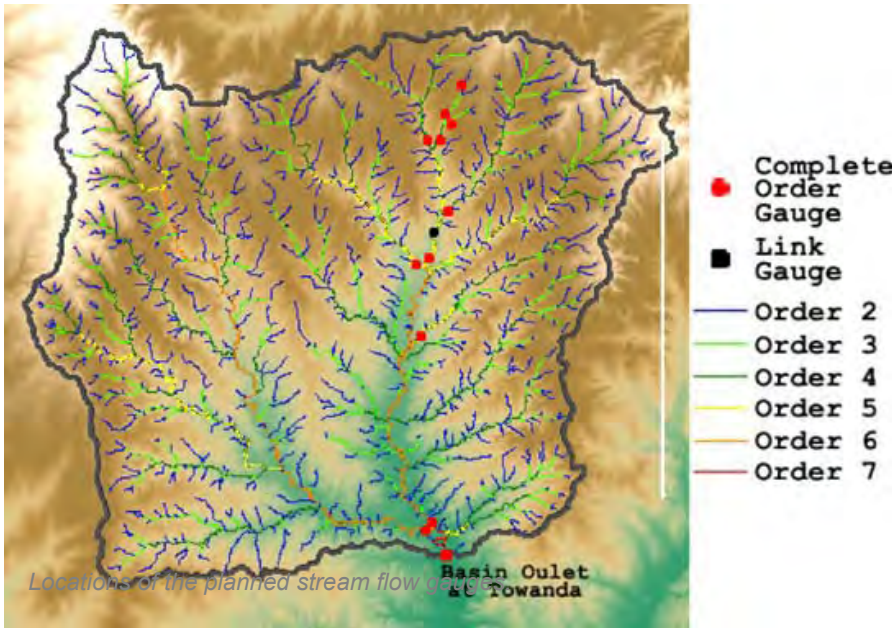
Tests of Spatial Scale Invariant Statistics in Floods and Riparian Evapotranspiration and their Biophysical Bases on the 1100 sq. km. Whitewater Basin, Kansas

Vijay K. Gupta
Funding: NSF, DOE

Our project is part of a broad, multidisciplinary Hydro-Kansas (H-K) program involving several academic institutions and federal agencies. It is designed to test two integrative scientific hypotheses. The short-term goal is to validate the existence of fundamental, statistical scale-invariant relationships for floods and riparian vegetation evapotranspiration (ET), which can be tested from coupled biophysical processes involving water, energy, terrain and vegetation on time scales of individual rainfall-runoff events. The long-term goal is to extend this research to seasonal, annual and inter-annual time scales.

Accomplishments

H-K is an example of the research proposed in the Water, Earth, Biota (WEB) report to NSF (*http://cires.colorado.edu/hydrology*), involving specific hypotheses and observations in the Whitewater Basin, Kansas. In the first phase of the H-K project (2001-present), we developed a digital watershed environment for numerical modeling that is being used for testing the biophysical basis of statistical scaling hypotheses, and for data archiving. Initial results illustrate the signatures of channel network geomorphology and temporal rainfall variability in flood-scaling parameters. Diagnostic testing of the flood-scaling hypothesis requires a large number of gauging stations at the end of complete Horton-Strahler streams; obtaining a high-density set of stream flow hydrographs from the existing USGS gauging technology is difficult and cost-prohibitive. Thus, we developed and tested a new stream-gauging methodology on the Whitewater during the second phase of the project (2003-2004). Initial results are promising and comparable to or better than the well-established, century-old USGS methodology. The third phase (2005-06) includes plans to install 12 stream flow gauges at the end of complete Horton-Strahler streams (figure this page). In addition, 14 rainfall-gauging sites in Whitewater Basin are being installed in the third phase and will be used in tandem with NEXRAD at Wichita for estimating space-time variable rainfall. A network for auto-mated data acquisition and transmission to a central facility is being designed and implemented by the H-K collaborating institutions. NSF and the DOE Atmospheric Radiation Measurement (ARM) climate research facility (ACRF) in the Southern Great Plains (SGP) are supporting the H-K research.



Locations of the planned stream flow gauges

Significance

The H-K project illustrates first steps towards developing a new unified network-based theory that couples hydrologic science and engineering, hydrometeorology, landscape geomorphology with statistical variability in floods across multiple scales of a river basin. The Riparian ET scaling hypothesis will bring boundary-layer meteorology and landscape ecology into the H-K program. Development of an integrative observational and theoretical core-research H-K program has the potential to incorporate stream ecology, biogeochemistry, climate variability and anthropogenic impacts in a mesoscale river basin.

Tectonics of Foundering Lithosphere, Sierra Nevada, California

Craig H. Jones
Funding: NSF EarthScope 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 conducting a new seismological experiment to understand the dynamics of this process.

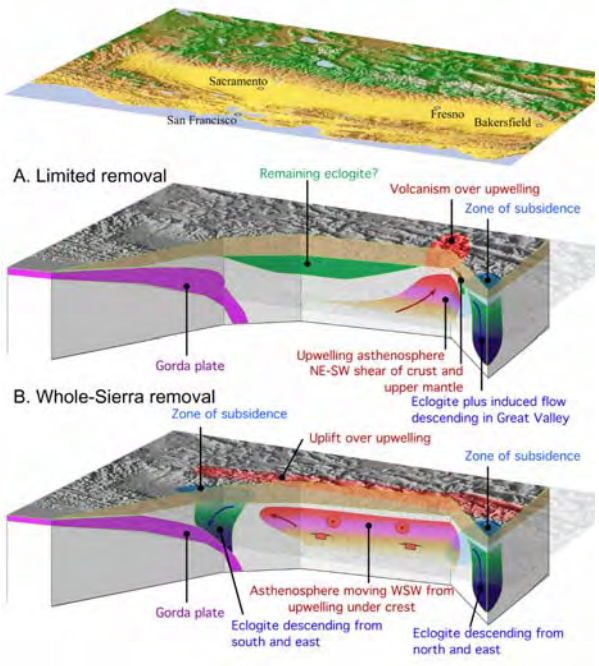
Accomplishments

The present grant represents the very first deployment of the FlexArray facility being constructed by IRIS PASSCAL as part of the US Array component of the NSF ~$200M MRE (Major Research Equipment) EarthScope program. In just over six months from award, we have placed a network of forty field stations in two states, four national forests, and two national parks. Four CU students, as well as a hosted IRIS intern from Georgia Tech, have gained considerable field experience. Although the full analysis awaits completion of this first phase of the experiment, an early examination of P-wave travel times indicates sufficient data to fully image the foundering mantle lithosphere under the Sierran foothills. Surprisingly, the material seems to be plunging to the southeast. Early analysis suggests that the anomaly is about 250-300 km deep, and the top might well extend to the crust just northeast of Fresno, California.

CIRES students complete final checks on seismometer.

Significance

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. Recognizing that the Sierra overlies freshly-removed lithosphere provides the chance to understand this process from observations. Previously, Dr. Jones and his colleagues (including CIRES Fellow G. Lang Farmer) had proposed that the foundering of sub-Sierran lithosphere had led to widespread uplift of the Sierra and western Great Basin, extensional faulting in the western Great Basin, contraction across the California Coast Ranges, and a shift in Pacific-North America plate motion from the western towards the eastern side of the Sierra (figure below, bottom panel). Work by Jones and CIRES Fellow Peter Molnar had shown that the descent of this lithosphere was consistent with Rayleigh-Taylor instabilities and laboratory experiments on rock rheology provided that high-stress limits on power law rheologies were honored, indicating that such high-stress limits on rock strength are probably real. The constraint of the new experiment on the base of the descending body is critical in providing bounds on descent of this kind of material. Furthermore, the unusual geometry of the descending body, not predicted by experiments to date, poses new challenges for understanding this process and suggests unforeseen factors at play.



Competing explanations in the Sierra: localized lithospheric foundering with minimal implications (center) and widespread foundering with widespread consequences (bottom).

Aquatic Biogeochemistry of Nitrogen

William M. Lewis, Jr.

A new topic of interest this year for me and for Professional Research Associate James McCutchan as well as Fulbright Fellow Tara Higgins has been the gas content of bubbles emanating from the South Platte River below Denver. This topic fits within the framework of our previous and current wide-ranging biogeochemical studies of the South Platte River. In the last few years we have focused on the biogeochemistry of nitrogen. The river supports high rates of nitrification, which involves microbial conversion of ammonia to nitrate under oxic conditions. As a seeming paradox, the river also supports very high rates of denitrification, which involves the conversion of nitrate to N_2 gas by microbes under anoxic conditions. Our past studies have shown that nitrification occurs within the water column and at the substrate-water interface, where oxygen is available. In the so-called hyporheic zone, below the surface of substrate, the water moves slowly and the process of organic matter decomposition reduces oxygen concentrations to less than 2 mg/L, at which point denitrification becomes possible. Thus, spatial compartmentalization within the river and its bed allows both nitrification and denitrification to occur in the same reach of river.

Recently we developed a method for estimating river denitrification rates based on the diffusive efflux of N_2 gas from the water surface, thus making possible for the first time realistic estimation of denitrification rates in an entire river. Previously, rates have been estimated under controlled (incubation) conditions that could not replicate the spatial complexity and scale of an entire river.

In the process of studying nitrogen efflux by diffusion across the water-air interface, we noted copious release of bubbles from the sediment surface under some circumstances (see figures at left). Bubbles of this type are identified in many aquatic environments and almost always are dominated by methane or CO_2. We found that bubbles in the South Platte are dominated by N_2. This is the first case that we know of in which N_2 production by denitrification has proceeded to such an extent that N_2 is actually released as bubbles from the sediment surface. We are in the process of estimating the release rates, the conditions leading to this type of release, and the means of incorporating this ebullition flux into estimates of total N_2 release estimated previously only from diffusive losses.

How Does Climate, Especially Climate Change, Affect Erosion?

Peter Molnar

Description

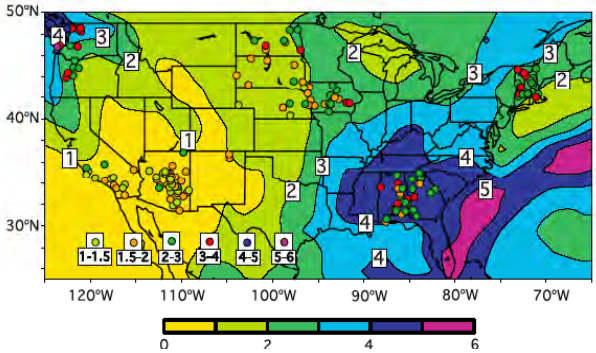
Peter Molnar devoted part of his research effort in 2005 to understanding erosion of high terrain, with the ultimate goal of answering the question: How does climate, especially climate change, affect erosion? One study addressed glacial erosion; a second considered the statistics of flooding; and a third attempted to redress a myth about the principal role of tectonic processes in erosion.

Accomplishments

Whereas rivers commonly incise valleys with longitudinal profiles that are concave upward, glaciers erode steep headwalls that give way to nearly flat valleys downstream. *Anderson et al.* [2006] offered a simple explanation for this difference and buttressed this with a simple mathematical model. Glaciers should erode where the flux of ice is most rapid, and in most alpine environments this occurs at high altitudes, between ridge crest and toes of glaciers, where ice flux vanishes. Thus, erosion is most rapid in the middle of the longitudinal valley.

Molnar et al. [2006a] showed that for rivers in different climates in the USA, the cumulative distributions $N(Q)$ of both daily and peak annual discharges Q can be described by a power-law relationship: $N(Q) \sim Q^a$. Moreover, the exponent a depends on climate, such that a is smaller in arid than humid regions (see figure below). Using this fact, we asked the question: Would a shift toward a more arid (or humid) climate increase or decrease incision rates? In the limit of very arid climate, increased aridity reduces incision rates. (As discharge drops to zero, incision ceases.) For sufficiently humid climates, a shift toward greater aridity, however, could accelerate incision, but only if incision occurred during very rare, large storms, those that occur with recurrence intervals as large as ~1000 years.

In what might be seen as a polemic, *Molnar et al.* [2005b] argued that the most important role of tectonics in erosion is not the elevating of rock to higher elevations, as most seem to believe, but the fracturing of rock, which makes fragments of rock more amenable to transport by rivers and glaciers.



Map showing locations of stream gauges that we studied and values of a in equation (1) that we estimated from mean daily discharge measurements, superimposed on contours of mean daily rainfall in mm/day. Small values of correlate with regions of low precipitation.

Significance

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 that 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.

References

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Carbon-Climate Interactions in a Colorado Subalpine Forest

Russell K. Monson

Funding: Department of Energy, National Science Foundation

For the past eight 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 CO_2 from the trees and soils of the ecosystem and their response to interannual climate variation. Our site is one of over 200 worldwide that function in an integrated network known as Fluxnet. The purpose of Fluxnet is to provide fundamental insight and data to modelers interested in predicting regional and global carbon budgets, particularly in response to future climate change. We have particularly 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 2-3 weeks earlier, on average, over the past decade, 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.

We have discovered that the potential for this ecosystem to remove CO_2 from the atmosphere responds negatively to the earlier spring warm-up for two reasons. First, most of the annual CO_2 uptake occurs in the late-spring, when the forest is fed by melting snow. Earlier springs are correlated with less springtime snow and thus less potential for photosynthesis by the forest. Second, the forest soil loses less carbon through its microbial respiration under a snowpack than when it's exposed. Earlier springs cause the soil to become exposed earlier in the year, and thus cause an earlier change from a small CO_2 source to a large CO_2 source. In many ecosystems of the world, earlier spring warming will translate into increased CO_2 sequestration from the atmosphere. In the mountain forests of the Western U.S., this will likely not be the case due to their extreme sensitivity to changes in the winter snow regime.

Niwot Ridge AmeriFlux site; subalpine forest; lodgepole pine, subalpine fir, Englemann spruce; 3500 ft elevation.

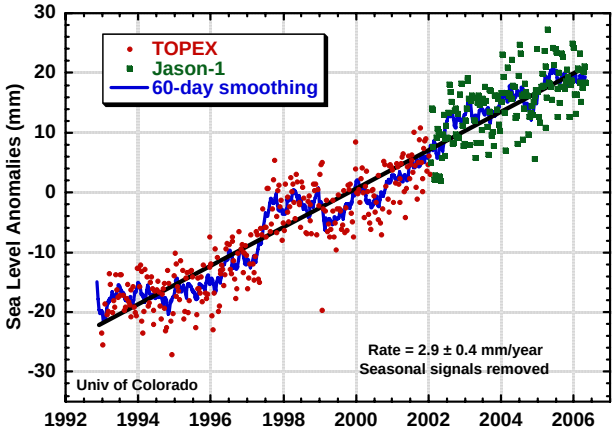
A Multidisciplinary Investigation of Present-Day Sea Level Change

R. Steven Nerem

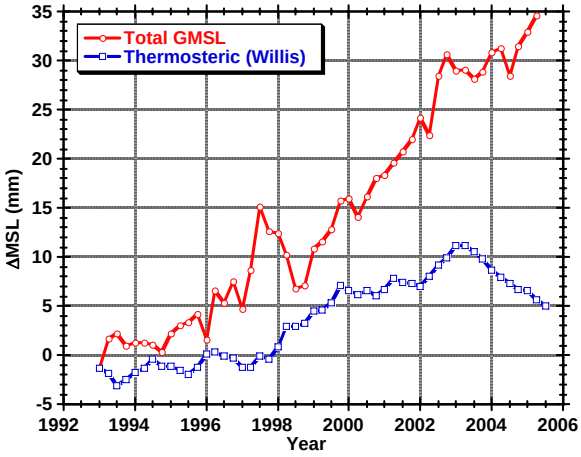
Observations of long-term sea-level change can provide important corroboration of climate variations predicted by models and can also help us prepare for the socioeconomic impacts of sea level change. The TOPEX/Poseidon and Jason satellites have observed a mean rate of sea-level rise of 3 mm/year since 1993 (figure below left). Current efforts focus on determining the causes of this change and relating the satellite record of sea-level change to the longer-term record from tide gauges.

Accomplishments

Much has been learned over the past year regarding the contributions to the observed record of sea-level change from satellites. Of the observed 3 mm/year global averaged sea-level rise, approximately half is now thought to be due to the warming of the oceans (thermal expansion) and the other half due to the addition of freshwater from the continents. The latter is mainly due to the melting of ice in mountain glaciers, Greenland, and Antarctica. The total rise is significantly greater than has been observed over the last 75 years from tide gauges (~1.8 mm/year), and is in rough agreement with observed increases in ocean temperature and the melting of continental ice. However, ocean temperature measurements have shown a recent cooling of the global ocean which has not been observed in the satellite altimetry (figure below right).



Recently, a new technique has been developed that allows the direct measurement of the continental water contributions from space. The GRACE satellite mission has precisely measured temporal variations in the Earth's gravitational field since 2002. As the melting of ice in mountain glaciers and ice sheets, in addition to other runoff, adds water mass to the oceans, GRACE has demonstrated the ability to directly measure this change in mass. GRACE can also determine the relative contributions of different areas on the continents. At seasonal frequencies, GRACE ocean mass estimates have been shown to compare quite well with estimates from satellite altimetry corrected for thermal expansion using shipboard measurements. The seasonal variations in ocean water mass are due to the seasonal exchange of water with the continents, and thus GRACE measurements are expected to make their greatest impact on studies of the global water cycle. However, eventually GRACE should help unravel the differences we have seen between the altimetry and the ocean temperature measurements, as in theory these are due to changes in global ocean mass.



Significance

Satellite altimeter and gravity measurements are taking a significant role in the formulation of the next IPCC climate assessment. Satellite altimetry has conclusively shown that sea-level rise has been higher over the last 12 years as 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. 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.

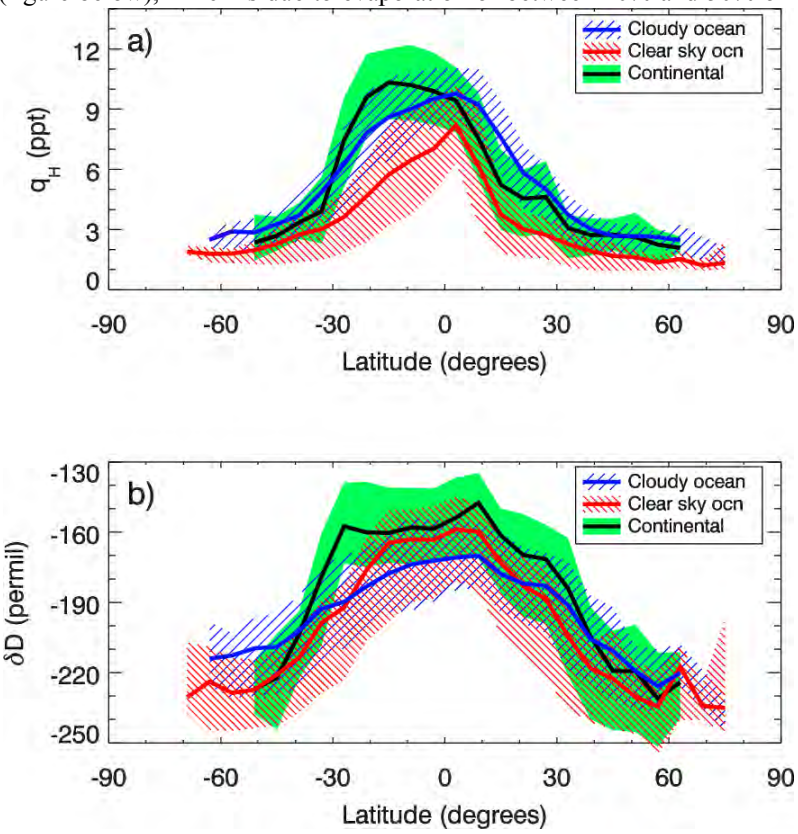
Global Hydrologic Cycles Seen with Water Isotope Measurements from Space

David Noone
In collaboration with the NASA Jet Propulsion Laboratory

Observations from the Tropospheric Emission Spectrometer on board NASA's Aura spacecraft have allowed development of a new climatology of isotopic composition of water vapor. Key uncertainties remain in the understanding of evaporation and cloud processes and how their variations affect climate. The new measurements of the HDO to H_2O ratio (expressed as δD) provide insight to hydrologic exchange because lighter isotopes preferentially evaporate and heavier isotopes preferentially condense. As such, the isotopic composition is used to identify characteristics of hydrologic processes as water vapor is tracked from its evaporative source to condensation sink. In this way the space-based climatology provides an unprecedented perspective on water cycling and establishes a baseline against which future changes in the global hydrologic cycle can be measured.

Accomplishments

We find the extra-tropical oceanic hydrology is described well by a balanced cycle of condensation, as saturated air moves poleward in the cloudy regions that deplete the atmosphere in heavy HDO molecules, and evaporation into cloud free air which enriches the atmosphere in HDO at a greater rate. The isotopic composition of cloudy and clear sky observations is the same at around 30° in both hemispheres and can be interpreted as a typical location of the global evaporation source. In the tropics a closed hydrologic cycle is exposed as a balance between water gain during evaporation in the subtropics and supplied to the tropics by advection, with water lost during convection and precipitation which leaves the vapour highly depleted before outflow, presumably aloft, returns the dry air to the subtropics. The difference between the tropical and extratropical regimes is characterized by the strong isotopic depletion in the cloudy data in the tropics (figure below), which is due to evaporation of between 20% and 50% of rain falling from convective storms. Over tropical continents, vapor is typically enriched relative to vapor over oceans and suggests evapo-transpiration and continental convection are significant in the supply of boundary layer vapor to the free troposphere, and highlights processes that have not been well recognized in previous studies of tropospheric climate.



Contrast between cloudy and clear sky ocean, and continental observations. Zonal mean observed (a) water vapour volume mixing ratio and (b) δD binned at 6° latitude. Oceanic observations are stratified as clear sky (cloud optical depth less than 0.3 and humidity less than 50%, red, 53% of all observations) and cloudy (cloud optical depth greater than 0.3 and humidity greater than 80%, blue, 27% of all observations) conditions. All land observations (black curve, green shading) represent 12% of observations. Hatched area is bounded by the 25 and 75 percentiles of each subset.

Normalized U.S. Hurricane Damage: 1900-2005

R. A. Pielke, Jr., J. Gratz, D. Collins, C. Landsea, M. Saunders, and R. Musulin

Consider economic damage (adjusted for inflation) related to hurricane landfalls in the United States, 1900-2005, as shown in Figure 1. Although damage is growing in both frequency and intensity, this trend does not reflect increased frequency or strength of hurricanes. In fact, while hurricane frequencies have varied a great deal over the past 100+ years, they have not increased in recent decades in parallel with increasing damages. To the contrary, although damage increased during the 1970s and 1980s, hurricane activity was considerably lower than in previous decades.

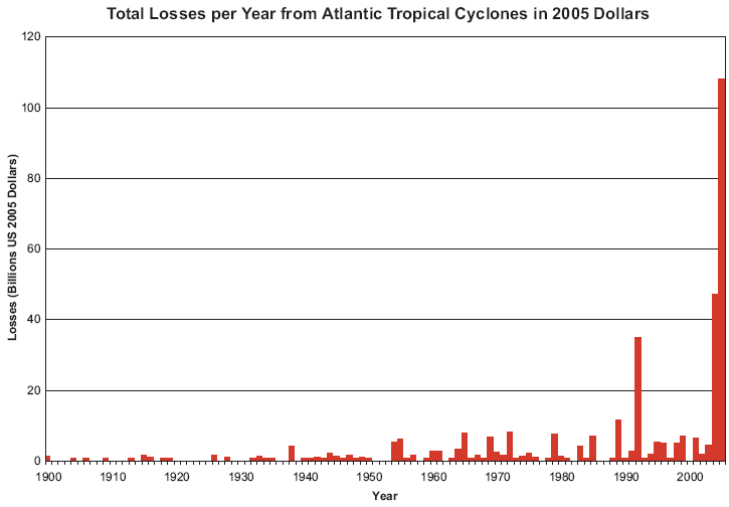


Figure 1. Trend in U.S. hurricane damage, 1900–2005.

To explain the increase in damage, it is therefore necessary to consider factors other than variability or change in climate. Society has changed enormously during the past century and coastal development has taken pace at an incredible pace. Given the significance of societal change in trends of hurricane damage, one way to present a more accurate perspective on such trends is to consider how past storms would affect present society. We developed a methodology for normalizing past hurricane damage to present-day values (using wealth, population, and inflation). Figure 2 shows the historical losses of Figure 1 normalized to 2005 values. The normalized record shows that the impacts of Hurricane Andrew, at close to $53 billion (2005 values) (unpublished analysis by author, updated from *Pielke and Landsea*, 1998), would have been far surpassed by the Great Miami Hurricane of 1926, which would have caused an estimated $137 billion damage had it occurred in 2005, exceeding similarly accounted costs of Katrina. We can have some confidence that the normalized loss record accounts for societal changes because, unlike the unadjusted data, the adjusted damage data accurately reflect well-understood patterns of climate variability, such as the signal of El Niño and La Niña in hurricane frequencies.

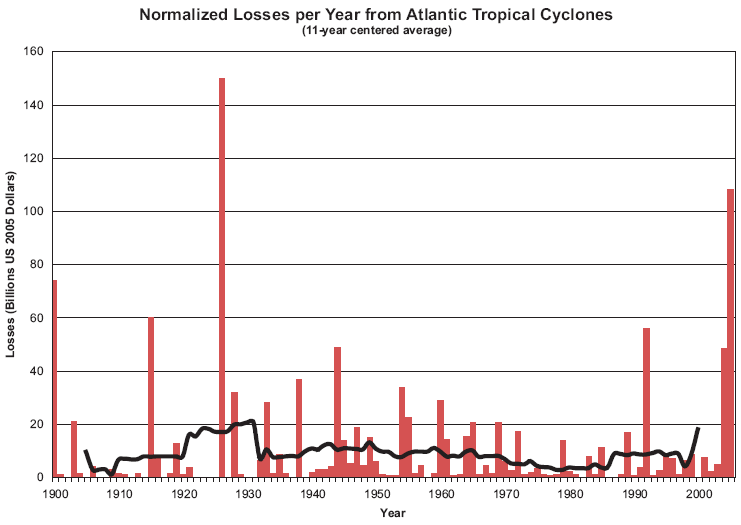


Figure 2. Estimated hurricane damages 1900–2005 if storms of the past made landfall with coastal development of 2005. The black line is the 11-year centered moving average of estimated hurricane damage.

Understanding the Spatio-Temporal Variability of the North American Monsoon: Implications to Water Resources Management in the Southwestern US

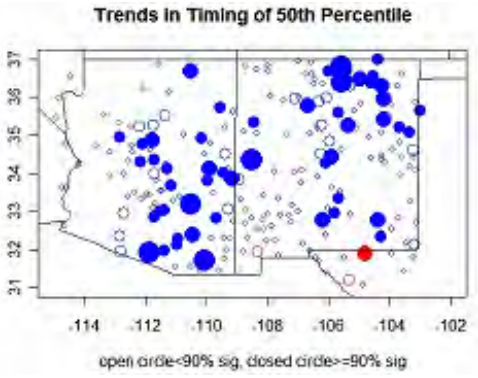
Balaji Rajagopalan

Funding: National Oceanic and Atmospheric Administration

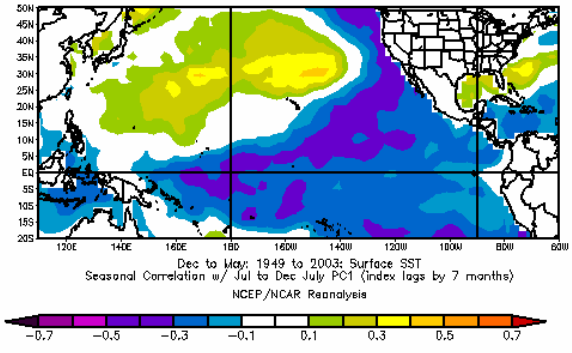
Significant part of the streamflows in the South Western US region occurs during summer due to North American Summer Monsoon (NASM) precipitation (up to 50% of annual precipitation occurs during summer). Although, the NASM is not a strong phenomenon, unlike its Indian and Asian counterpart, its impact on water resources management and planning activities is unquestionable. Therefore, understanding the spatio-temporal variability of summer precipitation and the associated hydrologic cycle is crucial for developing effective water management strategies. To this end, this interdisciplinary research effort will broadly involve: (a) Diagnosis: Understanding the spatio-temporal and interannual variability of the summer precipitation, temperature and streamflows (b) Prediction: Developing improved methods for ensemble hydrologic prediction that incorporates the climate variability information and (c) Water Management: Incorporate all of this in a Decision Support System (DSS) for water management – with application to the Pecos River Basin.

Accomplishments

Analysis is performed on the spatio-temporal attributes of North American Monsoon System (NAMS) rainfall in the southwestern USA. Trends in the timing and amount of monsoon rainfall for the period 1948-2004 are examined. The timing of the monsoon cycle is tracked by identifying the Julian day when the 10th, 25th, 50th, 75th, and 90th percentile of the seasonal rainfall total has accumulated. Trends are assessed using the robust Spearman rank correlation analysis and Kendall Theil slope estimator. Principal component analysis is used to extract the dominant spatial patterns and these are correlated with antecedent land-ocean-atmosphere variables. Results show a significant delay in the beginning, peak and closing stages of the monsoon in recent decades. The results also show a decrease in rainfall during July and a corresponding increase in rainfall during August and September. Relating these attributes of the summer rainfall to antecedent winter/spring land and ocean conditions leads us to propose the following hypothesis: warmer tropical Pacific sea surface temperatures (SSTs) and cooler northern Pacific SSTs in the antecedent winter/spring leads to wetter than normal conditions over the desert southwest (and drier than normal conditions over the Pacific Northwest). This enhanced antecedent wetness delays the seasonal heating of the North American continent that is necessary to establish the monsoonal land-ocean temperature gradient. The delay in seasonal warming in turn delays the monsoon initiation, thus reducing rainfall during the typical early monsoon period (July) and increasing rainfall during the later months of the monsoon season (August and September). While the rainfall during the early monsoon appears to be most modulated by antecedent winter/spring Pacific SST patterns, the rainfall in the later part of the monsoon seems to be driven largely by the near term SST conditions surrounding the monsoon region along the coast of California and the Gulf of California. The role of antecedent land and ocean conditions in modulating the following summer monsoon appears to be quite significant. This enhances the prospects for long-lead forecasts of monsoon rainfall over the southwestern US, which could have significant implications for water resources planning and management in this water-scarce region.



Trends in the timing of the median summer rainfall. Blue circles indicate delay in the timing and red advancement; filled circles are significant at 90% confidence level.



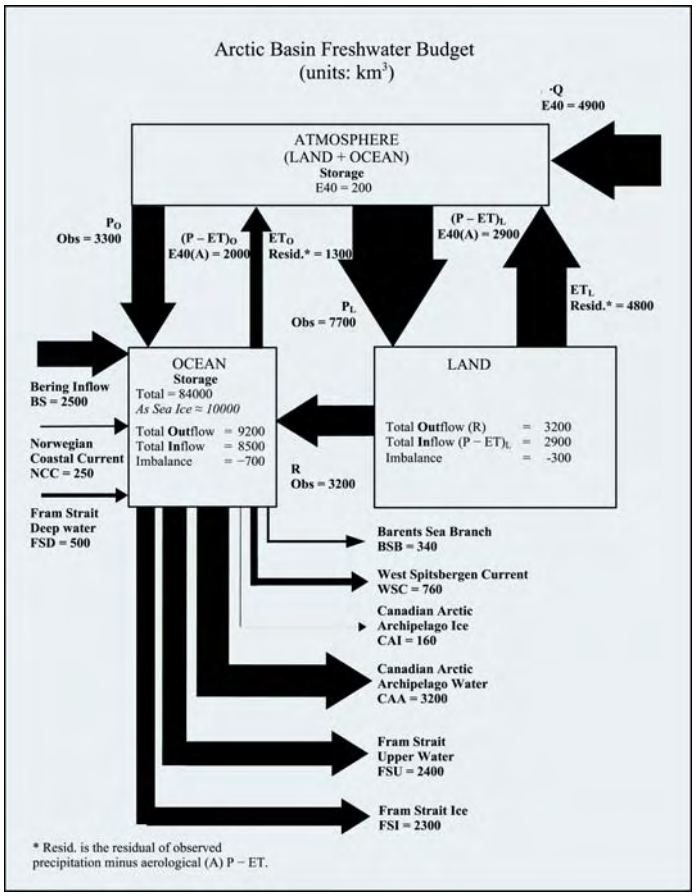
Leading principal component of July precipitation over the North American Monsoon Region with the preceding winter/ spring SST. Note the correlation with the tropical Pacific SSTs.

The Freshwater Budget of the Arctic

Mark C. Serreze, Andrew P. Barrett, Andrew G. Slater
Funding: NASA and NSF

The Arctic freshwater system is shaped by a remarkable conjunction of latitude, geography and marine processes, and its climatic impacts extend beyond the Arctic. Research over the past year has focused on synthesizing information gathered over the past decade to document the principal pathways between the atmospheric, terrestrial, and oceanic components of the Arctic freshwater system. This effort combines terrestrial and oceanic observations with insights gained from atmospheric reanalyses, land surface and ice-ocean models. As an outcome of this work [*Serreze et al.,* 2006], we have assembled a modern view of the Arctic's mean annual freshwater budget (figure below). The atmospheric box combines the region over the Arctic Ocean and the vast land region that drains into it. The boxes for land and ocean are sized proportional to their areas. The arrows denote the freshwater transports in units of km^3 per year, with the width of the arrows proportional to the size of the transports. Freshwater stores are in km^3. P denotes precipitation, and ET evapo-transpiration. R is river runoff to the Arctic Ocean. Subscripts "L" and "O" denote land and ocean, respectively. "A" means aerological estimate from atmospheric reanalysis.

Annual mean freshwater input to the Arctic Ocean is dominated by river discharge (38%), inflow through Bering Strait (30%) and net precipitation (24%). Total freshwater export from the Arctic Ocean to the North Atlantic is in turn dominated by transports through the Canadian Arctic Archipelago (35%) and via Fram Strait in both liquid (26%) and sea ice (25%) form. All terms are computed relative to a reference salinity of 34.8. Compared to earlier estimates, this budget features a larger import of freshwater through Bering Strait and a larger liquid-phase export through Fram Strait. While there is no reason to expect a steady state, error analysis indicates that the difference between annual mean oceanic inflows and outflows (~700 km^3, or ~8% of the total inflow) is indistinguishable from zero. Freshwater in the Arctic Ocean has a mean residence time of about a decade. This is understood in that annual freshwater input, while large (~8500 km^3), is an order of magnitude smaller than the oceanic freshwater storage of ~84000 km^3 (representing both liquid water and sea ice). Freshwater in the atmosphere, as water vapor, has a residence time of about a week. Seasonality in Arctic Ocean freshwater storage is still highly uncertain, reflecting both sparse hydrographic data and insufficient information on sea ice volume. These uncertainties mask seasonal storage changes forced by freshwater fluxes. Of flux terms for which data are sufficient for analysis, the Fram Strait ice outflow shows the largest interannual variability.



Annual mean freshwater budget of the Arctic.

Serreze, M.C., A.P. Barrett, A.G. Slater, R.A. Woodgate, K. Aagaard, R. Lammers, M. Steele, R. Moritz, M. Meredith, and C.M. Lee (2006), The large-scale freshwater cycle of the Arctic, *J. Geophys. Res*. (in press).

Aspen Seismic Station for Improved Colorado Earthquake Data

Anne Sheehan
Funding: NSF, USGS

A new seismic station near Aspen, Colorado, was installed June 2005 by the Sheehan research group at CIRES in collaboration with scientists at the National Earthquake Information Center of the U.S. Geological Survey in Golden, Colorado.

Accomplishments

The Snowmass station is part of the U.S. Advanced National Seismic System and uses a satellite link to continuously relay data to the National Earthquake Information Center. The seismic station is broadband with a high dynamic range, meaning that it can record a large frequency and amplitude range, making it possible to record both local earthquakes and distant earthquakes at a large range of magnitudes. Data from the station can be used to determine the seismicity and seismic hazards in the northern Rio Grande Rift and southern Rocky Mountains, and can be used for tomographic and other types of seismic imaging. Seismicity in the southern Rockies is poorly characterized because of a lack of seismograph station coverage. The data are scanned by computer and by human analysts to locate earthquakes from Colorado and the surrounding region. In its first few weeks of operation, the station recorded a magnitude 2.8 mining-induced earthquake that caused damage at an underground coal mine near Paonia, Colorado. Located high in the Snowmass ski area, the station consists of a seismometer, a digitizer, and a satellite dish to send information to the National Earthquake Information Center. The station is powered by car batteries that are recharged by solar panels. The Snowmass station is the first Advanced National Seismic System station to be run by cooperation between the University of Colorado, Boulder, and the U.S. Geological Survey.

Significance

The Snowmass seismic station enhances the monitoring of earthquakes in the southern Rocky Mountain region. The data from the station will be used for tomographic imaging of the Rocky Mountains and the North American continent. The station is also an important teaching tool for geology and geophysics classes at the University of Colorado.

CU graduate students Gaspar Monsalve and Tom de la Torre, together with Colgate undergraduate Christina Viviano, at Snowmass seismic station near Aspen, Colorado, June 2005.

CIRES Aerosol Studies Have Led to Important Applications to Problems in World Health

Robert E. Sievers

Funding provided by Aktiv-Dry LLC through a grant from the FNIH as part of the Grand Challenges in Global Health initiative.

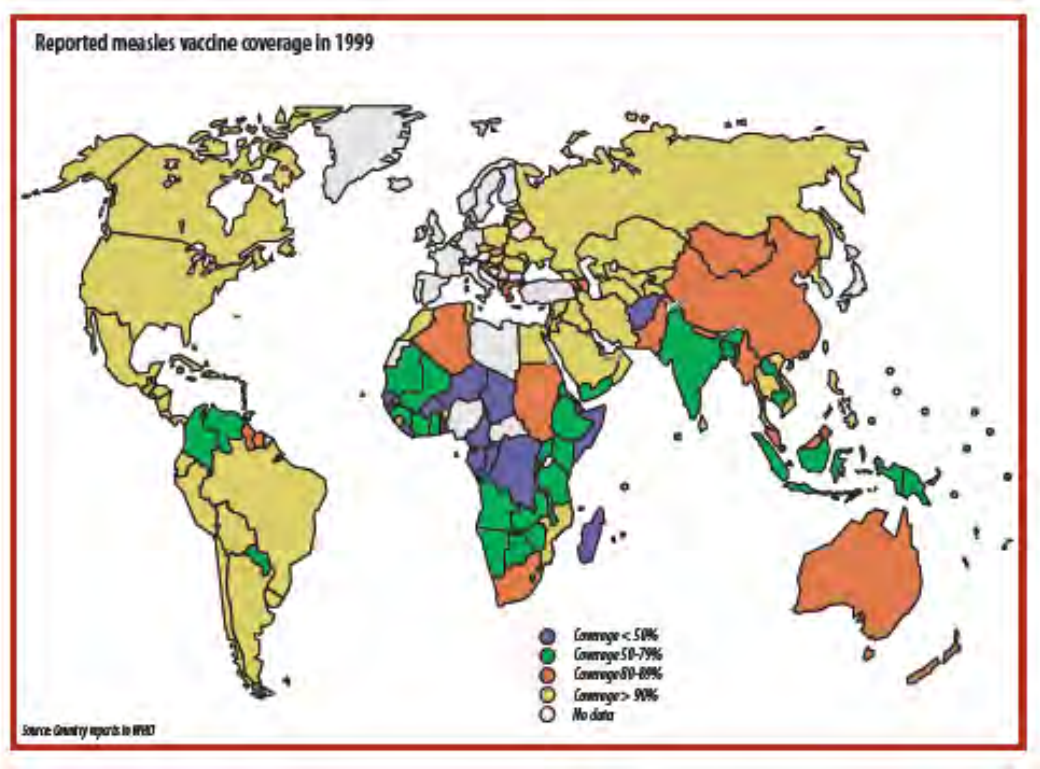
Studies by the Sievers group of atmospheric aerosols led to new methods of synthesizing aerosol microparticles. This methodology for processing was patented in 1996 and has been applied subsequently by several pharmaceutical companies and vaccine scientists. The process consists of stabilizing microparticles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

Accomplishments

Aerosol scientists, physicians, immunologists, formulation experts, engineers, device designers, and others are working together to make a stable, inhalable vaccine to reduce deaths from measles (now ca. 1,000 per day).

Elements for success are within reach but need to be integrated:

- Nebulization and drying processes at near-ambient conditions have produced 1-5 μm particles of live-attenuated measles vaccine without detectable loss of activity.
- Needle-free simple inexpensive, yet effective, powder dispensers are being perfected, then will be evaluated with stable microparticles of vaccine.
- Stability, safety and efficacy will be examined.



From the World Health Organization and UNICEF

Kilimanjaro: Interpretation of Observed 20th Century Glacier Retreat Rates

Konrad Steffen
Funding: NASA Cryospheric Sciences
Collaboration: University of Innsbruck, Austria

Purpose and Objectives

Glaciers in tropical regions have retreated drastically since the mid and second half of the 19th century, with glaciers on Africa's highest mountain, Kilimanjaro, being no exception to this trend. The retreat of glaciers on Kilimanjaro has in recent years attracted broad attention, with their disappearance sometimes linked to tropical warming. To re-evaluate possible causes of glacier retreat on Kilimanjaro we organized an expedition in summer 2005 and installed an automatic weather station, made geothermal heat flux measurements, mapped the remaining ice masses with high resolution GPS, and monitored the turbulent fluxes for estimates of moisture flux. In addition, the remaining ice bodies on Kilimanjaro were mapped using high spatial resolution images from the Quickbird satellite taken in February 2003.

Vertical ice wall (approximately 15-m height) on top of the Kilimanjaro plateau (> 5700-m elevation). Vertical wall retreat that governs the retreat of plateau glaciers is irreversible, and changes in 20th century climate have not altered their continuous demise. The areal extent of glaciers on Kilimanjaro was 2.51 km^2 in February 2003

Accomplishment

All ice bodies on Kilimanjaro have retreated drastically between 1912-2003. Despite negative air temperatures, areal retreat of plateau glaciers is governed mostly by solar radiation-induced melt on vertical walls that characterize their north and south margins. Though the processes responsible for the formation of the vertical walls is still not well understood, once established, the vertical wall retreat is irreversible; no change in 20th century climate appears to have significantly altered their ongoing demise.

Though constant shrinkage of the plateau glaciers could have started as a result of a slow change in climate, through a process that allowed the glaciers to reach some threshold to produce vertical walls, evidence for a sudden change in climate prior to the 20th century appears to come from the slope glaciers. The rapid recession of slope glaciers in the first part of the 20th century clearly shows that they were drastically out of equilibrium. The strong imbalance at the beginning of the 20th century can only be explained by a sudden shift in climate shortly before the strong retreat rates began. Slope glaciers are still out of equilibrium, and though 20th century changes in air temperature at the height of the glaciers do not appear responsible, we cannot rule out that changes in moisture (reduction in specific humidity) may be linked to their ongoing imbalance.

Laboratory Studies of Cirrus Clouds

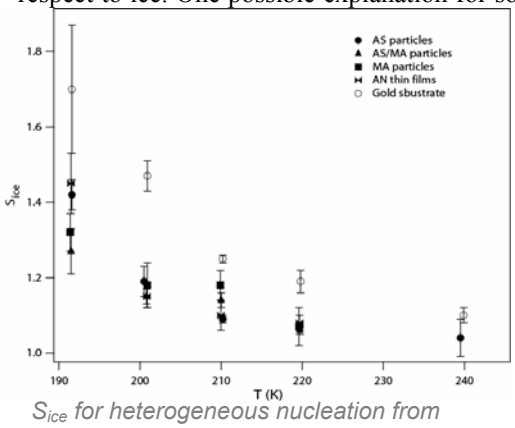
Margaret A Tolbert

Cirrus clouds, composed of water ice, cover up to 30% of the Earth's surface at any time and subvisible cirrus are almost always present in parts of the tropics. Depending on meteorological conditions, the appearance of cirrus clouds ranges from wide sheets 100 to 1000 km in length from the outflow of cumulonimbus anvils, to wispy filaments from jet stream-induced wind shear, to a subvisible cloud layer near the tropical tropopause, A photograph of cirrus clouds in Boulder, CO is shown in at left.

Cirrus clouds over Boulder, photo by Mark Zondlo.

Cirrus and subvisible cirrus clouds play an important role in the climate system as well as controlling the amount of water getting 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 last year in the Tolbert research group have probed several aspects of ice nucleation.

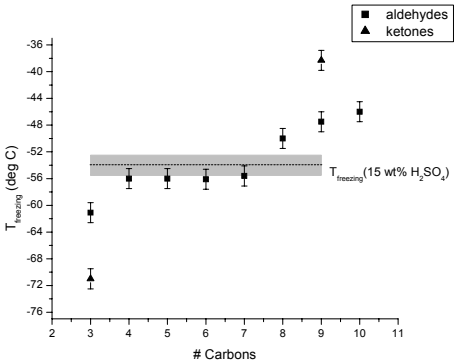
One outstanding issue in upper tropospheric chemistry is the widespread observation of supersaturations with respect to ice. One possible explanation for some of the observations is that metastable cubic ice, rather than stable hexagonal ice, might form at the low tropopause temperatures. Remarkably, although inferred, the vapor pressure of cubic ice had never been measured. In a paper in press in GRL, we measured the vapor pressure of cubic ice and found it to be approximately 10% higher than that of hexagonal ice. Thus while cubic ice may play a role in upper tropospheric water vapor, the effect is not large.



S_{ice} for heterogeneous nucleation from Shilling et al., JGR, 2006.

Two other studies in the Tolbert group probed ice nucleation in the laboratory. In one, we probed heterogeneous nucleation of ice on solid ammonium sulfate (AS), solid maleic acid (MA), mixed AS/MA particles, and thin ammonium nitrate (AN) films and the results are shown in at left. It can be seen that all of these solids nucleate ice at relatively low ice saturation ratios ($S_{ice} = P_{H2O}/VP_{ice}$). This is particularly intriguing because none of the solids provide an exact lattice match for the crystal structure of ice. This indicates that other factors, such as defects, may be responsible for the heterogeneous ice nucleation and that current theories are insufficient to explain heterogeneous ice formation on relevant solid atmospheric nuclei.

We have also probed ice nucleation on sulfuric acid particles coated with a series of aldehydes and ketones and the results are shown at right. Here we see that small soluble organics lower the ice freezing temperature, likely by lowering the solution activity. In contrast, larger low solubility organics can actually raise the freezing temperature, which we interpret as being due to heterogeneous ice nucleation on the frozen organic. These studies suggest that organics from different sources may have differing impacts on ice nucleation in the atmosphere.



Freezing temperature as a function of chain length from Beaver et al., Atm Chem Phys, 2006.

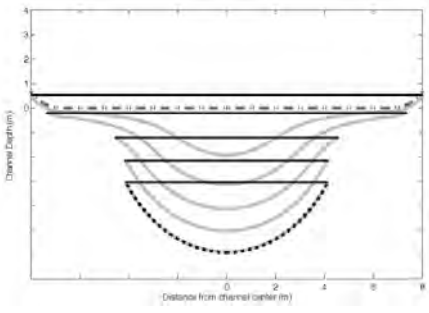
Modeling River Network Response to Tectonic and Climatic Forcing

Greg Tucker and Cameron Wobus
Funding: ARO Terrestrial Sciences, NSF Earth Sciences, UK NERC

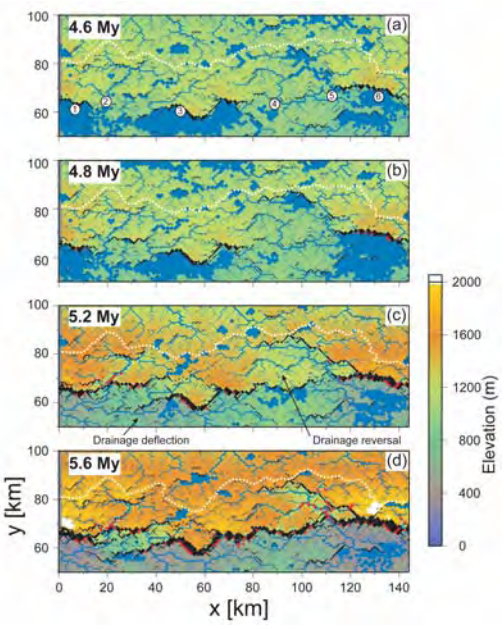
We live in a world that in which climate is changing, and yet we know remarkably little about how that change is likely to impact erosion and sedimentation patterns. Our research group is working toward improved mathematical models of landform change in response to climatic and tectonic forcing. Recent work has established a theoretical framework for describing the role of rainfall distribution, revealing that time variability in rainfall can be as important as its average rate in controlling rates of erosion and transport. In a similar vein, modeling has demonstrated the potential importance of storm duration in carving the structure of river networks. Climate involves more than just rainfall, of course, and we have worked toward building and testing theoretical frameworks to examine the impact of other factors, such as vegetation cover and intermittent permafrost.

Accomplishments

A key element of a drainage network's behavior is the geometry of its embedded channels. Channel geometry strongly influences fluid stresses, energy dissipation rates, and sediment transport efficiency. Yet current models of landscape evolution effectively ignore the dynamics of individual channels by treating them as static, one-dimensional features. New data on bedrock channel response to tectonic uplift, collected from a natural experiment in the Italian Apennines, have been collected. The Rio Torto is a bedrock river that is currently in a state of transient response to accelerated motion on an active normal-fault block. Measurements of channel geometry, grain size, and rock mass strength along the Rio Torto reveal that the channel has responded to differential uplift by both steepening and narrowing along a several-kilometer stretch upstream of an active fault. Channel narrowing has had a profound impact on the pattern of energy dissipation, which differs markedly from what the standard model would predict. In order to understand fundamental controls on the geometry of bedrock channels, we have developed a physically based model that computes the evolution of a channel cross-section in response to the stress field generated by flowing water (below left). The model uses a quasi 1D approximation for turbulent stresses, and assumes that the rate of wall erosion scales with boundary shear stress. The model predicts that incising equilibrium channel forms will have a near-constant width-to-depth ratio, with a slight dependence on boundary roughness. It also predicts an inverse relationship between width and gradient, consistent with our observations from central Italy. We are currently working to expand our database by compiling data from transient bedrock channels along the margins of the Colorado Front Range. We are also working to refine the geometry model by incorporating alluvial cover dynamics and stochastic flow variability. Ultimately, a better understanding of bedrock channel dynamics will significantly improve the fidelity of models of landscape evolution such as that shown below right.



Left. Time sequence of evolving channel forms, showing channel perimeter (thick gray lines), water surface (solid black lines), initial channel configuration (dash-dot) and final equilibrium cross section (dotted). Source: Wobus, Tucker, and Anderson, GRL, in review.

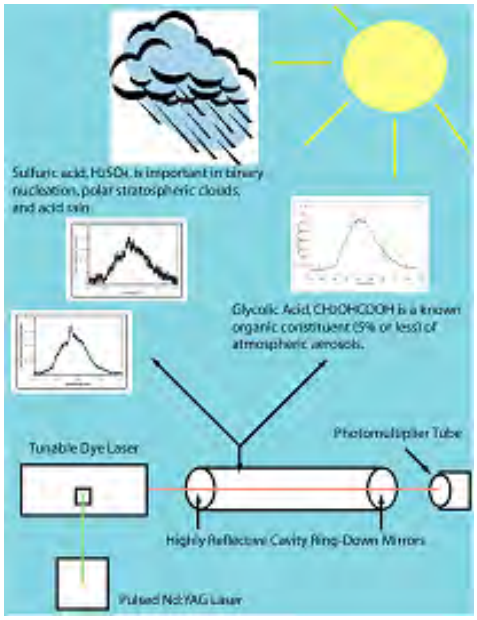


Right. Four time-snapshots of evolving topography and drainage patterns from a simulation of landscape evolution in an active extensional fault array. Images show topography (color shading), faults (black), drainage networks and lakes (blue), and drainage divides (white). Source: Cowie et al., Basin Research*, in press.*

Spectroscopy of Atmospheric Acids and their Complexes with Water

Veronica Vaida
Funding: NSF

Molecules in the atmosphere may undergo photodissociation via absorption of solar radiation. Low energy solar radiation, in some cases aided by water, can lead to reaction. Recent studies in the Vaida labs have focused on understanding vibrational overtone spectroscopy and photochemistry of atmospheric acids. This research contributes experimental spectroscopic data to the literature concerned with nucleation and the involvement of acids in aerosol and cloud formation.



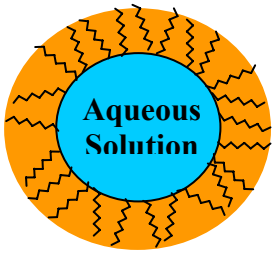
Accomplishments

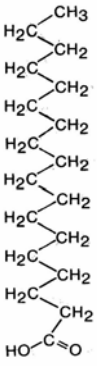
In the last few months (with NSF financial support and a collaboration with Steve Brown at NOAA), the Vaida group has constructed a pulsed cavity ring-down spectrometer to examine overtone transitions near dissociation. With this instrument we measured the near IR absorption cross sections of H_2SO_4, glycolic and malonic acids and modeled the effect of the proposed solar photochemistry to atmospheric aerosol formation.

Mills, M. J., Toon, O. B., Vaida, V., Hintze, P. E., Kjaergaard, H. G., Schofield D. P., Robinson, T. W., J. Geophys. Res. (2005) 110, D08201.
Vaida, V., Kjaergaard, H. G., Hintze, P. E., Donaldson, D. J. *Science* (2003) 299 1566.

Investigating Organic Films at the Air-aqueous Interface as Proxies for Atmospheric Aerosols

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.





Accomplishments

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.

Tervahattu, H., Juhanoja, J., Vaida, V., Tuck, A. F. Niemi, J. V., Kupiainen, K., Kulmala, M., Vehkamaki, H. J. Geophys. Res. (2005)110, D06207.
Eliason, T.L., Gilman, J.B., and Vaida, V. *Atmos. Environ*. (2004) 38 1367.
Gilman, J.B., Eliason, T.L., Fast, A., and Vaida, V. *J. Colloid Interface Sci*. (2004) 280 234.

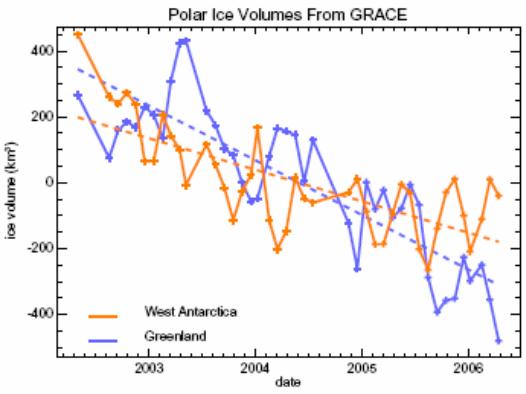
Time-Variable Gravity from GRACE

John Wahr, Isabella Velicogna, and Sean Swenson
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. This 9-year GRACE mission is mapping the 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 of about 300 km and larger.

Accomplishments

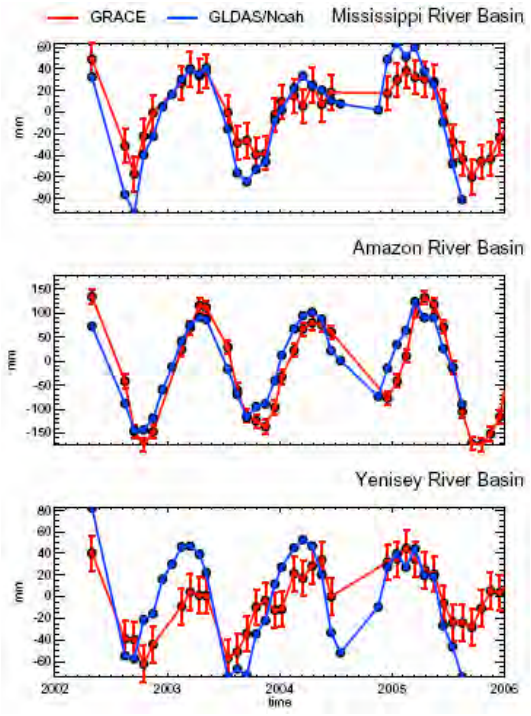
We have been using these data to look at a number of geophysical signals, particularly those that involve the storage of water (including snow and ice) on continents and in the polar ice sheets.



Monthly GRACE estimates of ice mass volume for Greenland and West Antarctica, between April, 2002 and April, 2006. The mean has been removed.

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 figure at left shows monthly GRACE results for the mass variability of Greenland and the West Antarctic Ice Sheet, between April, 2002 and April, 2006. The best fitting trends, shown as the dashed lines, are 250 ± 40 km^3/yr of ice for Greenland and 150 ± 20 km^3/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 figure below shows monthly water storage variations for three river basins, and compares the results with output from the GLDAS/Noah land surface model. The error bars on the GRACE results represent 68.3% confidence limits. The agreement between GRACE and GLDAS/Noah is spectacular in the Mississippi, showing that the GLDAS/Noah model does an excellent job predicting water storage variations there. There is a slight phase lead in GLDAS/Noah in the Amazon, and a larger phase lead (of about 2 months) in the Yenisey. This is probably partly because the model has no surface liquid water component, and (for the Yenisey) is partly an indication that the model may melt snow too early. This kind of information is being passed back to modelers to help them improve their products.

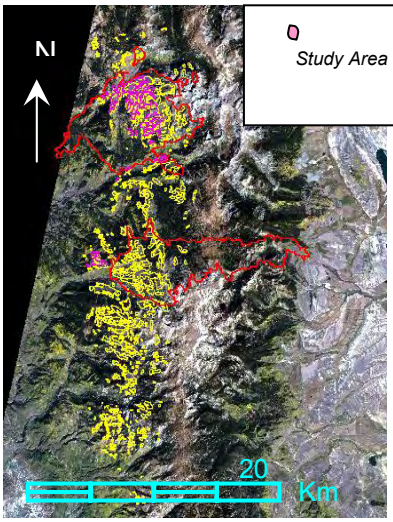


Water storage results for three river basins, obtained using specially constructed averaging kernels for those basins. (The Yenisey River is in Siberia.) GRACE results, with their 68.3% confidence limits, are shown in red. Results from the GLDAS/Noah land surface model are in blue.

Ecological Resilience: Disturbance Interactions and Regeneration in a Subalpine Forest

Carol Wessman and Cristina Rumaitis-del Rio (Columbia University)
Funding: EPA, CIRES

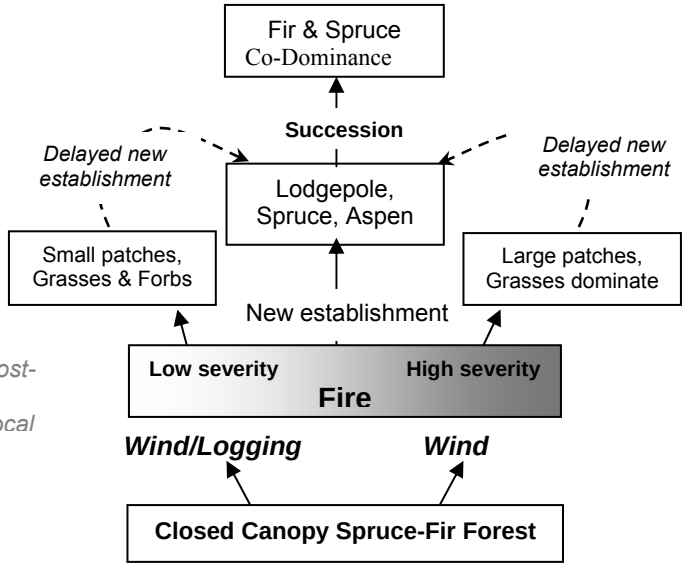
Non-equilibrium ecology suggests that the structure, composition, and dynamics of ecosystems are contingent on disturbance and management legacies. However, field observations do not yet provide compelling evidence for relationships described by some of the core concepts in non-equilibrium theory, such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



Landsat image (9/24/01) of the study area showing recent disturbance history. Yellow: 1997 blowdown; Magenta: 1999-2000 salvage logging. Red: 2002 fire. Black area is the edge of image.

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 (figure left). 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.

Accomplishments:
Results to date show that despite massive structural disruption of the overstory by the windstorm, ecosystem processes were maintained. Conditions in the salvaged-logged areas were similar to south-facing clearcuts, likely delaying reestablishment of forest cover for many decades. While the initial effects of the 2002 fire tended to "erase" the effects of previous disturbances on soil properties and nitrogen cycling, surveys four years after the fire suggest that pre-fire disturbances have a pronounced influence on regeneration rates. Conifer regeneration failures as a result of pre-fire disturbances may mean that the ecosystem is characterized by spatially variable forest-grassland mosaic unlike the landscape structure under previous fire regimes (figure below).



Proposed influence of disturbance history on post-fire regeneration. Conifer regeneration may be delayed due to interactions of landscape and local

Education and Outreach Program

Description
The CIRES Education and Outreach (EO) program provides opportunities for educators, students and scientists. Our work emphasizes scientific inquiry, links with research scientists and current research, and uses of place-based and field-based teaching methods

Selected Accomplishments
Earthworks: Earth System Science for Secondary Science Teachers
The annual CIRES Earthworks workshop for secondary science teachers served twenty six educators from eighteen states. Earthworks 2006 participants designed and conducted field-based studies in limnology, the science of the upper atmosphere, dendrochronology, geology and meteorology. Participants find the interaction with researchers to be instrumental in their learning. One participant says the most effective learning occurred upon "meeting and working with real scientists. It helped me to get a better grasp on what kids should be able to do and how to teach them to 'think like a scientist'."

Scientists and teachers examining a tree core sample during the 2006 Earthworks workshop.

Front Range Math and Science Partnerships
Teachers from five local school districts attended an institute on Earth and space science led by outreach scientist Sandra Laursen. The teachers engaged in inquiry-based activities, lab work, field trips, and discussions during the intensive three-week session. During four summer and fall follow-up sessions, teachers do additional field and class work and conduct "lesson studies" on their own classroom practice and student learning. The institute is offered by a Math/Science Partnership funded by the Colorado Department of Education.

The GK-12 Graduate Student Fellows Program
The CIRES Outreach program participates in the GK-12 Fellows Program at CU-Boulder (which places graduate student fellows from the STEM (science, technology, engineering, math) disciplines into middle and high school science classes. Partner schools have a significant Hispanic population, and many of the students are in English as a Second Language programs. This past year, thirteen graduate fellows provided content expertise and classroom support in five BVSD schools. Four graduate students were advised by a CIRES Outreach Scientist, and one of these students won a CU-sponsored Best Should Teach award this past year.

National Ocean Sciences Bowl

Although they don't live near an ocean, a group of Colorado students who excel in ocean sciences won a trip to Bermuda as a result. In 2006, CIRES Outreach hosted one of the largest National Ocean Sciences Bowl (NOSB) regional competitions in the country, which was won for the fifth consecutive year by the Poudre High School team from Fort Collins, CO. The Colorado team went on to win second place at the final competition in Pacific Grove, CA, receiving a six-day trip to the Bermuda Biological Station for Research as their prize. Although we are the only competition site within a land-locked state, the CIRES NOSB competition is one of the largest in the country, drawing teams from Colorado, Utah, and Kansas. The competition is designed to stimulate interest in the ocean sciences, encourage oceanography studies in high school, and demonstrate the importance of the oceans in our daily lives. This competition would not be possible without the generous support of volunteers from NOAA, CIRES, CU, and other Front Range institutions, numerous prize donors, and financial support from the Consortium for Oceanographic Research and Education (CORE).

The winners of the 2004 Colorado Ocean Sciences Bowl and 3rd place overall in the Nationals. An excellent effort from the only landlocked state in the competition.

Resources for Scientists in Partnerships with Education (ReSciPE)

ReSciPE is an NSF-funded project designed to assist scientists who are engaged with K-12 education. The project includes professional development workshops for scientists about how to work effectively within K-12 education, makes digital resources available, provides consultation help and includes a social sciences research study to identify how best to support scientists in these endeavors. A slate of nine traveling half- to full-day workshops on "Scientific Inquiry in the K-12 Classroom," have been provided for groups of working scientists, their education collaborators, teachers and graduate students, including workshops at NOAA sites in Boulder, CO and Asheville, NC. To learn more or to discuss a workshop for your group see *http://cires.colorado.edu/education/k12/rescipe/.*

International Polar Year

Mark McCaffrey led community workshops to provide direction for the International Polar Year 2007-08 education and communication efforts. These included the CIRES and NOAA-sponsored "Poles Together" workshop, which brought together one hundred U.S. and international participants. During the workshop, polar researchers, science educators, and communication experts planned education, outreach, and communication strategies for the IPY. This was followed by the IPY Communications and Education (ICE) on-line workshop in which 240 participants expanded upon the previous work to define a set of key concepts and messages necessary to polar literacy. This work provides a framework that IPY investigators can use to coordinate and define their education, outreach and communications work.

Impact

The work we do extends the expertise and research of the institute into the community. It allows opportunities for scientists to engage in education and outreach, thereby satisfying their own interests and those of their funding agencies. This support from research institutes can be very important to our educational partners. One local district representative writes that support provided through CIRES "has been the force keeping Earth Systems Science alive at the 6-12 grade level" in that district. For more information on these or other Outreach activities, see *http://cires.colorado.edu/~k12.*

CIRES Scientific Centers

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. Although measurements from space are emphasized, aircraft and field measurements are integral to any remote sensing project.

Within CSES the aim is to work on all scales of problems extending from technique development in small test sites to understanding pattern and process on a regional and global scale. Data from the available electromagnetic spectrum, extending from the UV to the microwave region are used. CSES facilities were developed with generous support from the W.M. Keck Foundation and matching funds from the University. The laboratories are dedicated to both research and teaching. CSES has five faculty associates. For the interval 1998-2005, CSES published 112 reviewed journal articles and book chapters.

Remote Sensing Research
The primary areas of study at CSES include arctic climatology, ecology, geology, hyperspectral imaging, hydrology, paleoclimate, and remote sensing. A long-term goal of CSES research is to investigate problems in global geoscience, in particular questions of global change, through use of satellite observations. At present, the emphasis is on understanding the land and land-atmosphere interactions and the cryosphere. Some of the topics include biochemical cycles involving vegetation, soils, hydrology and water budgets, and human-induced change. Predictive models are being developed that incorporate inputs derived from satellite remote sensing data, and make it feasible to address global-scale questions.

Tires placed on sand dune near Logan, New Mexico in an attempt to stabilize the dune.

Accomplishments

Ecology
Work during the past year on carbon sequestration in Southwestern rangelands demonstrates that dryland regions are changing mosaics of woody plant classes whose trends through time are logistically difficult to track with traditional ground based techniques. Fieldwork linked to remote sensing imagery offers the capability to monitor and track changes in aboveground carbon pools over large dryland regions and at frequent intervals.

Polar Climate
Evidence of a temperature regulation mechanism at high latitudes related to sea-surface temperatures was found, which might explain the lower rate of observed arctic warming than predicted by climate models. Researchers also found a strong feedback from biosphere albedo in a simple model of the Earth's climate system. Finally, observed trends in reanalysis products were compared with previous claims of tropospheric warming causing some of the rise in tropopause height in the same data and showed that no warming existed in the data.

Climate Modeling
Researchers published a simple, nonlinear climate model study called a Dynamical Area Fraction Model (DAFM), which laid the basic theoretical framework for developing simple nonlinear-coupled dynamic models. Two subsequent experiments with this revised model suggested the domination of negative feedback from the hydrologic cycle on the climate regulation: the active hydrological cycle greatly reduced the global climate temperature, despite powerful positive hydrological feedbacks like the ice-albedo and hydrological greenhouse feedbacks. These results contrast with anthropogenic explanations of climate change that rely heavily on assumptions of positive feedbacks from the hydrological cycle.
Expansive Soils

100 ft long trench, 15 ft deep, in the lower part of the Pierre Shale near Roxborough Park East, southwest of Denver, CO

Data from three trenches dug into the Pierre Shale in the northern Front Range show that reflectance spectroscopy is a viable technique to detect the swell potential of smectitic soils and will provide results in seconds rather than days and at a significantly lower cost than standard methods.

Education and Student Opportunities

Remote sensing is not a discipline in itself, but rather a major, evolving tool applicable to studies of the earth involving the atmosphere, biosphere, hydrosphere, cryosphere, and the solid earth. 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.

CSES Facilities

The CSES facilities include approximately 8000 sq. ft. of lab and office space completely refurbished in 1994 with support from the W. M. Keck Foundation of Los Angeles, California. CSES occupies the 2nd floor South and West wings of the Ekeley Science building in the heart of the CU campus. CSES also contains a 24-seat classroom for teaching, including 10 Windows workstations.

Future of CSES

Because of the retirement of CSES director Alexander F.H. Goetz in 2006, CSES will be evaluated by CIRES for possible reorientation under a new director.

Center for Science and Technology Policy Research

Description
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's vision of establishing research and outreach across traditional academic boundaries. The vision of the Center is to serve 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, including research, education and service. The Center fulfills these objectives through activities within the following four "Strategic Intents":

- Help guide the University of Colorado in educating the next generation of science and technology policy decision makers.
- Help make the nation's science portfolios more responsive to societal needs. Example areas include climate and global change, disasters, nanotechnology, biotechnology, and renewable/sustainable energy.
- Provide various 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 institution at the University of Colorado-Boulder.

Accomplishments
The Graduate Certificate in Science and Technology Policy was awarded to its first two recipients. One of those recipients, Shep Ryen, accepted a job offer with the staff of the House Science Committee. Our first Ph.D recipient, Erik Fisher, successfully defended his dissertation and has accepted a post-doc position at Arizona State University's Center for Nanotechnology in Society.

Dr. Frank Press's April 11 visit completed our very popular lecture series "Policy, Politics, and Science in the White House: Conversations with Presidential Science Advisors." In the past FY we brought to the CU-Boulder campus the following five former presidential science advisors for two-day visits and talks with students, faculty, scientists and the general public: Dr. Edward David (Nixon advisor), Dr. Neal Lane (Clinton advisor), Dr. Donald Hornig (Johnson advisor; pictured at left), Dr. George Keyworth (Reagan advisor), and Dr. Press (Carter advisor). These are in addition to last year's visits of Dr. John Marburger (Bush advisor) and Dr. John Gibbons (Clinton advisor). The Center is editing a book based on the science advisors' talks in Boulder.

In the second year of our five-year NSF-sponsored project, Science Policy Assessment and Research on Climate (SPARC), we organized workshops in Honolulu, Hawaii to examine RISA science policy, and in Munich, Germany to analyze the connection between climate change and disaster losses. SPARC researchers also made 16 presentations and wrote 14 articles in connection with the project.

The Center entered into a collaboration this year with Arizona State University on a new National Science Foundation (NSF) project exploring the societal implications of nanotechnology. NSF awarded ASU a 5-year, $6.2 million grant under its Nanoscale Science and Engineering Program to create a Center for Nanotechnology in Society. The Policy Center will contribute to this project by organizing a National Consensus Conference panel in Colorado to identify values intended to guide policymakers and then develop specific policy recommendations for the future development of nanotechnology. It will also help conduct exploratory research aimed at assessing the implementation of federal policies on the societal dimensions of nanotechnology at local university lab settings.

Center graduate student Joel Gratz completed his study for the National Weather Service titled "Lessons in Technology Transfer Policy for the Atmospheric Sciences: A case study in Public-Private-Academic Partnership on Level II Radar Data," focusing on the NWS's national network of 158 NEXRAD WSR-88D weather radars. The

study explores the development and outcomes of the current Level-II radar data dissemination system and makes recommendations for weather community leaders.

Center researcher Myanna Lahsen completed her NSF project titled "Our Science, Their Science" which studied the interplay of science, culture, power and politics in international affairs through a focus on Brazil's Large-Scale Biosphere Atmosphere (LBA) experiment. Lahsen made four presentations and has eight publications either finalized or in preparation based on her study.

Center visiting fellow Lisa Dilling has an edited volume forthcoming from Cambridge University Press (with NCAR's Susi Moser) titled *Creating a Climate For Change: Communicating Climate Change and Facilitating Social Change* [anticipated publication December 2006].

Roger Pielke, Jr. has a new book, titled *The Honest Broker: Making Sense of Science in Policy and Politics*, forthcoming from Cambridge University Press [anticipated publication in early 2007]. In the book Pielke argues that scientists have choices about how they decide to engage with policy and politics. The book provides some guidance as to how such choices might be made, and their consequences for individual scientists and the broader community.

Climate Services Clearinghouse, a one-stop shopping website that draws together climate services and products across sectors, from NOAA, non-NOAA government agencies, academia, and the private sector, was completed in January 2006 and is in the process of being transitioned to NOAA Climate Services.

Products
Center staff produced 31 peer-reviewed and non-peer-reviewed publications in the past fiscal year, and gave 64 presentations at academic conferences and other events (52 by staff, 12 by graduate students). Other Center products include a quarterly newsletter, a national outreach briefing, an extensive Web site, and a well-regarded science policy weblog that receives more than 2,300 visitors a day, was recently named one of the 50 most popular science blogs by *Nature* magazine, and was described as an "excellent, informative site" by *Science* magazine. The Center also hosted 18 talks by affiliates and visitors.

Impacts
The Center continues to be viewed as a serious source of analysis and information by science and technology policy decision makers. Center Director Roger Pielke, Jr., was invited to testify at the House Committee on Government Reform's hearing "Climate Change: Understanding the Degree of the Problem." Center staff were quoted or referred to 91 times over the past year by media including the Associated Press, New York Times, Nature, LA Times, Fox News, China Daily, Wall Street Journal, and numerous local and regional publications.

Our graduate students continue to make inroads into decision-making circles as well. During the summer of 2006 a Center graduate student interned for the second year with the Office of Management and Budget (OMB) and, as mentioned previously, a Center graduate is now on the staff of the House Science Committee.

National Snow and Ice Data Center

Description
The goal of the National Snow and Ice Data Center (NSIDC) is to make fundamental contributions to cryospheric science and to excel in managing data and disseminating information to advance understanding of the earth system. NSIDC was established by NOAA in 1982. Additional information is available at http://nsidc.org.

NSIDC contains seven data centers, including NOAA@NSIDC, which focuses on NOAA data sets. NSIDC supports one of eight Distributed Active Archive Centers (DAACs) funded by the National Aeronautics and Space Administration (NASA) to archive and distribute data NASA satellites and field measurement programs. NSIDC also supports the Arctic System Science Data Coordination Center, the Antarctic Data Coordination Center and the Antarctic Glaciological Data Center for the National Science Foundation.

Accomplishments
Data management activities at NSIDC have resulted in over 500 data sets accessible through NSIDC's Web pages and an additional 900 data sets accessible via the Global Change Master Directory (GCMD).

NSIDC has a leading role in International Polar Year 2007-2008 (IPY) data management. NSIDC is coordinating the IPY-endorsed IPY Data and Information Service, an international federation of data centers, archives, and networks working to ensure proper stewardship of IPY and related data. NSIDC has received some funding for IPY-related data activities but is seeking more comprehensive support.

Research at NSIDC includes activities related to the cryosphere and climate change:

- ***Ice sheets and glaciers***: Glacier and ice sheet mass balance is critical as an indicator of climate change and as a source of fresh water contribution to the oceans. NSIDC scientists developed a new map of Antarctica and have been documenting the rates of movement of glaciers and critical parts of the Antarctic ice sheet.
- ***Sea ice***: Sea ice is important both 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 the ice as they occur, has indicated declines in arctic sea ice extent during recent years.
- ***Permafrost and frozen ground:*** Changes in the extent of permafrost and frozen ground are an indicator of climate change and have an impact on native communities and terrestrial ecology. The carbon tied up in permafrost and frozen ground could impact the global carbon balance. Scientists at NSIDC are integrating remotely sensed data with in situ data to refine predictions of frozen ground conditions.
- ***Snow cover and snow hydrology:*** Changes in the freshwater contribution to the northern seas are impacting the dynamics of ocean circulation. NSIDC's scientists are working with sparse data, in conjunction with synthesis and modeling approaches, to understand Arctic hydrologic issues.
- ***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 by using approaches such as the Sea Ice Index noted above.
- ***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 the local people.

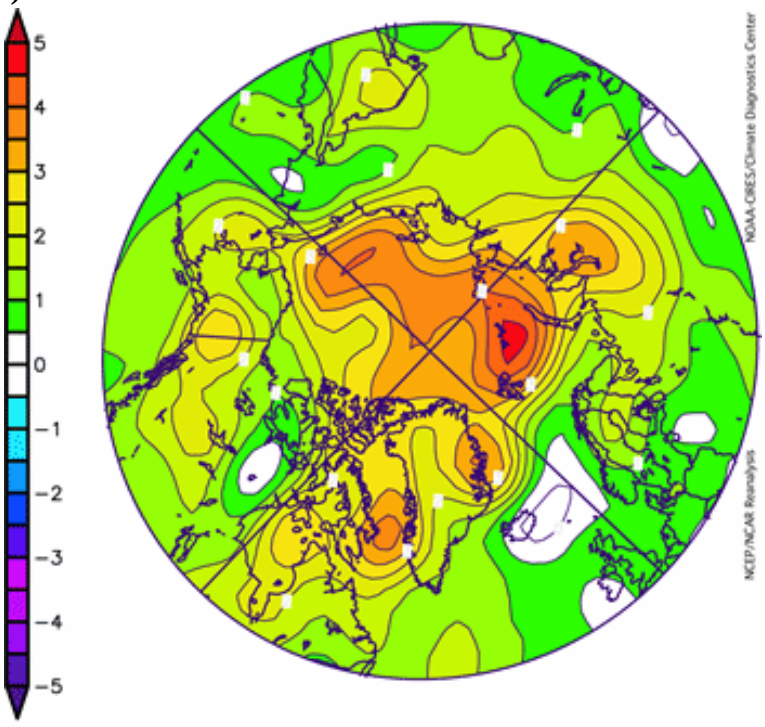
The research activities and publications of NSIDC scientists are presented in the NSIDC Annual Report (*http://nsidc.org/pubs*).

Impacts
- ***Data transfer to the science community***
  Our Web site is the primary gateway for NSIDC users to access our data and information (http://nsidc.org/data). Our data are also accessible via the GCMD and Geospatial One Stop (GOS) Web sites. NSIDC transferred 6.4 million web pages to 1.1 million unique users during FY '06. NSIDC distributed 3.9 million files with 46.1 TB of digital data during FY '06. NSIDC also distributed data on computer media, including 41 tapes and 3498 CDs and DVDs.

- ***Societal impacts***
  Researchers using NSIDC data products are assessing and monitoring changes in the cryosphere that may have profound impacts on society. NSIDC scientists are a resource for the news media in articles explaining what is happening and why changes are taking place throughout the cryosphere: Permafrost extent is declining, glaciers are retreating, ice shelves on the Antarctic Peninsula have disintegrated, and arctic sea ice extent is shrinking. Arctic temperatures were above normal (see figure below) during 2005.

Products
NSIDC's component data centers provided a wide range of cryospheric data and products during FY '06.

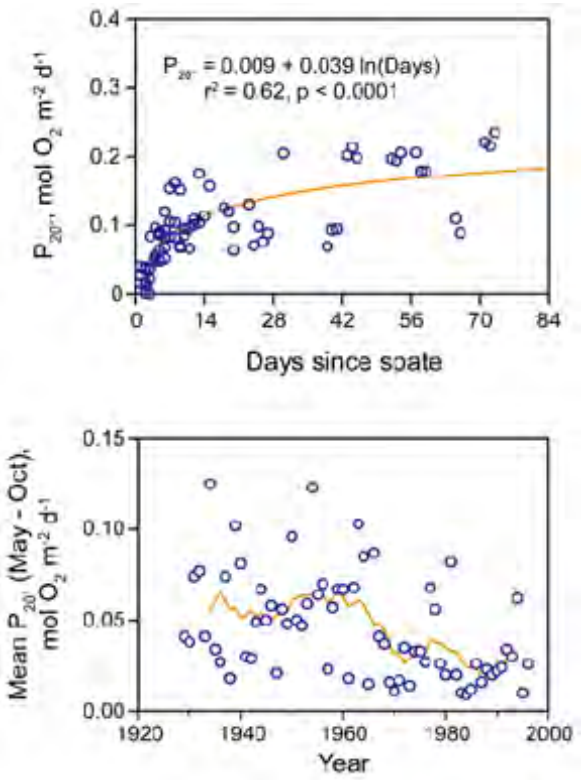
- ***NOAA at NSIDC and the World Data Center for Glaciology, Boulder***
  The NOAA project at NSIDC operates in cooperation with the NOAA National Geophysical Data Center and Arctic Research Office to extend the NOAA National Data Center catalog of cryospheric data and information products, with an emphasis on in situ data, data rescue, and data sets from operational communities.
- ***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.
- ***The Arctic System Science (ARCSS) Data Coordination Center (ADCC)***
  NSF has funded the ADCC at NSIDC to house data from Office of Polar Programs (OPP) Arctic System Science funded investigators, and to provide tools for investigators both submitting and looking for data.
- ***Antarctic Glaciological Data Center (AGDC)***
  The NSF OPP funds AGDC to archive and distribute glaciological and cryospheric-system data obtained by the U.S. Antarctic Program. Compiled data include ice velocity, firn temperature, shallow ice core measurements, geochemical composition of ice cores, snow pit data, and satellite images of ice shelves.
- ***U.S. Antarctic Data Coordination Center (USADCC)***
  NSF OPP funds USADCC to improve access to U.S. funded Antarctic scientific data by creating descriptions of these data and entering them into the Antarctic Master Directory (AMD), a node of the Global Change Master Directory (GCMD). The AMD is a Web-based, searchable directory of thousands of data descriptions submitted by scientists from over twenty countries.
- ***The Frozen Ground Data Center (FGDC)***
  The FGDC is a collaborative effort between the World Data Center (WDC) for Glaciology, Boulder and the International Arctic Research Center (IARC). FGDC works internationally to collect and distribute data gathered over many decades that are critical for environmental change detection and impact assessment.
- ***Global Land Ice Measurements from Space (GLIMS)***
  GLIMS, a cooperative project with the US Geological Survey, is designed to monitor the world's glaciers primarily using data from the ASTER instrument aboard the Terra spacecraft launched in 1999. More then 54,000 glaciers are now entered in the GLIMS data base.



Arctic temperature anomalies for 2005, which was the record low year for sea ice.

Center for Limnology

During 2005, the Center for Limnology continued its long-term study of biogeochemical and metabolic processes in the South Platte River below Denver. This river, like many other rivers in populated sectors of the West, is subject to extensive hydrologic manipulation, loading of nutrients derived from municipal and agricultural sources, and physical disturbance.



Recovery of photosynthetic rates following flood disturbance (upper panel) and a 70-year reconstruction of photosynthetic potential (lower panel) for the South Platte River

During 2005 Center personnel finished and submitted for publication a 70-year reconstruction of river metabolism (photosynthesis and respiration) based on a new idea involving quantitative coupling between photosynthesis, respiration, and shields stress, which can be computed from flow. Because daily flow records are available over a very long period of time, the quantitative relationships that we have demonstrated empirically can be used in reconstructing photosynthesis and respiration and in showing how these have changed through time as the flow regime of the South Platte has changed in response to water management.

Counter-intuitively, water management has led to a higher degree of bed disturbance in the river, which has suppressed photosynthesis progressively as water management has had an increasing role in controlling the river hydrograph. Increased disturbance has occurred because maintenance of higher base flows as a byproduct of water management has lead to average flows that more closely approach the threshold for disturbance than had been the case for the original hydrograph. Therefore, even small thunderstorms cause flows to rise above the threshold for bed disturbance. Bed disturbance removes algal biofilms, thus shutting off photosynthesis. After disturbance, an organized rebound occurs; overall photosynthesis for the year can be calculated from rebound rates and timing of disturbances. Respiration is less affected from photosynthesis, which means that the stream has become increasingly dominated by oxygen-consuming processes than by oxygen-producing processes. The method also provides the potential to predict metabolic effects of water-management schemes on the key metabolic processes in rivers.

Also during 2005, the Center for Limnology developed a detailed mechanistic system model of the South Platte River below Denver. The model focuses on biogeochemical processes that control nitrogen, carbon, and dissolved oxygen. This model incorporates physical processes such as gas exchange rates, travel time for water, and the relationships between river stage and river cross sections, as well as empirically determined rates of ammonification, nitrification, denitrification, photo-synthesis, and respiration. The model, which is currently in the final stages of validation, will be used in predicting future conditions in the South Platte River as the river undergoes chemical changes associated with increasing amounts of waste discharge and more intense management as cities withdraw more water for domestic use.

The Center for Limnology during 2005 benefited from the presence of Tara Higgins, Fulbright Scholar from Ireland. Dr. Higgins brought with her a work in progress involving the conversion of abandoned Irish peat excavation zones to lakes through the blockage of drainage that was introduced when the peat was removed. The key question for the Irish government is whether or not such a practice would produce a pleasing and productive environmental asset. Previous attempts to turn the abandoned peat excavation areas into forest resources or agricultural resources have not fared well.

According to the work of Tara Higgins, the potential for these lands to be occupied by lakes makes their environmental asset seem to be very high. As shown by some lakes created as part of a pilot project, the peatland lakes support significant populations of game fish following appropriate stocking and are visited for both recreational fishing and for travelers or vacationers in search of scenic views. Tara's work on the limnology of the lakes shows that some locations may be much better suited than others for the lakes, as predicted from the relative availability of key nutrients that determine the potential for production of algae and other aquatic plants.

Artificial lake created on worked-out cutaway peatland in Ireland; (b) an industrial peat field, pre-flooding; (c) a cutaway peatland that has been recently inundated.

The Center for Limnology also supported studies of nitrogen fixation in Colorado lakes. Of particular interest in this year, through the graduate work of Mark Bradburn, is the relationship between nitrogen fixation rates and solar irradiance within the water column of lakes. This key relationship has been studied very little, and yet it probably explains much of the success or failure in the nitrogen fixation of cyano bacteria in lakes that develop nitrogen shortages. Cyano bacteria are of great practical interest because of their potential to produce toxins harmful to animals and humans as well as being an aesthetic nuisance.

Another research topic for 2005 has been phosphorus dynamics involving sediment-water column nutrient flux in lakes. James Anthony, graduate student, has developed a turbulence control machine that allows undisturbed cores of lakes, along with their overlying water, to be treated experimentally in determining the relationship between turbulence, phosphorus release, and sediment chemistry. The research is intended to produce new information on the role of sediments in contact with surface waters of a lake as a nutrient source during the growing season, when nutrients are scarce.

The Center for Limnology became the geographic locus of the International Society for Limnology during 2005. The Center Director took responsibilities as general secretary - treasurer of this very old international organization. Center personnel have been involved in helping the society cope with modernization involving publications, electronic communication, and services to members, taking into account the global distribution of members. Norlin library at CU has become custodian of the international archives, which date back about a century.

The Center continues its historical involvement in tropical limnology through preparation of chapters for two books dealing with tropical aquatic environments. The first volume, which deals with streams, will contain a contribution from the Center for Limnology dealing with physical environmental gradients that figure importantly in the ecological transitions from temperate to tropical streams and rivers. The second volume focuses on tropical fish communities, and the Center's contribution to that volume focuses on the Center's previous studies of the Orinoco floodplain and its aquatic food webs.

Climate Diagnostics Center

Overview
The Climate Diagnostics Center (CDC) provides a research focus in CIRES for efforts to advance understanding and predictions of the climate system and its component processes. CDC activities involve a coordinated program of observational, diagnostic and modeling studies aimed at significantly advancing understanding and predictions of climate variability. Research disciplines include, but are not limited to, atmospheric sciences, oceanography, 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.

Accomplishments
The CDC has produced nearly 200 peer-review publications over the past five years on a broad range of climate-related topics. CDC members have also provided scientific input into numerous national and international programs including:

1) Assisting the Western Governors' Association (WGA) in the development of a plan for a National Integrated Drought Information System (NIDIS).
2) Contributions to National Research Council Studies such as "Under the Weather: Climate, Ecosystems, and Infectious Disease." National Academy of Sciences Press.
3) Contributions to the development of the Inter-American Institute for Global Change Research (IAI) Collaborative Research Networks (CRN) in, among other areas, providing climate diagnostics information and data in support of a health early warning system for the Americas.
4) Contributions to the IPCC Fourth Assessment Report Chapters for Working Groups I, II, & III.
5) Contributions to and serving on numerous WMO, national, AMS and AGU climate research panels and journal editorial board such as CLIVAR, THORPEX, NCAR steering committees, GLOBEC, AOPC GCOS, *Journal of Climate, International Journal of Climatology, Journal Arctic and Alpine Research*, HEPEX, as well NASA, NSF, USDS, and DOE advisory and review panels.
6) Contributions to the development of the interagency Climate Change Science Program strategic plan.
7) Contributing to the development of a national climate service implementation plan.
8) Lead authorship of a report to Congress on the May 2003 Extended Tornado Outbreak.
9) Ongoing updates and improvements to the International Comprehensive Ocean-Atmosphere Data Set (ICOADS), providing observations of surface ocean conditions currently back to 1784.
10) Sponsoring and hosting nearly 100 seminars between the beginning of 2002 and the end of 2005. Members of the CDC Staff have contributed to the university's academic mission through activities such as:
    - Partnering in the establishment of the interdisciplinary NOAA Office of Global Programs Western Water Regional Integrated Sciences and Assessment.
    - Teaching an undergraduate course titled "Our Changing Environment"
    - Hosting three CIRES Visiting Fellows.
    - Serving on seven University of Colorado graduate student thesis committees.
    - Hosting and supervising five undergraduate students working on climate research.

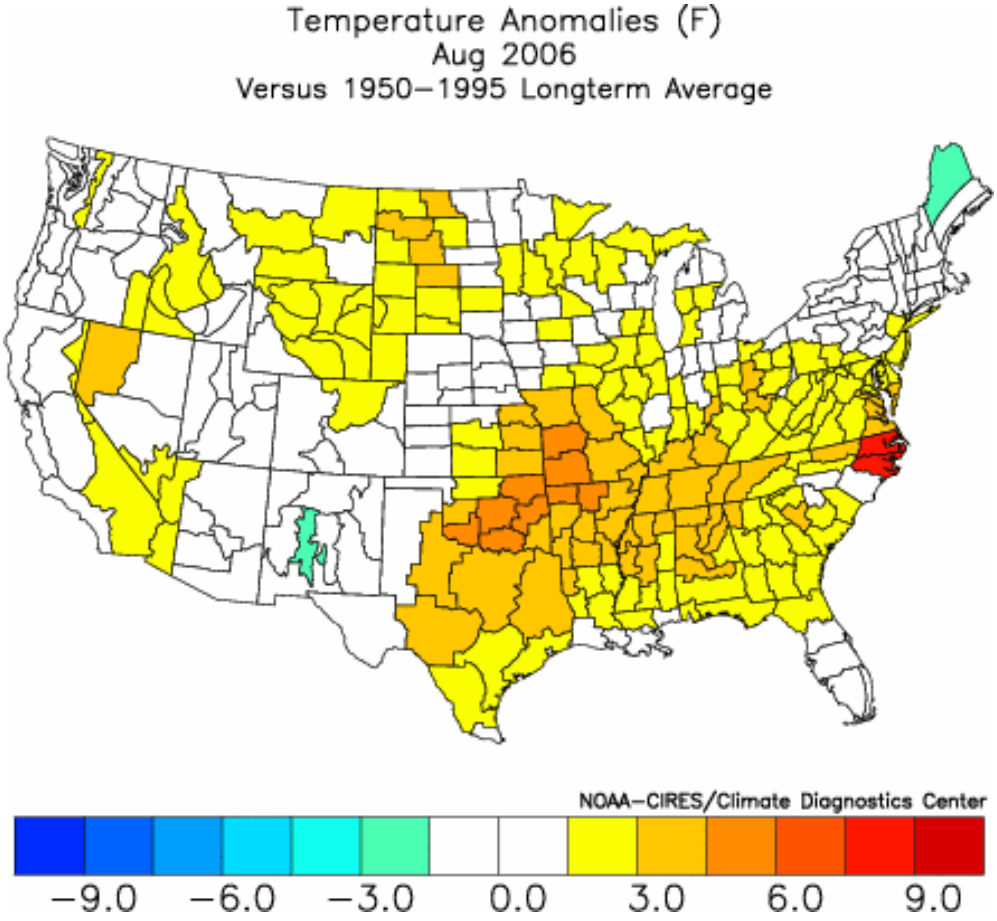
Recent highlights
CDC scientists provide regular input to the production of the U.S. Drought Monitor. They produce experimental seasonal forecasts every month based on tropical ocean conditions, and have created a web page to display forecasts. On the state level, they regularly provide input to and make briefings at meetings of the Colorado Water Availability Task Force and to other stakeholders on the current and projected evolution of ENSO-related anomalies and their implications for the southwestern U.S. Some experimental CDC forecasts are now being used by regional wildfire managers.

CDC scientists recently discovered an emerging long-term trend toward an increasing year-to-year variance (decreasing reliability) of streamflow across the major river basins in western North America: Fraser, Columbia, Sacramento-San Joaquin, and Upper Colorado. They also demonstrated that a concurrent increase in the incidence of synchronous flows (simultaneous high or low flows across all four river basins) has resulted in expansive water resources stress. The observed trends are associated with trends in the wintertime atmospheric circulation and ocean

temperatures, raising new questions on the detection, attribution, and projection of regional hydrologic climate change.

CDC continues to participate strongly in the OGP-funded regional assessment on the effects of climate variability on water resources in the Interior West ("Western Water Assessment," or WWA). CDC scientists held frequent interactions with other federal and state agencies such as the Department of the Interior, including the Bureau of Reclamation and the Fish and Wildlife Service, and other user groups, such as the Denver Water Board, Colorado River Water Conservation District, and Colorado Drought Task Force. An important objective of this research is to learn how to better incorporate climate information and forecasts into water resource decisions in this highly water-sensitive region.

CDC also continued its strong tradition of public outreach and service to the broader scientific community. CDC staff gave numerous media interviews and specialized climate briefings, and developed new web pages explaining basic and applied CDC climate research in laymen's terms. This web site also contains links to many experimental and applied climate products developed at the Center.



Plot created at http://www.cdc.noaa.gov/USclimate/USclimdivs.html

Innovative Research Program

Sea Ice on Mars? Earth-Mars Satellite Altimetry Comparison and Theoretical Modeling

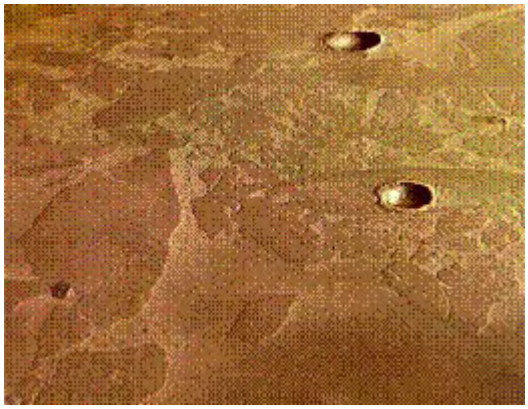
Investigators: Todd E. Arbetter (CIRES/NSIDC), Ted A. Scambos (CIRES/NSIDC)

Objectives

Investigate the possibility of relict frozen sea ice in Elysium Planitia, Mars, by comparison of Martian and Terran satellite imagery and satellite elevation data. Examine the likely characteristics of sea ice on Mars using appropriately modified dynamic sea ice models.

Background and importance

Patterns in recent imagery from the High Resolution Stereo Camera (HSRC) aboard the Mars Express spacecraft suggest the existence of a frozen sea of water ice in the Elysium Planitia region of Mars (*Murray et al., Nature*, March 17, 2005). The features, estimated to be approximately 5 million years old, cover an area 800 km by 900 km, similar in size to the North Sea. Estimated past water depth (from basin topography) is 45 meters. The features are claimed to be inconsistent with solidified basalt lava flows observed elsewhere on Mars, although previous studies suggested this. Size and scale of the fracture and floe patterns suggests (to *Murray et al*.) a layer of ice once floated above a liquid sea (figure right). The liquid drained or sublimated, leaving a dust-covered, relict, sea-ice-like pattern.



A comparison of images from Earth and Mars seems to superficially support the contention by *Murray et al*. (Figure 2). It should be noted that solid basalt does not float on liquid basalt magma, and so directly analogous igneous processes are not possible. Closer inspection of the rubble field around one of the craters (Figure 2) shows it is analogous to the flow of plates around icebreakers (Figure 3).

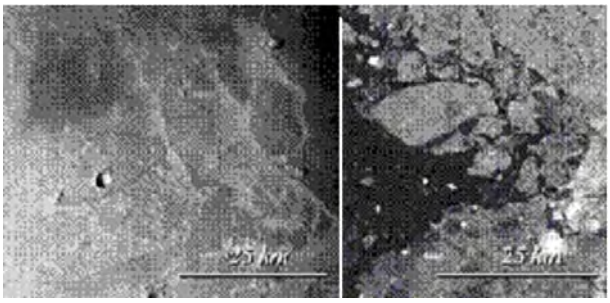


Figure 2 (left): HSRC image of 'fractured plate'-like features in Elysium Planitia (far left). Antarctic pack ice (near left). Murray et al. (2005) hypothesize that the Martian features are remnants of an ice-covered sea. Note the 'puzzle-fit' shapes of the large floe and 'shelf' along the right edge of the Martian image.

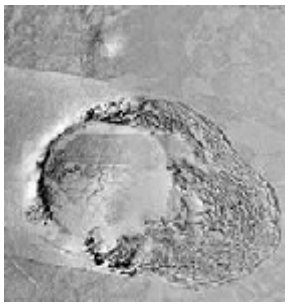


Figure 3 (right): Closeup of a crater in Elysium Planitia. The diameter is approximately 1.5 km. The existence of a rubble field to the right of the crater and a lead-like feature to the left suggest that the crater may have impeded a floe of ice traveling from right to left. Features within the crater suggest a floe which grounded within the crater as the water level subsized. (Murray et al. 2005).

Why is this important?

The HSRC imagery represents the most direct evidence to date of the recent existence of a large body of liquid water on the Martian surface. The presence of liquid water is essential to speculation that life may have existed, or may exist, on Mars.

What makes this innovative?

We will use a modified sea ice model as the basis for a Mars-analog ice-covered ocean, and explore what kind of large-scale sea ice fracture and drift patterns might be expected on Mars using idealized experiments. We will compare Mars and Terran laser elevation profiles (from MOLA and GLAS) in search of sea-ice structures that may be used to resolve the debate.

Research plan
Observationally, we will gather laser altimetry data from both Arctic and Antarctic sea ice (using ICESat's GLAS data) and the Elysium Planitia region using MOLA. ICESat data is archived at NSIDC, and readily available. MOLA data is at *http://pds-geosciences.wustl.edu/missions/mgs/mola.html*, complete with tools for plotting profiles and information on the use of the data. Using satellite images and the profiles, we will compare structures and scales of the two surface types (Martian sea-ice-analog (?) and Antarctic sea ice).

A viscous-plastic rheology sea ice model with a multiple-category distribution resolving relative fractions of level and ridged ice in a distribution of thicknesses (*Flato and Hibler,* 1995) will serve as the basis for the model experiments. The dynamics of this model are governed by a momentum balance which includes wind and ocean drag terms as well as an internal ice strength parameterization. The Coriolis term will be modified to be appropriate for the Martian planetary radius and rotation rate, with the assumption that the southern boundary lies along the equator. Because of the lower Maritan gravity, less energy will be required for ridging (*Rothrock* 1975, *Hibler* 1980, *Flato and Hibler* 1995), so the strength and deformation of sea ice will be altered. A ~160x180 domain of 5-km resolution, with shoreline and bathymetery features approximated from the Elysium Planitia morphology, will serve as the testbed for initial model experiments. These will include idealized wind forcing with uniform and sinusoidally varying wind stresses including the possibility of a shear zone across the ocean (for example, westerlies in the northern half of the ocean, easterlies in the southern half). The growth rate of the Martian sea ice will be determined by an estimated flux balance, assuming a constant air temperature across the model domain. The dominant terms in the flux balance equation will be downwelling shortwave radiation, radiative cooling, and conduction of heat through the ice. Because of the thin Martian atmosphere, we will assume that turbulent heat fluxes and downwelling longwave radiation are negligible.

An important difference between the two planets in this analog comparison is the lower Martian surface air temperature and atmospheric density. In separate, simplified models, we will investigate the basic processes of Martian sea ice growth and thickening, by using appropriately modified thermodynamic algorithms. Martian water bodies are likely very saline, with sulfate salts (as recent results from the Spirit and Opportunity rover imply); these will change the freezing point and growth rate, as well as growth characteristics. For example, in a nearly-saturated salt water body at low to extremely low temperatures (e.g. -20°C to -80°C, typical of Mars), the process of ice growth and brine rejection would lead to evaporite precipitation by freezing.

Expected outcome and impact:
The detailed comparison of MOLA and IceSat imagery, as well as model results, will offer more evidence to support or contradict the hypotheses of Murray et al. The results from the model experiments will explore possible behavior of a Martian ice-covered sea. Further, the IRP grant will serve as an important 'seed money' project to assist in the development of more-detailed, larger grants to NSIDC from NASA given its new Moon-Mars exploration focus.

Is Climate Change on the Tibetan Plateau Driven by Land Use/Cover Change?

Investigators: Oliver W. Frauenfeld (NSIDC), Tingjun Zhang (NSIDC)

Objective

The goal of this proposal is to address the degree to which long-term temperature changes on the Tibetan Plateau (TP) are influenced by land use and land cover changes. If we are able to quantify this component of climate warming and find support for our hypothesis that temperature increases are primarily driven by surface processes related to changes in land cover, this will then enable us to pursue a full research proposal and a more comprehensive analysis of land surface processes on the TP.

Background and importance

Similar to high-latitude regions of the Northern Hemisphere, high-altitude areas seem to be especially susceptible to global climate change and have been shown to have warmed more, and perhaps sooner, than the rest of the globe. The TP in particular has been argued to be a harbinger of climate change due to its early and accelerated warming. Anthropogenic greenhouse gas forcing is generally considered to be the main cause of the observed warming in high-elevation areas. However, evaluating the degree to which greenhouse gas loading contributes to the warming is difficult because topography (especially on the TP, which has the most complex terrain on the globe) is too poorly resolved in general circulation models. Models overlook many of the climatological details of mountain regions, making it difficult to evaluate the consequences of climate change on the hydrology, glaciers, or ecosystems.

Like elsewhere on the globe, an equally important anthropogenic component to climate change may be land cover and land use changes on the TP. These local–regional surface effects related to agriculture and urbanization potentially outweigh greenhouse gas forcing. In fact, our recent research has shown that plateau-averaged station records, biased toward low-lying populated regions, show a warming trend of 0.16°C decade^{-1} over the last 50+ years. However, plateau-wide trends from an independent data source free of surface contamination indicate no trend. This has led us to hypothesize that, indeed, land use/cover change (LUCC) could largely account for the reported warming on the TP.

Why is this important?

The TP plays a prominent role in the Asian monsoon system by acting as an anomalous midtropospheric heat source. Additionally, seven of the world's largest rivers originate on the plateau, and changes in this region are thus crucial for the water resources of most of the Asian continent. Climate change on the TP is arguably of heightened importance, as it impacts the livelihood of more than half of the world's population.

LUCCs are especially relevant on the TP as over 62% of the plateau is used for agriculture: farmlands, forests, and a majority (80%) is used for livestock grazing. According to some studies, the carrying capacity of parts of the TP has been far exceeded, partly due to inappropriate land management practices implemented in the 1950s. Additionally, urbanization, which can result in 8–11°C higher temperatures than in surrounding rural areas, has occurred on the TP in cities such as Lhasa, Golmud, and Xining. However, as in high-latitude regions, even villages and small towns at high altitudes can exhibit a strong urban heat island effect, especially during the cold season. In cold regions like the TP, this is accompanied by earlier snowmelt and increased thickness of the thawed layer, resulting in permafrost degradation and thus a further altered land surface. The many civil engineering projects currently under way, such as the construction of the Qinghai-Xizang railroad, combined with a conscious effort by China to urbanize the TP, will lead to further and likely greatly accelerated population increases and land surface changes in the future.

Research plan

We first plan to detect and quantify changes in vegetation using historical AVHRR Normalized Difference Vegetation Index (NDVI) data for the last ~25 years, as well as 2000–present vegetation indices from MODIS. While NDVI can obviously only tell us the degree of "greenness" of the surface, this data source can still be useful to identify regions that are characterized by a decrease in vegetation cover, as well as areas that have undergone desertification. Having identified areas of land cover change, we expect to find amplified local air temperature increases in those regions, and lower or no temperature increases in undisturbed regions, where NDVI indicates no change.

We are in a unique position to acquire data not generally available to the public since the National Snow and Ice Data Center (NSIDC) is also a World Data Center (WDC). As such, we have recently obtained daily temperature

data (1950s–2000) for 161 stations on the TP from the China Meteorological Administration. In addition to NDVI we will thus employ these long-term daily station records, as well as reanalysis products such as the European Centre for Medium-Range Weather Forecasts' 40+ year reanalysis (ERA-40), which we recently verified to accurately represent temperature variability on the TP.

Furthermore, to establish the degree to which station temperature records are influenced by urbanization, we may be able to compare co-located stations in, and away from, urbanized regions. For some sites on the TP, extensively quality controlled, corrected, and adjusted station records are available from the National Climatic Data Center (NCDC). Comparisons between our *in situ* records and NCDC's could also allow us to quantify the contribution of urbanization to the observed temperature increases.

What makes this innovative?

The innovativeness of this project arises from the fact that never before have land cover changes in this part of the world been assessed in terms of their contribution to climate change. While that assessment warrants a much larger effort than is proposed here and includes important social sciences components, our LUCC hypothesis needs to be verified before we can pursue any larger effort in this regard. Elsewhere on the globe, LUCCs have been shown to be a major contributor to anthropogenic warming. The TP likely represents one of the most crucial areas of LUCC and climate change on the globe, yet surprisingly LUCCs have not been evaluated for this region. This is partly because, outside of Asia, relatively little interest exists in the TP and research efforts geared towards this part of the world are difficult to fund. Although some effort has gone to evaluating climate change, e.g., the role of the TP (in particular, its snow cover) on the Asian monsoon, these and other investigations have been limited by coarse-scale gridded data products, notoriously plagued by data sparseness in this part of the world. This CIRES proposal, if funded, would therefore represent a first step towards an unprecedented effort to quantify anthropogenic changes on the TP directly relevant to over half of the world's population.

Additionally, NSIDC is in a unique position for this research because of its link to WDCs around the globe, including those in China, as well as an existing relationship with the Institute for Plateau Meteorology in Chengdu, a division of the China Meteorological Administration.

Expected outcome and impact

We expect to find that areas characterized by surface changes, such as decreases in vegetation cover, are also characterized by an amplified warming signal. Similarly, the urbanized and moderately industrialized regions on the TP are expected to exhibit amplified warming. This initial outcome would lead to further research, including (1) a comprehensive study of the impacts and feedbacks of climate change on land-surface processes related to LUCC, including soil moisture, frozen ground, snow cover, and the hydrologic cycle, (2) an assessment of the social causes and effects of LUCC and climate change, including educational outreach components geared toward local Tibetans, and (3) the generation of a variety of publicly available data sets and time series, to be archived at NSIDC, describing LUCC as well as climate change on the TP. The scientific impact of this proposed (and potential future) research is that because of the TP's importance for the water resources for virtually the entire Asian continent, changes in this part of the world are of heightened significance. Furthermore, because of the accelerating population increases and analogous land surface alterations on the plateau, quantifying past and present changes will allow us to predict future impacts on climate as well as on the livelihood of the entire Asian population.

Anthropogenic Carbon Forcing in a Simple Climate Model with Coupled Hydrological and Carbon Cycles

Investigators: V. Gupta, T. Chase, K. Nordstrom, CIRES' Center for the Study of Earth from Space

Introduction

The Earth's climate is a highly non-linear system operating through complex feedback loops. This system has been generally stable over billions of years, despite a slowly warming sun and other perturbations. Thus it can be viewed as dominated by long periods of negative feedbacks, punctuated by periods in which positive feedbacks change the system dramatically. Since these positive feedback regimes have not run away, it is clear that negative feedbacks must once again come to dominate after some time. More recently, the postulated climate change due to increased anthropogenic carbon forcing in the last century relies heavily on assumptions of positive feedbacks from the hydrological cycle, which generate large surface warming. The hydrological cycle is a pervasive and highly non-linear portion of the climate system. It is compelling, therefore, to assume that it plays a key role in both positive and negative feedbacks, and hence in regulating the climate. This has been demonstrated in a simple climate model by Nordstrom et al. [3], described below. The carbon cycle, another key component of the global climate system, is also dominated by both positive and negative feedbacks, an issue featured prominently in a distinguished lecture at CIRES [5]. On earth, these two cycles are coupled in a complex manner. Our broad objective in this proposal is to study the global climate as a coupled system incorporating both positive and negative feedbacks from both the hydrological and carbon cycles. In particular, we want to investigate the impact of anthropogenic carbon forcing on extreme floods and droughts in such a climate system.

Background

Recently, *Nordstrom et al*. [3] published a simple, nonlinear climate model called a Dynamical Area Fraction Model (DAFM). This represented a generalization of their first paper [2], which laid the basic theoretical framework and was published in the prestigious volume *Scientists on Gaia II*. The generalization in [3] contained a full surfacial energy balance; stratiform rainfall; a dynamic ocean; dynamically adjusting clouds with height-dependent albedo; fully dynamic ice caps; and two types of competing biota, representing one species of tree and one of grass. It also contained a static carbon cycle that did not respond to external forcing. All parameterizations were constructed on dynamic boxes, which lend the model its name.

Nordstrom et al. [3] performed two experiments with the DAFM. In both cases, results were surprising. In the first experiment, [3] varied the solar input over the range of .7 to 1.3 times the present day values for the full model and compared it to an identical run with all water-related variables fixed to their steady-state values at present-day earthlike conditions. Despite the presence of some very powerful positive hydrological feedbacks like the ice-albedo and hydrological greenhouse feedbacks, the active hydrological cycle reduced system response by up to 50% (figure next page).

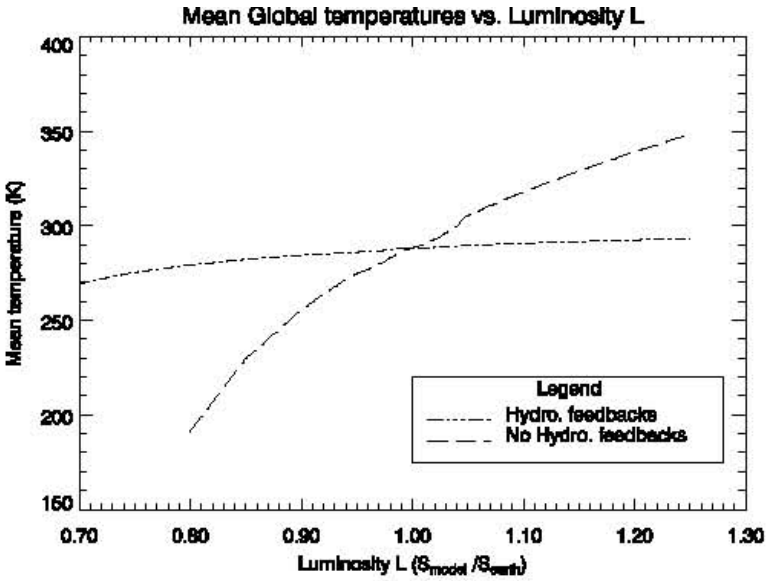
In the second experiment, [3] tested the response of the model to changes in the optimal growing temperature for biota. In this case, despite an overwhelmingly powerful contribution to energy balance from the hydrological cycle at large, the biota were capable of adjusting the mean global temperature by approximately 1.6K. This is on the order of the change expected by the IPCC [1] in response to a doubling of CO_2.

Objective

In the earth climate system, there exist some very important couplings between the hydrological cycle and the carbon cycle. Chief among these are the sequestering of carbon in the surface waters of the terrestrial ocean; the sequestering and re-release of carbon due to the birth-death cycle in the planet's biomass; and the behavior of stomatal density in response to local changes in carbon, which directly affect evapotranspiration in vegetated regions. These couplings have frequently been overlooked in the literature, as people have tended to focus on either the carbon cycle or the hydrological cycle. We propose to include first order parameterizations of a dynamic carbon cycle, as discussed in eg. [4], coupled to the fully dynamic hydrological cycle presented in [3] in order to study the effect on the global means of temperature and rainfall under changes in the anthropogenic carbon forcing.

Methodology

Simple coupled biosphere and hydrosphere parameterizations have already been developed as part of the DAFM described in [3]. Similar to a box model, a DAFM's boxes are sized at some fraction of the global area and contain a representation of their local surfacial mean climate state. However, a DAFM's boxes, or "area fractions," are allowed to dynamically expand and contract against one another following physical parameterizations of their own. Thus dynamic boundaries between ecosystems are designed into the model at a fundamental level.



Comparison of global mean temperature T vs. luminosity L in a DAFM integration with fixed hydrological cycle to a DAFM with a dynamic hydrological cycle. The carbon cycle is static.

A carbon cycle model has been studied in some detail in the model of [4] and was featured prominently [5]. Fluxes of carbon include temperature-dependent oceanic sequestration and outgassing from the atmosphere; removal of soil carbon when plants are born; sequestration of atmospheric carbon during plant life cycles; return of carbon to both soil and atmosphere upon plant death; and sequestration of soil carbon in ocean water due to runoff. Both trees and grasses will be considered C_3 species for purposes of estimating carbon uptake, with tree mass representing a much larger effect on the carbon cycle.

Merits and timeliness of the project

By focusing on ecosystem dynamics and the coupled transfer of water, carbon, and energy between ecosystems, this research is expected to make progress towards understanding the relative strength of some important positive and negative feedbacks in the climate system. It will thereby shed light on processes responsible for the discrepancy between complex climate models and observations. This project is highly interdisciplinary, fosters collaboration between CIRES members, and crosscuts several CIRES science themes. NSF has been funding two new initiatives since 2002, one each on the water and carbon cycle. We have been told by our program manager at NSF that the two will be linked in a single, highly interdisciplinary rfp to be announced later this year at a projected level of $40 million. We want to do substantial groundwork by the time the rfp is out and believe we will be extremely competitive for funding once this current project has been done. Therefore, this project fits very well within the guidelines for the CIRES innovative research program.

References

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Mountain Temperatures at Fine Spatial Scales

Investigators: Jessica Lundquist (NOAA-CIRES Climate Diagnostics Center), Martyn Clark (CIRES' Center for Science and Technology Policy Research), Andrew Slater CIRES' (National Snow and Ice Data Center)

Objectives

Running a standard weather station in the high mountains is very costly, and as a result, few measurements exist in mountainous regions. However, innovative new technology, deployed on existing structures (trees) instead of towers, may provide a low-cost key to filling in the gaps. First, we will test the stability, accuracy, and precision of various low-cost sensors against a standard instrument. Second, we will test several different radiation shield designs. Finally, we will deploy these temperature sensors in a variety of elevations and topographic settings in both the Niwot Ridge long-term ecological research (LTER) station and the Fraser Experimental Forest. We will then work across different scales to learn how localized temperature patterns on both sides of the continental divide relate to large-scale weather patterns, and how well long-term meteorological stations represent the surrounding topography.

Background and importance

In the western United States, over half of the water supply is derived from mountain snowmelt, where the snow delays runoff and provides water in the spring and summer, when it is needed most. In recent decades, snowmelt runoff timing has advanced one to three weeks earlier in mountainous catchments across western North America, responding primarily to temperature changes. However, these general trends are quite variable between basins, and at high elevations, little is known about the spatial and temporal variations of critical processes like snowmelt, runoff, or even temperature.

Mountains are spatially complex and sparsely sampled. Temperatures are usually interpolated from distant stations, assuming a constant decrease in air temperature of 6.5°C per 1000-m elevation gain. However, examination of observed surface temperatures indicates that they differ diurnally, synoptically, and seasonally and do not always increase linearly with elevation, which can have profound impacts on snowmelt and runoff forecasts. For example, Singh (1991) found that changes of 1OC per km in the lapse rate for the Beas watershed (345 km^2, spanning 1900 to 5400-m elevation) produced variations of 28-37% in the modeled snowmelt runoff over a two-month period.

Due to cost restrictions, prior studies have focused on long-term temperature changes at one measurement site or spatially-extensive measurements for a period of less than a week. To be useful, studies must span both spatial and temporal scales. Fortunately, innovative new instruments, such as the Onset Tidbit and the iButton, are inexpensive, self-recording, and can be densely deployed across mountain landscapes for extended time periods. A collection of temperature sensors deployed in Yosemite National Park, California for the past two winters has shown spatial patterns in average daily temperature that differ from the standard lapse rate by over 5°C, with the most marked differences occurring during periods with inversions. Temperature variations such as these are controlled primarily by local topography, vegetation, and larger-scale weather patterns. Thus, we hope to establish relationships between these patterns, local temperatures, and temperature measured at long-term meteorological stations. We can then use these relationships to better interpret data at long-term stations, to better interpolate temperature across the landscape.

Research plan

The strength of these new sensors is in their ability to enhance the interpretation of existing long-term, real-time weather stations. Thus, we propose to deploy 50 sensors each in two established study areas: the LTER station at Niwot Ridge, on the east side of the continental divide, which has four climate stations that have been operational since 1952, and the Fraser Experimental Forest on the west side of the divide, which was the site of extensive field measurements during the Cold Land Processes Experiment and has eight weather stations operational since 1969. Together, the two study sites will allow us to compare processes on the west and east sides of the Rocky Mountains. Instruments will be suspended from tree branches, using dental floss and upside-down funnels for radiation shields. Different configurations of attachments and shields will be tested, including an examination of how trees influence the measurements (by deploying instruments on existing meteorological towers and on nearby trees). Each site will be documented with GPS measurements and photographs. Sites will sample a wide-variety of elevations and topographic characteristics. Scientists will return to the sites for repeat photo-documentation and to download

instrument data at approximately four-month intervals. Large-scale weather patterns will be determined using the NCEP-NCAR reanalysis data. Local winds, radiative energy balance, and relative humidities will be determined from the existing weather towers. Spatial patterns will be analyzed within a statistical GIS framework, and dense temperature measurements will be compared with those estimated by Glen Liston's MicroMet model for distributing temperatures in complex terrain.

Expected outcome and impact

We expect both the Hobo and iButton sensors to perform well (based on preliminary tests by Jason Hubbart at the University of Idaho). We expect to observe repeatable spatial patterns in temperature that will depend on local topography and winds, which will vary between the west and east sides of the continental divide. The immediate outcome will be improved ability to distribute temperature spatially, which can be used to improve snowmelt forecast models for the streams of the Fraser and Niwot Ridge areas, both of which provide water for the Boulder/Denver area. However, the impacts of this study are expected to be much wider. Once the value of these small sensors is demonstrated, they can be deployed in any watershed and will fundamentally change the way mountain observing systems are designed.

References

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Realization of Snow / Vegetation Interactions Using Field Spectroscopy

Investigators: Noah Molotch (Visiting Fellow) and Thomas Painter (NSIDC)

Objective

Our objective is to quantify the impact of vegetation on snow metamorphism (i.e. snow grain size and liquid water content). The broader impact is an improved understanding of hydrologic response to land cover change. A feedback loop between vegetation and snow exists in which the distribution of snow and the timing of snowmelt largely control vegetation health during the growing season while vegetation intercepts snowfall and dramatically alters snow / atmosphere energy exchange and therefore the mass balance of the snow cover. Previous works have not been able to directly link vegetation-altered energy flux to alterations in snow cover ablation because quantitative measurements of snowpack microstructure are extremely time consuming. The proposed research will use field spectroscopy coupled with contact illumination to rapidly measure the vertical and horizontal stratigraphic distribution of grain size and liquid water content (Figure 1a) in snow trenches excavated surrounding coniferous vegetation (Figure 1b). The rapid acquisition of snow grain size and liquid water content measurements afforded using field optical spectroscopy will allow us to quantify the spatio-temporal variation in snow metamorphism surrounding vegetation. The proposed research is unique in that it will be the first attempt to bridge the gap between vegetation-induced alterations to snowpack / atmosphere energy exchange and snowpack mass balance.

Background and Importance

In this study we propose to characterize snow/vegetation interactions using field spectroscopy, improving understanding of hydrological/ecological feedbacks at the hillslope scale with implications for the regional scale. Studies of snow/vegetation interactions have primarily been performed in high-latitude regions (60–70°). In such regions snowmelt rates are negatively correlated with snow water equivalent; shallower areas melt faster than deeper areas. Due to snow interception by trees, snow depth often decreases from crown-edge to tree trunks (Figure 1b) (*Faria et al.,* 2000). Thus, snowpack metamorphic rates and grain size may increase with proximity to tree trunks. Much less is known about these interactions at continental lower latitude (30–40°) sites, where lower solar zenith angles (i.e. higher incident solar radiation) and lower atmospheric emissivities (i.e. lower incident longwave radiation) may cause snowmelt energy to decrease with increasing canopy density. Understanding the effect of vegetation on snow metamorphic rates is necessary to mathematically represent the physics of snowmelt under forest canopies. Such an understanding is a vital step to explicitly representing snow/vegetation interactions in distributed hydrologic models.

Characterizing the influence of vegetation on snow metamorphism is difficult using standard procedures (i.e. a hand-lens) because it is extremely time consuming and lacks repeatability. To reduce the field time required to obtain measurements of snow characteristics we propose to use an Analytical Spectral Devices FR field spectroradiometer (ASD-FR) coupled with an ASD High Intensity Contact Probe (Figure 1a). The ASD-FR samples reflectance, radiance, and irradiance in the wavelength range 350-2500 nm at 3-10 nm spectral resolution. While the coupling of the ASD-FR with the contact probe has been used to infer mineralogy for studies of swelling soils, it has not been used to determine stratigraphic information of snow.

Figure 1. (a) Snow grain size stratigraphy measured at 2 cm sampling interval using the ASD-FR, Red Mountain Pass, CO. (b) Excavated snow trench extending radially from a coniferous tree trunk, Wolf Creek Pass, CO. - note the increase in snow depth with distance from the tree.

We will analyze ASD-FR spectra for snow grain size (*Nolin and Dozier*, 2000) and liquid water content (*Green et al.,* 2002). Our approach is unique in that information will be obtained through a snow column, where previous work has focused only on properties of the surface snow. This important step will extend existing hyperspectral approaches for snow to a 2-dimensional (and by extension 3-d) domain. These two-dimensional, vertical images of snow grain size will illuminate previously unexplored interactions between vegetation and snow.

What makes this innovative?
To date the influence of coniferous vegetation on snowpack microstructure has not been documented. Thus, the proposed research is innovative in that it will quantify the influence of vegetation on snow metamorphism both vertically through the snowpack and horizontally at increasing distances from the vegetation. The application of spectroscopy to measuring snow/vegetation interactions is a new methodology with the potential to advance understanding of the linkages between vegetation and snowpack microstructure beyond any previous attempts.

Expected Outcome and Impact:
By utilizing an unbiased and rapid technique for monitoring snow properties we will be able to collect spatially continuous (both vertically and horizontally) measurements of snow grain size and liquid water content. This innovative approach will enable us to answer the questions: 1) how does snow grain size change with proximity to vegetation?; 2) how does the control of vegetation on grain size and liquid water content change through the snow accumulation and snowmelt seasons?; and 3) do the feedbacks between vegetation and snowpack metamorphism change as a function of vegetation density? We intend to summarize results pertaining to these questions in a peer-reviewed forum. This research will have an impact on hydrological modeling of seasonally snow covered systems as snow cover ablation rates must be parameterized separately in forested versus unforested areas. The improved understanding of snow vegetation interactions will also impact our understanding of how ecosystems respond to climate variability.

Research Plan
The research will consist of a series of intensive observation periods (IOP's) in which spectroscopic measurements of snow grain size and liquid water content will be made in cardinal directions surrounding six previously selected trees in a mixed conifer forest site in the Valles Caldera National Preserve (VCNP), Jemez Mountains, New Mexico. The VCNP has been chosen as there are substantial leveraging opportunities in the form of housing, snowmobiles, and hydrometeorological instrumentation, focused on other aspects of hydrological/ecological feedbacks. Existing observations of sap flow, CO_2 and H_2O vapor flux, snow depth and soil moisture will provide information on the response of the vegetation to water inputs and water related stress. At multiple heights above, within and below the canopy, existing observations of wind speed, net radiation, temperature and relative humidity will allow us to ascertain the influence of the vegetation on snow surface/atmosphere energy exchange. The characterization of snow grain size distribution surrounding the vegetation proposed under this research will link leveraged observations of snow surface/atmosphere interactions and vegetation response to water inputs/water stress. IOP-I will focus on studying snow/vegetation interactions during the premaximum accumulation season (February). IOP-II will focus on the wet / dry snow transition period (late March) and IOP-III (mid-April) will focus on the ablation season.

References
Faria, D.A., Pomeroy, J.W., and Essery, R.L.H. (2000), Effect of covariance between ablation and snow water equivalent on depletion of snow-covered area in a forest, Hydrological Processes, 14: 2683- 2695.

Green, R. O., Dozier, J., Roberts, D. A., and Painter, T. H. (2002), Spectral snow reflectance models for grain size and liquid water fraction in melting snow for the solar reflected spectrum, Annals of Glaciology, 34: 71-73.

Nolin, A. W., and Dozier, J. (2000), A hyperspectral method for remotely sensing the grain size of snow, Remote Sensing of Environment, 74(2): 207-216.

Collaborative Studies of Atmospheric Aerosols

Investigators: M.A. Tolbert, R. Garland, A.R. Ravishankara, E. Lovejoy and T. Baynard

Objective

The objective of this study is to determine the water uptake and optical properties of complex aerosol compositions.

Background and importance

The interaction of solar and terrestrial radiation with atmospheric particles strongly impacts the global and local environment. For example, it is well known that tropospheric aerosols play an important role in the global climate system. Tropospheric aerosols directly affect climate by scattering and absorbing incoming solar radiation (aerosol direct effect), leading to a cooling at the surface. Indirectly, aerosols impact climate by serving as cloud condensation nuclei (aerosol indirect effect). While the indirect effect of aerosols on clouds is thought to be a negative forcing (surface cooling), there are considerable uncertainties in the magnitude of the effect. According to the IPCC, aerosol effects represent some of the most uncertain aspects of the climate system (*IPCC*, 2001). In addition to their importance globally, aerosol optical problems impact us on a local scale. For example, tropospheric aerosols are a major cause of visibility reduction. The Boulder/Denver area experiences poor visibility year round, with violations of the state visibility standard one in three days each winter. By far the largest contribution to this visibility reduction is particles. A key factor in both the climate and visibility issues is how the ambient particles take up water and grow to sizes where they can most optimally interact with the radiation field.

While past research has determined how simple model aerosol systems respond to light, emerging research indicates that the true atmospheric system is considerably more complex. A key finding in the last decade is that tropospheric sulfate aerosols, once thought to be pure, are essentially all internal mixtures of many components, with organics comprising 50% or more of the particle mass (*Murphy et al.,* 98). Organics have strong biogenic and anthropogenic sources and appear to be ubiquitous in the tropospheric aerosol. The effect of the organics on the ability of the sulfate particles to take up water and grow into clouds is not well established and represents a significant weakness in our understanding of the aerosol-cloud-climate loop. The uptake of water by the complex mixtures is also important for determining the direct effect of aerosols on climate. Finally, water uptake by the complex aerosols allows them to grow to sizes where they effectively scatter light and reduce visibility. The proposed studies will use a novel technique to probe the water uptake and optical properties of complex aerosols containing both organic and inorganic components.

What makes this innovative?

While research in the Tolbert and Ravishankara groups has been focused on similar issues over the last 20 years, so far there has yet to be an actual collaborative effort. The proposed collaboration will bring together campus and NOAA expertise on atmospheric aerosols and enable a larger objective to be met than would be possible separately. We are proposing an innovative laboratory study to measure water uptake and optical properties by complex aerosols using cavity ring down spectroscopy. This is a very new technique for the study of atmospheric aerosols in the field, and has great potential for advancing fundamental knowledge of atmospheric aerosol properties through laboratory work.

Research plan

We propose to generate internally mixed organic/inorganic aerosols using established techniques. After formation, the aerosols will then be passed through a differential mobility analyzer (DMA) to size select out one particular size from 0.1 to 1 micrometer in diameter for detailed analysis of the relative humidity dependence. Very few laboratory studies have been performed on size-selected aerosol samples, but is critical to relate laboratory results to the atmosphere.

After a monodisperse sample of the aerosol of interest is generated, the particles will be monitored using cavity ring down (CRD) spectroscopy. CRD spectroscopy has been used extensively for the analysis of atmospheric gases. Very recently, the technique has been applied to measurements of atmospheric aerosols (*Thompson et al*., 2003, *Pettersson et al*., 2004). In brief, the CRD system consists of a 90-cm cavity enclosed by two highly reflective mirrors. Laser light at 532 nm is coupled into the cavity and the ring down signal is measured through the output mirror using a photomultiplier tube. The background ring down decay constant represents light losses due to the mirrors and Rayleigh scattering by gases in the cell. Ring down times are shorter when aerosols are in the cell because of additional losses due to particles scattering and absorbing the light. The difference in the decay constant

is then used to determine the total extinction due to particles. The extinction is a function of the particle number density, size distribution, and refractive index. The proposed experiments will directly measure the relative humidity dependence of aerosol optical properties, which significantly influences aerosol climate forcing and visibility.

Expected outcome and impact

We expect to determine the optical response of internally mixed organic/inorganic aerosols of various compositions to growth and evaporation in response to changes in relative humidity. Because of the extreme sensitivity and flexibility of the novel technique to be used, we will be able to study a wide range of organic species encompassing both biogenic and anthropogenic sources. By understanding how different aerosol compositions take up water and respond to light, we will provide essential data for the evaluation of the climatic and visibility impacts of natural and anthropogenic organic emissions.

References

Intergovernmental Panel on Climate Change (IPCC), *Climate Change 2001: The Scientific Basis*, edited by J. H. Houghton et al., Cambridge Univ. Press., New York, 2001.

Murphy, D. M., D. S. Thomson, A. M. Middlebrook and M. E. Schein. "*In situ* single-particle characterization at Cape Grim." *Journal of Geophysical Research*, 103, 1664-1669, 98.

Pettersson, A., E. R. Lovejoy, C. A. Brock, S. S. Brown and A. R. Ravishankara. "Measurement of aerosol optical extinction at 532nm with pulsed cavity ring down spectroscopy." *Journal of Aerosol Science*, 35, 8: 995-1011, 2004.

Thompson, J. E., H. D. Nasajpour, B. W. Smith, and J. D. Winefordner, "Atmospheric aerosol measurements by cavity ringdown turbidimetry," *Aerosol Science and Technology*, 37, 221-230, 2003.

CIRES Visiting Fellows

Post-Doctoral Fellows

Roya Bahreini
Ph.D., California Institute of Technology
Sponsor: Fred Fehsenfeld
Ambient measurements of size-resolved chemical composition of aerosols using the Aerodyne Aerosol Mass Spectrometer

Kevin Vranes
Ph.D. Lamont-Doherty Earth Observatory, Columbia University
Sponsor: Roger Pielke, Jr.
Examining decision making under uncertainty for climate change and severe storms, water resource management and earthquake mitigation

Cameron Wobus
Ph.D., Massachusetts Institute of Technology
Sponsors: Greg Tucker and Peter Molnar
A study of the links between climate and surface processes, focusing on erosion processes in river systems draining the eastern Colorado Front Range

Research and Education Fellow

Jadwiga H. Richter
Ph.D., University of Washington
Sponsors: Susan Buhr and Susan Avery
OUTREACH: Developing weather and climate educational opportunities for Mile Hi Girl Scouts
RESEARCH: Convectively generated gravity waves: Comparison between source parameterization and radar data

Sabbatical Fellows

Oscar Mesa
Ph.D. University of Mississippi, 1986
Sponsor: Vijay Gupta
Physical Basis of Long Range Persistence of Hydroclimatological Records

José A. Rial
Sabbatical Fellowship from the Univ. of North Carolina at Chapel Hill
Sponsors: Konrad Steffen and Mike Hardesty
Prediction of future global climate change

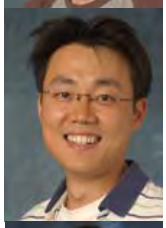
(Tim) Andrew Stern
Sabbatical Fellowship from Victoria University of Wellington, New Zealand
Sponsor: Peter Molnar
Incisional Erosion, Isostatic Rebound and Uplift Processes of Mountain Ranges

Gunilla Svensson
Sabbatical Fellowship from Stockholm University
Sponsors: John Cassano and Ben Balsley
Modeling of the atmospheric boundary layer in regional and climate models within GEWEX Atmospheric Boundary Layer Study (GABLS)

Michael Tjernström
Sabbatical Fellowship from Stockholm University
Sponsors: John Cassano and Ben Balsley
Arctic boundary-layer and cloud processes, from field experiment data and modeling, with an over-reaching aim to improve formulations of Arctic climate processes in climate models

Graduate Research Fellows

James Anthony
From: Iowa State University, BS Animal Ecology, MS Limnology
Ph.D.: Ecology and Evolutionary Biology
Academic Advisor: William M. Lewis, Jr.
Research Area: Release of phosphorus from lake sediments



Eungul Lee
From: Konkuk University, Seoul South Korea, BS Geography, MS Climatology
Ph.D.: Geography
Academic Advisor: Thomas N. Chase
Research Area: Subtropical northeast Asian monsoon and dynamic tropopause level as a diagnostic for monsoon activity

Ricardo Mantilla
From: Universidad Nacional de Colombia, BS Civil Engineering, MS Water Resources
Ph.D.: Civil, Environmental, and Architectural Engineering
Academic Advisor: Vijay K. Gupta
Research Area: Physical understanding of scaling properities of peak flows

Courtney Mashburn
From: Hendrix College, Conway AR, BA Chemistry
Department: Chemistry and Biochemistry
Academic Advisor: Margaret A. Tolbert
Research Area: Atmospheric chemistry of mineral dust

David McAdams
From: Linfield College, McMinnville OR, BS Chemistry
Department: Chemistry and Biochemistry
Academic Advisor: Robert E. Sievers
Research Area: Stabilization, micronization and drying by CAN-BD of measles vaccine aerosols

Atsuhiro Muto
From: Chiba University, Japan, BS Earth Science
Department: Geography
Academic Advisors: Konrad Steffen/Ted Scambos
Research Area: Measurement, analysis, and modeling of shallow borehold temperatures in snow/firn layers in Antarctica and Greenland

Appendices

Governance and Management

CIRES Leadership

Konrad Steffen: Director
William M. Lewis, Jr.: Associate Director
Paul Sperry: Associate Director for Science (*departed 3/06*)
Jon Rush: Associate Director for Administration

CIRES amended its division structure during 2005-2006 to better serve its members. The number of divisions was expanded from four to six. They are:

Cryospheric and Polar Processes: Roger Barry, Associate Director
Environmental Biology: Carol Wessman, Associate Director
Environmental Chemistry: Fred Fehsenfeld, Associate Director
Environmental Observations, Modeling and Forecasting: Michael Hardesty, Associate Director
Solid Earth Sciences: Roger Bilham, Associate Director
Weather and Climate Dynamics: Randall Dole, Associate Director

Fellows Committees

Council of Fellows
CIRES 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 Fellows met nine times in 2005-2006.

The Council of Fellows met nine times during FY05-06. Aug. 18; Sept. 15; Oct. 20; Nov. 17 and Dec. 15,,2005, and Jan. 26; Feb. 23; March 23 and April 13, 2006.

Richard Armstrong (Senior Research Scientists, National Snow and Ice Data Center)
Susan K. Avery (Vice Chancellor for Research and Dean of the Graduate School; Professor, Electrical and Computer Engineering)
Ben B. Balsley (Research Professor, Electrical and Computer Engineering)
Roger G. Barry* (Director, NSIDC; Professor of Geography)
Roger Bilham (Professor of Geological Sciences)
John Cassano* (Assistant Professor of Atmospheric and Oceanic Sciences)
Thomas N. Chase* (Assistant Professor of Geography)
Xinzhao Chu* (Assistant Professor of Aerospace Engineering)
Shelley D. Copley* (Professor of Molecular, Cellular and Developmental Biology)
Randall M. Dole (Director, Climate Diagnostics Center)
David Fahey (Research Physicist, Chemical Sciences Division)
Christopher W. Fairall (Supervisory Physicist, Physical Science Division)
G. Lang Farmer (Professor of Geological Sciences)
Fred C. Fehsenfeld (Senior Scientist, Chemical Sciences Division)
Graham Feingold (Scientist, Physical Science Division)
Noah Fierer* (Assistant Professor, Ecology and Evolutionary Biology Department)

Timothy J. Fuller-Rowell (Senior Research Scientist, CIRES/Space Environment Center)
Vijay K. Gupta* (Professor of Civil, Environmental and Architectural Engineering)
R. Michael Hardesty (Chief, Atmospheric Lidar Division, Chemical Science Division)
José-Luis Jiménez* (Assistant Professor of Chemistry and Biochemistry)
Craig Jones (Associate Professor of Geological Sciences)
William M. Lewis, Jr.* (Director, Center for Limnology; Professor of Ecology and Evolutionary Biology)
Peter H. Molnar* (Professor of Geological Sciences)
Russell K. Monson (Professor of Ecology and Evolutionary Biology)
Andrew M. Moore* (Professor of Atmospheric and Oceanic Sciences) [*departed 12/05*]
William D. Neff (Director, NOAA/ESRL Physical Science Division)
Steven Nerem (Professor of Aerospace Engineering)
David Noone* (Assistant Professor of Atmospheric and Oceanic Sciences)
Roger Pielke, Jr.* (Director, Center for Science and Technology Policy Research; Professor of Environmental Studies Program)
Balaji Rajagopalan (Assistant Professor of Civil, Environmental and Architectural Engineering)
Prashant Sardeshmukh (Senior Research Scientist, Assistant Director of Climate Diagnostics Center)
Mark Serreze (Research Professor of Geography, Senior Research Scientist, National Snow and Ice Data Center)
Anne F. Sheehan* (Professor of Geological Sciences)
Robert E. Sievers* (Professor of Chemistry and Biochemistry)
Susan Solomon (Senior Scientist, Chemical Sciences Division)
Konrad Steffen* (Professor of Geography, Director of CIRES)
Margaret A. Tolbert* (Professor of Chemistry and Biochemistry)
Greg Tucker* (Assistant Professor of Geological Sciences)
Veronica Vaida (Professor of Chemistry and Biochemistry)
John M. Wahr (Professor of Physics)
Carol A. Wessman* (Professor of Ecology and Evolutionary Biology)

* = *rostered in CIRES/Graduate School*

Emeritus Fellows
John Birks – Professor of Chemistry and Biochemistry
Alex Goetz – Professor of Geological Sciences
Carl Kisslinger – Professor of Geological Sciences
George Reid – Senior Scientist, NOAA CRD
Hartmut Spetzler – Professor of Geological Sciences
Doug Robertson – NOAA/NOS/NGS

CIRES Affiliates
Henry Diaz – NOAA Climate Diagnostics Center
Ray Fall – Professor of Chemistry and Biochemistry
Ray E. Habermann – National Geophysical Data Center
Pieter Tans – NOAA/ESRL Global Monitoring Division

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 a two-year term, renewable for one term, and two voting members that are the Members' Council representatives. The Associate 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 submits 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, as well as people representing the user groups that are supported by the CIRES Computing Facility. The Director of CIRES appoints the Chair of the committee as well as one other Fellow. Additional members are nominated and selected by the CAC. All members serve a three-year term.

Distinguished Lectureship Series
This lecture series was created to bring 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' visit.

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 and NOAA. Nominations for new Fellows are considered once yearly.

Graduate Research Fellowship Committee
Approximately five graduate research fellowships are awarded to CIRES-affiliated graduate students each year through a CIRES competition. This group serves as the review and selection committee for these fellowships.

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 dependa upon the funds available and funds requested, but averages about six.

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.

Bridge Funding and Sabbatical Leave 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 CU Program Review Committee, and others. They are created as a need arises, exist to accomplish a specific task, and are then disbanded.

CIRES Members' Council (CMC)

The Members' Council 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 Fellows' Council 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 Fellows Council/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.

Student Diversity Programs

Significant Opportunities in Atmospheric Research and Science Program (SOARS)

SOARS is a model learning community and mentoring program for promoting racial and gender equity in the atmospheric and related sciences. Created by and administered through the National Center for Atmospheric Research (NCAR), CIRES is partnering in this highly successful program while providing NCAR with a wider range of disciplines to place students. It is a multi-summer, four year undergraduate and graduate program for students majoring in an atmospheric science or a related field such as biology, chemistry, computer science, earth science, engineering, environmental science, mathematics, meteorology, oceanography, physics, or social science.

This year, CIRES funded **Karen Diaz**, Undergraduate in Environmental Engineering, Polytechnic University of Puerto Rico, San Juan. Her research project is "Background Measurements in Ozonsondes: Are current estimates correct?" Her mentor is Holger Vomel.

Undergraduate Research Opportunities Program (UROP)

The Undergraduate Research Opportunities Program (UROP) creates research partnerships between faculty and undergraduate students. Research in this context is interpreted as any scholarly or creative activity ranging from traditional scientific experimentation to the creation of new artistic works. UROP awards stipends and/or expense allowances to students who undertake an investigative or creative project in collaboration with a faculty member. Although projects are normally designed around some aspect of the faculty sponsor's research, they may also develop from a student's original ideas, which a faculty sponsor has endorsed. Whether the context is scholarly or artistic, UROP projects call for significant input on the part of the faculty sponsor. Program information can be found at *http://www.colorado.edu/Research/UROP/*.

Kerry Kemp, in Ecology and Environmental Biology, mentored by Prof. Carol Wessman, is exploring "The Effects of Compound Disturbances on Understory Species Composition in Subalpine Forests of the Rocky Mountains."

Personnel Demographics

Category	Total CIRES Personnel	CIRES Personnel Supported by NOAA Funding			
		TOTAL	*B.S.*	*M.S.*	*Ph.D.*
Research Scientist	175	110			110
Visiting Scientist	16	7			7
Postdoctoral Fellow	13	4			4
Associate Scientist	210	111	61	47	3
Administrative	30	22	18	4	
TOTAL greater than 50% NOAA support		**254**	**79**	**51**	**124**
Undergraduate Students	55	10			
Graduate Students	47	13	8	5	
Received less than 50 NOAA support		79	14	10	55
TOTAL	546				
Count by OAR Division					
CSD		75			
PSD		63			
GSD		16			
GMD		51			
TOTAL OAR		205			
NGDC/NESDIS		28			
NWS/SEC		15			
TOTAL NOAA		248			
Obtained NOAA employment within the last year		5			

Publications from Calendar Year 2005

CIRES scientists and faculty published 353 peer-reviewed and 209 non-peer-reviewed papers during the preceding calendar year. The following table tabulates these by affiliation of first author and their peer review status. We recognize that publication count alone is only one measure of institute impact, but it is the simplest to tabulate and compare. A better grasp of how CIRES research is extending the boundaries of scientific knowledge will be found in the Executive Summary and following detailed sections.

	CIRES Lead Author				NOAA Lead Author				Other Lead Author			
	2001	2002	2003	2004	2001	2002	2003	2004	2001	2002	2003	2004
Peer-Reviewed	164	112	177	165	43	60	31	56	127	110	183	134
Non-Peer-Reviewed	*	*	100	100	*	*	10	43	*	*	24	55

	CIRES Lead Author				NOAA Lead Author				Other Lead Author			
	2005	2006	2007	2008	2005	2006	2007	2008	2005	2006	2007	2008
Peer-Reviewed	188				20				145			
Non-Peer-Reviewed	161				10				38			

* Included in peer-reviewed publications

Refereed Publications

Adachi, A., T. Kobayashi, K.S. Gage, D.A. Carter, L.M. Hartten, W.L. Clark and M. Fukuda, 2005: **Evaluation of three-beam and four-beam profiler wind measurement techniques using a five-beam wind profiler and collocated meteorological tower.** *J. Atmos. Ocean. Technol.*: Vol. 22, No. 8, 1167-1180.

Akmaev, R.A., 2005: **Comments on "On maximum entropy profiles."** *J. Atmos. Sci.*: Vol. 62.

Akmaev, R.A., 2005: **"Greenhouse cooling" in the upper atmosphere**. *Bull. Amer. Meteorol. Soc.*: Vol. 86, 479-480.

Akmaev, R.A., V.I. Fomichev, and X. Zhu, 2005: **Impact of middle-atmospheric composition changes on greenhouse cooling in the upper atmosphere**. *J. Atmos. Solar-Terr. Phys.*: Vol. 68.

Albert, M, C. Shuman, Z. Courville, R. Bauer, M. Fahnestock, and T. Scambos, 2005: **Extreme firn metamorphism: impact of decades of vapor transport on near-surface firn at a low-accumulation glazed site on the East Antarctic plateau.** *Annals of Glaciology*: Vol. 39, 73-78.

Aldener, M., S.S. Brown, H. Stark, J.S. Daniel, and A.R. Ravishankara, 2005: **5. Near-IR absorption of water vapor: Pressure dependence of line strengths and an upper limit for continuum absorption**. *Journal of Molecular Spectroscopy*: Vol. 232, 223-230.

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Wilson, D.K., S.L. Collier, V.E. Ostashev, D.F. Aldridge, N.P. Symons, and D.H. Marlin, 2005: **Time-domain modeling of acoustic ground impedance,"** *Forum Acusticum*, Budapest, Hungary, August 29 - September 2 (2005).

Wilson, D.K., V.E. Ostashev, S.L. Collier, D.F. Aldridge, N.P. Symons, D.H. Marlin, 2005: **Time-domain calculations of attenuative and dispersive sound propagation in porous media**. *Acoustical Society of America Meeting, 2005.*: Vol. 118, 1866-1866.

Wilson, D.K., M.L. Moran, S.A. Ketcham, J. Lacombe, T.S. Anderson, N.P. Symons, D.F. Aldridge, D.H. Marlin, S.L. Collier, and V.E. Ostashev, 2005: **High-fidelity simulation capability for virtual testing of seismic and acoustic sensors**. *SPIE Defense and Security Symposium, 28 March - 1 April, Orlando, Florida, 2005.*

Wolfe, D.E., C.W. Fairall, M. Ratterree, A.W. Brewer, J.M. Intrieri, B.J. McCarty, S. Tucker, D.C. Law, A.B. White, and D.E. White, 2005: **Shipboard multi-sensor wind profiles from NEAQS 2004: Radar wind profiler, high resolution Doppler lidar GPS rawindsonde**. *The 15th Conference on Applied Climatology/13th Symposium on Meteorological Observations and Instrumentation (Savannah, GA).*

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Refereed Journals in which CIRES Scientists Published in 2005

Abstracts of Papers of the Amer. Chemical Society
Accounts of Chemical Research
Acoustical Society of America, Journal of the
Advances in Water Resources
Aerosol Science and Technology
Agricultural and Forest Meteorology
Air and Waste Management Association, Journal of the
American Mineralogist
Annales Geophysicae
Annals of Glaciology
Applied and Environmental Microbiology
Applied Meteorology and Climatology, Journal of
Applied Optics
Arctic Research of the United States
Arctic, Antarctic, and Alpine Research
Astronautical Sciences, Journal of the
Astrophysics, Journal of
Atmos. Solar-Terrestrial Physics, Journal of
Atmospheric and Oceanic Technology, Journal of
Atmospheric Chemistry and Physics
Atmospheric Environment
Atmospheric Sciences, Journal of
Bacteriology, Journal of
Biogeochemical Cycles
Biogeochemistry
Boundary-Layer Meteorology
Bulletin of the American Meteorological Society
Chemical Physics Letters
Chemical Physics, Journal of
Climate Change, Journal of
Climate, Journal of
Cold Regions Science and Technology
Colorado Water
Current Science
Data Science Journal
Earth Interactions
Earth Planets and Space
Ecology
Ecosystems
Environmental Management
Environmental Science and Policy
Environmental Science and Technology
Environmental Sciences
Eos Transactions of the AGU
Faraday Discussions
Geochimica et Cosmochimica Acta
Geological Society of America, Journal of the
Geophysical Journal International
Geophysical Monograph Series
Geophysical Research Letters
Geophysical Research, Journal of
Geoscience Education, Journal of
Global and Planetary Change
Global Biogeochemical Cycles
GPS Solutions
Hydrological Processes
Hydrometeorology, Journal of
IEEE Geoscience and Remote Sensing Letters
International Geophysics
International Journal of Astrobiology
International Journal of Climatology
International Journal of Geomagnetism and Aeronomy
International Journal of Mass Spectrometry
International Journal of Photoenergy
International Journal of Rock Mechanics and Mining Sci.
Limnology and Oceanography Bulletin
Metabolic Engineering
Meteorologische Zeitschrift
Mineralogical Magazine
Molecular Spectroscopy, Journal of
Monthly Weather Review
Natural Hazards
Natural Hazards Review
Nature
NAWCADPAX Technical Memorandum
Newsletter of Societe Italiana di ElettroMagnetismo
Nonlinear Processes in Geophysics
North American Benthological Society, Journal of the
Oecologia
Optical Engineering
Palaeontologia Electronica
Photochemistry and Photobiology A – Chemistry,
Physical Chemistry, Journal of
Physical Geography
Physical Oceanography, Journal of
Physics and Chemistry of Minerals
Physics of Fluids
Physics of the Earth and Planetetary Interiors
Polar Geography
Policy Sciences
Population and Environment
Proceedings of the National Acadamies of Science
Pure and Applied Geophysics
Quarternary Journal of the Royal Meteorological Society
Radio Science
Remote Sensing of the Environment
Reviews of Geophysics
Revista Geologica de Chile
Science
Seismological Research Letters
Sound Vibration, Journal of
Spectrochimica Acta Part A - Molecular & Biomol. Spect.
Vadose Zone Journal
Water Resources Research
Weather
Weather and Forecasting, Journal of
Weather Modification, Journal of

Honors and Awards

Angevine, Wayne
CIRES Outstanding Performance Award
NOAA OAR Outstanding Scientific Paper of 2004

Auerbach, Nancy
NGDC Director's Award for the NOSA database and website

Bilham, Roger
S. Thomas Crough Memorial Lecture, Purdue University
Invited talk UNAVCO IRIS annual meeting

Burgdorf, Catherine
NASA Group Achievement Award to the Intercontinental Chemical Transport Experiment North America (INTEX-NA) Science Team

Cartwright, John
NGDC Director's Award for the NOSA database and website

Clifford, Steven F.
Member, of the National Academy of Engineering
Fellow, of the Acoustical Society of America
Fellow, of the Optical Society of America
IEEE, Meritorious Presidential Rank Award winner

Davis, Maxine
Department of Commerce Boulder Laboratories Postdoctoral Symposium

Dubé, William
CIRES Outstanding Performance Award for work done on lightweight racks for P3.

Duerr, Ruth
Certificate of Appreciation THIC

Fifarek, Richard
CDC-CIRES outstanding employee recognition award for 2005

Frauenfeld, Oliver
Career Track Promotion to Research Scientist II

Frost, Gregory
CIRES Outstanding Performance Award as part of the Texas Air Quality Team

Godin, Oleg
Keynote speaker Seventh International Conference on Theoretical and Computational Acoustics, Hangzhou, China

Holloway, John
NOAA's Office of Atmospheric Research Outstanding Paper of 2004

Howard, Allaina
Member of SLIM Advisory Board, Emporia State University
ACA Travel Award from the Academy of Certified Archivists

Hübler, Gerd
2005 Outstanding Performance Award as member of Texas Air Quality Team CIRES
NOAA's Office of Atmospheric Research Outstanding Paper of 2004
NASA Group Achievement Award for the Intercontinental Chemical Transport Experiment North America Science Team

Jimenez, Jose L.
Jimenez et al., *J. Geophys Res*., 108(D7), 8425, 2003) was recognized as "Top 1% in its field" by the "Essential Science Indicators" Program of the Institute of Scientific Information (ISI).

Jing, Xiangbao
Certificate of Recognition of FSL Team Member of the Month April 2005.

Joy, Craig
CIRES Promotion to Associate Scientist III

Kingsmill, David
NOAA OAR Outstanding Scientific Paper entitled "The impact of a prominent rain shadow on flooding in California's Santa Cruz Mountains: A CALJET case study and sensitivity to the ENSO cycle"

Lestak, Leanne
Promotion to Associate Scientist III

McKenzie, Valerie
Invited speaker at University of California Toxic Substances Research & Teaching Program
Best poster at the University of California Toxic Substances Research & Teaching Program

Moore, Fred
NASA Group Achievement Award in recognition of outstanding accomplishments and contributions to POLARIS, CRYSTAL-FACE, SOLVE, SOLVE-II, BOS
Best Poster: CMDL/NOAA Annual Meeting - Best Poster awarded for "Measured SF_6 Loss and its Influence on Age of Air Calculations
CIRES Outstanding Performance Award

Neuman, Andy
2005 CIRES Outstanding Performance Award as a member of the Texas Air Quality Team

Ostashev, Vladimir
Elected as an Associated Editor of The Journal of the Acoustical Society of America and as an Associated Editor of The Express Letters of this journal

Osthoff, Hans
Best poster presentation Boulder Laboratories

Peckham, Steven
NASA Group Achievement Award for the Intercontinental Chemical Transport Experiment conducted in Illinois and New Hampshire

Peng, Shiling
NOAA – CIRES CDC 2005 Employee Award

Persson, Ola
OAR Outstanding Scientific Paper of 2004

Quincy, Dorothy
CIRES Outstanding Performance Award

Scott, Donna
Nominated for Chancellor's Employee of the Year Award by NSIDC management and colleagues

Scott, Michon
Award of Excellence NASA Goddard Space Flight Center for work on *http://earthobservatory.nasa.gov*
Site of the Week School Library Journal For http://www.strangescience.net
$500 cash award Institute for Evolutionary Studies, Glasgow, Scotland for *http://www.strangescience.net*

Senff, Christoph
2004 NOAA/OAR Outstanding Scientific Paper co-author: "Effects of Petrochemical Industrial Emissions of Reactive Alkenes and NO_x on Tropospheric Ozone Formation in Houston, Texas"

Serreze, Mark
The Arctic Climate System (Cambridge University Press), won the award for best book in the Atmospheric Sciences from the Atmospheric Sciences Librarians International (ASLI)
Promotion to Senior Research Scientist

Sheffield, Elizabeth
Promotion to Associate Scientist III

Shin, Sang-Ik
Promotion to Research Scientist II

Shupe, Matthew
Received the ETL Employee of the Month Award in June of 2005.

Simons, Craig
CIRES Outstanding Performance Award

Smirnova, Tatiana
Team Member of the Month GSD/ESRL

Smith, Lesley
Promotion to Research Scientist III.
Superintendent's Honor Roll Boulder Valley School District for the Sombrero Marsh Education Program.

Stroker, Kelly
NGDC Featured Employee: Recognized for work done on the NOSA project.
Promotion Associate Scientist II

Swenson, Sean
Editors's Citation for Excellence in Refereeing Geophysical Research Letters

White, Allen
OAR Outstanding Scientific Paper Award: "The impact of a prominent rain shadow on flooding in California's Santa Cruz Mountains: A CALJET case study and sensitivity to the ENSO cycle."

Zhao, Conglong
CIRES Administrator's Award CIRES for developing a global atmospheric greenhouse gas measurement network that has revolutionized the study of the earth's carbon cycle.

Service

CIRES members serve the scientific communities within the University of Colorado and NOAA, and beyond through participation in professional societies; organization of meetings and special sessions at conferences; review of journal publications and proposals from funding agencies, and service on editorial boards for major journals and committees. Following is a selected list of such memberships and activities, reflecting CIRES employees' service and dedication to their diverse fields of expertise. It is impossible to list all the organizations which benefit from CIRES' involvement, but we have tried to include an overview here. For the sake of brevity, service to CIRES, the University of Colorado, and NOAA are not included as we are aiming to illustrate the global reach of CIRES expertise and contributions.

Professional Memberships

Acoustical Society of America
Alexander von Humboldt Association of America
American Association for Aerosol Research
American Association for the Advancement of Science
American Association of Geographers
American Association of Museums
American Association of Pharmaceutical Scientists
American Association of State Climatologists
American Astronautical Society
American Chemical Society
American Educational Research Association
American Indian Science and Engineering Society
American Meteorological Society
American Society for Limnology and Oceanography
American Society for Quality
American Society of Parasitologists
American Water Resources Association
American Water Works Association
American Geophysical Union
Association for Computing Machinery
Association for Science Teacher Education
Association of Mechanical Engineers
Australian Meteorological and Oceanic Society
Boulder Writers' Alliance
China Society of Glaciology and Geocryology
Colorado Alliance for Environmental Education
Colorado Association of Science Teachers
Colorado Lakes and Reservoirs Association
Colorado Science Education Network
Colorado Space Grant Consortium
Colorado Water Congress
Computer Professionals for Social Responsibility
Consortium of Universities for Advancement of Hydrologic Sciences
Cooperative Research and Development Foundation
Deutsche Gesellschaft fuer Polarforschung
Deutsche Physikalische Gesellschaft
Ecological Society of America
European Geophysical Society
Geoscience Education & Public Outreach Network
Institute of Electrical and Electronics Engineers
Intergovernmental Panel on Climate Change
International Association for Geomagnetism and Aeronomy
International Association for Mathematical Physics

International Facilities Management Association
International Glaciological Society
International Permafrost Association
International Society on General Relativity and Gravitation
International Union of Geodesy and Geophysics
IPY Data and Information Service, International Council of Science and World Meteorological Association
Morris K. Udall Foundation
National Association of Science Writers
National Center for Science Education
National Science Teachers Association
National Association for Research in Science Teaching
NSF Observing Facilities Advisory Panel
Optical Society of America
Remote Sensing Society
Rocky Mountain Climate Organization
Royal Meteorological Society
Science Communications and Marine Public Information Network
Society for Advancement of Chicanos and Native Americans in Science
Society for Technical Communication
Society of American Archivists
Society of Research Administrators
Society of Rocky Mountain Archivists
Special Libraries Association
US Permafrost Association
World Meteorological Organization

Editorial Service

Climate Research
Cold Regions Science and Technology
Computers & Geosciences
Geophysical Research Letters
Journal of Atmospheric and Solar-Terrestrial Physics
Journal of Hydrologic Engineering
Journal of Gephysical Research
Journal of Glaciology and Geocryology
Journal of Remote Sensing of Environment
Journal of Atmospheric Chemistry
International Association for Mathematical Geology
Mathematical Geology
Stochastic Environmental Research and Risk Assessment

Organizer/Convenor

6th Aerodyne Aerosol Mass Spectrometer (AMS) Users' Meeting
10th Symposium on Assimilation and Observing Systems for Atmosphere, Oceans and Land Surface: Special session: Multidisciplinary Global Modeling: The Really Big Picture
AGU Special session: Geophysical Information for Teachers workshop on hurricanes and severe weather for Louisiana educators
AGU Special session: Outstanding Issues in Seasonal to Interannual Climate Prediction
AGU: Chapman Conference on Dynamical Troposphere-Stratosphere Coupling
AGU: Special session: Deciphering Data
AGU: Special session: Ensemble Forecasts for Weather and Seasonal Climate
AGU: Special session: North American Summer Monsoon: Understanding Its Interannual and Intra-annual Variability and Implications to Water Resources Management
AGU: Special session: Outstanding Issues in Seasonal to Interannual Prediction

Association of American Geographers: Special session: Atmospheric Circulation Variability and the Cryosphere
Association of American Geographers: Special session: Changes in Climatic Variability and Atmospheric Circulation
Association of American Geographers: Special session: Climate and Cryosphere
European Geophysical Union session on education and outreach associated with International Science Years
GIS day-long track: Emerging Standards
IAGA/CAWSES Workshop: Long Term Changes and Trends in the Atmosphere
IAMG2005: Special session on Remote Sensing of the Environment and Geomathematics
Joint AGU Assembly: Special session: Climatological Variations in the Upper Atmosphere and Ionosphere
WCRP/Global Climate Observing System Surface Pressure Working Group 3rd Meeting

Review Papers and Proposals for:

Acoustical Society of America, Journal of the
Advances in Atmospheric Science
Advances in Space Research
Advances in Water Resources
Agricultural and Forest Meteorology
Agricultural Systems Journal
Agriculture and Forest Meteorology, Journal of
American Water Resources Association, Journal of the
Analytical Chemistry
Annals of Glaciology
Antarctic Science
Applied Meteorology, Journal of
Arctic, Antarctic, and Alpine Research
Atmospheric and Oceanic Technology, Journal of
Atmospheric and Solar-Terrestrial Physics, Journal of
Atmospheric Chemistry and Physics
Atmospheric Environment
Atmospheric Research
Atmospheric Science Letters
Atmospheric Sciences, Journal of
Austrian Science Foundation
Boundary-Layer Meteorology
Bulletin of the Seismological Society of America
Cambridge University Press
Canadian Journal of Fisheries and Aquatic Sciences
Canadian Journal of Zoology
Chaos
Chemical Boundary Layer Meteorology
Chemical Geology
Climate Change
Climate Dynamics
Climate Research
Climate, Journal of
Computational Acoustics, Journal of
Deep Sea Research
Department of Commerce
Department of Energy
Dynamics of Atmosphere and Ocean
Earth and Planetary Science Letters
Emirates Journal of Engineering
Environmental Science & Technology
Estuarine, Coastal, and Shelf Science

European Geophysical Union
Fluid Mechanics, Journal of
Geochemical Journal
Geofizika
Geophysical Research Letters
Geophysical Research, Journal of
Global and Planetary Change
GPS Solutions
Hydrologic Engineering, Journal of
Hydrological Processes
Hydrology, Journal of
Hydrometeorology, Journal of
IEEE Journal of Oceanic Engineering
IEEE Transactions on Geoscience and Remote Sensing
International Association of Geodesy
International Journal of Applied Earth Observation and Geoinformation
International Journal of Climatology
Limnology and Oceanography
Marine Biology
Meteorological Society of Japan, Journal of
Meteorology and Atmospheric Physics
Mississippi-Alabama Sea Grant Consortium
Monthly Weather Review
NASA
National Academy of Sciences/National Research Council
Nature
NOAA
NSF
Ocean Modeling
Oceanography, Journal of
Oxford University Press
Photogrammetric Engineering and Remote Sensing
Physical Chemistry, Journal of
Physical Oceanography, Journal of
Plant, Cell, Environment
Proceedings of the Royal Society (London)
Propulsion and Power, Journal of
Quarterly Journal of the Royal Meteorological Society
Quaternary Research
Radio Science
Rapid Communications in Mass Spectrometry
Remote Sensing of the Environment
Science
Seismological Society of America
Space Science Institute
Stochastic Environmental Research & Risk Assessment
Tellus
Terrestrial, Atmospheric and Oceanic Sciences, Journal of
U.S. Civilian Research and Development Foundation
USBR's Science and Technology Program
Volcanology and Geothermal Research, Journal of
Water Resources Research
Water Resources Research Institute
Waves in Random and Complex Media

Acronyms

ACA	Academy of Certified Archivists
ACRF	ARM Climate Research Facility
ACSYS	Arctic Climate System Study
ADCC	ARCSS Data Coordination Center
AFWA	Air Force Weather Agency
AGCM	Atmospheric Global Circulation Model
AGDC	Antarctic Glaciological Data Center
AGU	American Geophysical Union
AIRS	Advanced Infra Red Sounder
AL	Aeronomy Laboratory
AM2	Atmospheric Component
AMD	Antarctic Master Directory
AMEF	Architecture for Modeling Ecological Functions
AMIE	Assimilative Mapping of Ionospheric Electrodynamics
AMMA	African Monsoon Multidisciplinary Analysis
AMOS	Advanced Modeling and Observing Systems (CIRES scientific theme)
AMPS	Antarctic Mesoscale Prediction System
AMS	Aerosol Mass Spectrometer
AMS	American Meteorological Society
AMSU	Satellite microwave sensor
AOPEC	Atmospheric Observation Panel for Climate
ARB	American River Basin
ARCSS	Arctic System Science
ARL	Air Resources Laboratory
ASLI	Atmospheric Sciences Librarians International
ASD-FR	Analytical Spectral Devices FR Field Spectroradiometer
ASR	Arctic System Reanalysis
ATI	Atmospheric Technology Incorporated
ATOC	Atmospheric and Oceanic Sciences Department
ATOVS	Advanced TIROS Operational Vertical Sounder
AVE	Aircraft Validation Experiments
AVHRR	Advanced Very High Resolution Radiometer
AWR	Advanced Research WRF
AXS	Avalanche X-ray Spectrometer
BEIS 3	Biogenic Emission Inventory System 3
BMJ	Betts-Miller-Janjic
BSRN	Baseline Surface Radiation Network
BVSD	Boulder Valley School District
CAC	Computing Advisory Committee
CAFS	CCD-based Actinic Flux Spectroradiometers
CALJET	California Land-Falling Jets
CAN-BD	Carbon Dioxide-Assisted Nebulization with a Bubble Dryer®
CAPE	Convection and Precipitation/Electrification Experiment
CASES	Cooperative Atmosphere-Surface Exchange Study-99
CAWSES	Climate And Weather of the Sun-Earth System
CBLAST	Coupled Boundary Layers Air-Sea Transfer
CCD	Comparative Climate Data
CCF	CIRES Computing Facility
CCFP	Collaborative Convective Forecast Product
CCM	Community Climate Model
CCOS	Central California Ozone Study
CDC	Climate Diagnostics Center
CDEP/ARC	Climate Dynamics and Experimental Prediction/Applied Research Center
CEDAR	Coupling, Energetics, and Dynamics of Atmospheric Regions

CEMS	Continuous Emission Monitoring System
CFC	Chlorofluorocarbon
CFS	Climate Forecast System
CIN	Convective Inhibition
CIRES	Cooperative Institute for Research in Environmental Sciences
CISM	Solar wind model
CliC	Climate and Cryosphere
C-LIM	Coupled empirical-dynamical Linear Inverse Model
CLIVAR	CLImate VARiability and Predictability Program
CM	Core-Mantle
CMDL	Climate Monitoring and Diagnostics Laboratory
CME	Coronal Mass Ejection
CO	Carbon Monoxide
CO_2	Carbon Dioxide
COADS	Comprehensive Ocean Atmosphere Data Set
COARE	Coupled Ocean-Atmosphere Response Experiment
COBRA-NA	CO_2 Budget and Regional Airborne – North America
COFECHA	Computer program that assesses the quality of crossdating and measurement accuracy of tree-ring series
CoML	Census of Marine Life
CONUS	Continental United States
COOP	Cooperative Observer Network
CORE	Consortium for Oceanographic Research and Education
CORS	Continuously Operating Reference Stations
CPC	Condensation Particle Counter
CPP	Cryospheric and Polar Processes
CPT	Cape Point Observatory
CRADA	Wind profiler
CRD	Cavity Ring-Down Spectroscopy
CRN	Collaborative Research Networks
CRYSTAL-FACE	Cirrus Regional Study of Tropical Anvils and Cirrus Layers–Florida Area Cirrus Experiment
CSAP	Colorado Student Assessment Program
CSD	Chemical Sciences Division (ESRL)
CSES	Center for the Study of Earth from Space
CSTPR	Center for Science and Technology Policy Research
CSV	Climate System Variability (CIRES scientific theme)
CTIPe	Coupled-Thermosphere-Ionosphere-Plasmasphere-electrodyamics
CU	University of Colorado
CUCF	Central UV Calibration Center
CVI	Counterflow Virtual Impactor
CWCB	Colorado Water Conservation Board
DAAC	Distributed Active Archive Center
DAFM	Dynamical Area Fraction Model
DDS	Data Display System
DIAL	Differential Absorption of Light
DLL	Dynamic Linked Library
DLR	German Space Agency
DMA	Differential Mobility Analyzer
DMS	Dimethyl-Sulfide
DOD	Department of Defense
DOE	Department of Energy
DSRC	David Skaggs Research Center
DSS	Decision Support System
DWDM	Dense Wave Division Multiplexing
EASE	Equal-Area Scalable Earth grid
EBIO	Ecology and Evolutionary Biology

EC	European Commission
ECB	Environmental Chemistry and Biology
ECMWF	European Center for Medium Range Weather Forecasts
EIT	Extreme Ultraviolet Imaging Telescope
EMC	Environmental Monitoring Center
ENSO	El Niño/Southern Oscillation
ENVISAT	Advanced polar-orbiting Earth observation satellite
EO	Education and Outreach
EPA	Environmental Protection Agency
EPIC	Eastern Pacific Investigations of Climate
ESRL	Earth Systems Research Laboratory
ET	Evapotranspiration
ETL	Environmental Technology Laboratory
EUV	Extreme Ultraviolet
FAO	Food Agriculture Organization (UN)
FGDC	Frozen Ground Data Center
FNIH	Foundation for the National Institutes of Health
FRAMES	Fire Research And Management Exchange System
FSL	Forecast Systems Laboratory
FTE	Full Time Equivalent
FTP	File Transfer Protocol
GABLS	GEWEX Atmospheric Boundary Layer Study
GAIM	Global Assimilation of Ionospheric Measurements
GAW	Global Atmosphere Watch
GCM	Global Circulation Model
GCMD	Global Change Master Directory
GCOS	Global Climate Observing System
GDSIDB	Global Digital Sea Ice Data Bank
GEO	Geodynamics (CIRES scientific theme)
GEWEX	Global Energy and Water Cycle Experiment
GFDL	Geophysical Fluid Dynamics Laboratory
GFS	Global Forecast System
GHG	Greenhouse gas
GIFT	Geophysical Information For Teachers
GIS	Geographic Information System
GLAS	Geoscience Laser Altimeter System
GLDAS	Global Land Data Assimilation Systems
GLIMS	Global Land Ice Measurements from Space
GLOBEC	Global Ocean Ecosystem Dynamics
GMAO	Global Modeling and Assimilation Office
GMD	Global Monitoring Division (ESRL)
GNSS	Global Navigation Satellite Systems
GOES	Geostationary Operational Environmental Satellite
GoMACCS	Gulf of Mexico Atmospheric Composition and Climate Study
GOS	Geospatial One Stop Web sites
GPS-MET	Ground-based GPS Meteorology
GRACE	Gravity Recovery and Climate Experiment
GSD	Global Systems Division (ESRL)
GSI	Gridpoint Statistical Interpolation
GTOS	Global Terrestrial Observing System
HEPEX	Hydrological Ensemble Prediction Experiment
HFC	Hydrofluorocarbons
HIRS	High-Resolution Infrared Radiation Sounder
HMT	Hydrometeorological Testbed
HSRC	High Resolution Stereo Camera
IA	Integrating Activities (CIRES scientific theme)

IAGA	International Association of Geomagnetism and Aeronomy
IAI	Inter-American Institute
IAMG	International Association for Mathematical Geology
IARC	International Arctic Research Center
ICARTT	Int'l Consortium for Atmospheric Research on Transport and Transformation
ICE	IPY Communication and Education
ICESat	Ice, Cloud, and land Elevation Satellite
I-COADS	International Comprehensive Ocean-Atmosphere Data Set
IDEA	Integrated Dynamics through Earth's Atmosphere
IEEE	Institute of Electrical and Electronics Engineers
IEF	Interplanetary Electric Field
IGAC	International Global Atmospheric Chemistry
IGRF	International Geomagnetic Reference Field
IMS	Ice Mapping System
INSTAAR	Institute of Arctic and Alpine Research
IONS	INTEX Ozonesonde Network Study
INTEX-NA	Intercontinental Chemical Transport Experiment North America
IOP	Intensive Observation Period
IPCC	Intergovernmental Panel on Climate Change
IPY	International Polar Year
IRIS	Incorporated Research Institutions for Seismology
IRP	Innovative Research Program
ISI	Institute of Scientific Information
ITCT	Intercontinental Transport and Chemical Transformation
JFM	January-February-March
JGR	Journal of Geophysical Research
LAN	Local Area Networks
LAP-XM	Radar control software
LAS	Live Access Server
LBA	Large-scale Biosphere Atmosphere experiment
LIM	Linear Inverse Model
LLUC	Land Use/Cover Change
LSM	Land-Surface Model
LTER	Long-Term Ecological Research
LWP	Liquid Water Path
MBBDB	MultiBeam Bathymetric Data Base
MEGAN	Model for Emissions of Gases and Aerosols from Nature
MJO	Madden-Julian Oscillation
MLS	Microwave Limb Sounder
MLT	Mesosphere and Lower Thermosphere
MM5	Mesoscale Model 5
MMA	Monthly Mean Averages
MODIS	Moderate Resolution Imaging Spectroradiometer
MOLA	Mars Orbiter Laser Altimeter
MOZAIC	Measurement of ozone, water vapour, carbon monoxide and nitrogen oxides aboard Airbus in-service aircraft
MRF	Medium-Range Forecast
MSIS	Mass-Spectrometer-Incoherent-Scatter
NAAQS	National Ambient Air Quality Standards
NADPH	Nicotinamide Adenine Dinucleotide PHosphate
NAME	North American Monsoon Experiment
NAMS	North American Monsoon System
NARR	North American Regional Reanalysis
NASA	National Aeronautics and Space Administration
NASM	Nort American Summer Monsoon
NAVDAT	North American Volcanic and intrusive ignious rock DATabase

NCAR	National Center for Atmospheric Research
NCDC	National Climatic Data Center
NCEP	National Centers for Environmental Prediction
NCWCD	Northern Colorado Water Conservancy District
NDVI	Normalized Deviated Vegetation Index
NEAQS	New England Air Quality Study
NESDIS	National Environmental Satellite, Data, and Information Service
NetCDF	Network Common Data Form
netCDF	network Common Data Form
NEXRAD	Next Generation Radar
NGDC	National Geophysical Data Center
NGS	National Geodetic Survey
NIC	National Ice Center
NIDIS	National Integrated Drought Information System
NIST	National Institute of Standards and Technology
NIWA	National Institute of Water and Atmospheric Research
NLR	National Lambda Rail
NMM	Non-hydrostatic Mesoscale Model
NOAA	National Oceanic and Atmospheric Administration
NOHRSC	National Operational Hydrologic Remote Sensing Center
NOMADS	NOAA Operational Model Archive and Distribution System
NOS	National Ocean Service
NOSB	National Ocean Sciences Bowl
NPOESS	National Polar-orbiting Operational Environmental Satellite System
NRL	Naval Research Laboratory
NRLC	Natural Resources Law Center
NSF	National Science Foundation
NSIDC	National Snow and Ice Data Center
NSSL	National Severe Storms Laboratory
NWS	National Weather Service
O_3	Ozone
OAI	Open Architectural Initiative
OAR	Oceanic and Atmospheric Research
OBIS	Ocean Biogeographic Information System
ODS	Ozone-Depleting Substances
OGCM	Oceanic General Circulation Model
OGP	Office of Global Programs
OMB	Office of Management and Budget
OMI/AURA	Ozone Monitoring Instrument/Aura
OPC	Optical Particle Counter
OPP	Office of Polar Programs
OSDPD	Office of Satellite Data Processing and Distribution
PACS	Pan-American Climate Study
PASSCAL	Program for the Array Seismic Studies of the Continental Lithosphere
PBL	Planetary Boundary Layer
PCM	Polar Mesospheric Clouds
PCP	Pentachlorophenol
PCR	Polymerase Chain Reaction
PILS	Particle into Liquid Sampler
PIWP	Path-integrated Ice Water Path
PLP-LIF	Pulsed Laser Photolysis—Laser Induced Fluorescence
PLT	Post Launch Test
PLWP	Path-integrated Liquid Water Path
PM	Planetary Metabolism (CIRES scientific theme)
PMEL	Pacific Marine Environment Laboratory
PMH	Protocol for Metadata Harvesting

PMM	Precipitation Measurement Missions
POAM	Polar Ozone and Aerosol Measurement
POLARIS	Photochemistry of Ozone Loss in the Arctic Region in Summer
POMME	Geomagnetic field model
PR	Precipitation Radar
PRISM	Partnership for Research in Spatial Modeling
PSD	Physical Sciences Division (ESRL)
RCM	Rice University Inner Magnetospheric Convection Model
RDHPCS	Research and Development High Performance Computing System
ReSciPE	Resources for Scientists in Partnerships with Education
RFE	Radiative Forcing Efficiency
RGON	Remote Geophysical Observatory Network
RH	Relative Humidity
RISA	Regional Integrated Sciences and Assessments
RL	Residual Layer
RMS	Root-Main-Square
RP	Regional Processes (CIRES scientific theme)
RPCA	Rotated Princpal Component Analysis
RR	Rapid Refresh
RTDS	Real Time Data System
RTIGS	Real Time International GNSS Services
RTIS	Radiation Threat Identification System
RTVS	Real-Time Verification System
RUC	Rapid Update Cycle
SAGE	Stratospheric Aerosol and Gas Experiment
SBL	Stable Boundary Layer
SBUV	Solar Backscatter UltraViolet
SD	Standard Deviation
SEARCH	Study of Environmental Arctic Change
SEAT-A	Carbon data Assimilation System
SEC	Space Environment Center
SEMS	Scanning Electrical Mobility Sizer
SES	Solid Earth Sciences
SGP	Department of Energy Southern Great Plains
SHEBA	Surface Heat Budget of the Arctic Ocean
SIGRID	Sea Ice Grid
SLIM	School of Library and Information Management (Emporia State University)
SO_2	Sulfur Dioxide
SOARS	Significant Opportunities in Atmospheric Research and Science
SOCC	Satellite Operations Control Center
SOHO	Solar and Heliospheric Observatory
SOLVE	SAGE III Ozone Loss and Validation Experiment
SOM	Self-Organizing Maps
SPARC	Science Policy Assessment and Research on Climate
SPCZ	South Pacific Convergence Zone
SPRAT	South Platte Regional Assessment Tool
SSM-I	Satellite microwave sensor
SST	Sea Surface Temperature
STC	Subtropical Cells
STEM	Science, Technology, Engineering, Math
STEREO	Solar Terrestrial Relations Observatory
SURFRAD	Surface Radiation
SWA	Space Weather Analysis
SWDS	Space Weather Data Stores
SXI	Solar X-ray Imager
TB	Tibetan Plateau

TCBQ	Tetrachlorobenzoquinone
TCHQ	Tetrachlorohydroquinone
TEC	Total Electron Content
TexAQS	Texas Air Quality Study
THORPEX	THe Observing system Research and Predictability Experiment
TMO	Table Mountain Observatory
TOPEX	Ocean Topography Experiment
TRIM/GPM	Satellite maritime precipitation measurements
TRMM	Tropical Rainfall Measurement Mission
UAV	Unmanned Aerial Vehicle
UCATS	Chromatograph for Atmospheric Trace Species
ULS	Upward Looking Sonar
UNEP	United Nations Environment Program
UROP	Undergraduate Research Opportunities Program (CU)
USADCC	U.S. Antarctic Data Coordination Center
USBR	US Bureau of Reclamation
USDA	US Department of Agriculture
USDS	US Department of State
USGS	United States Geological Survey
UVMFRSR	UltraViolet Multifilter Rotating Shadowband Radiometer
VAD	Velocity Azimuth Display
VCNP	Valles Caldera National Preserve
VOC	Volatile Organic Carbon
VOCALS	VAMOS Ocean Cloud Atmospheric Land Study
WCRP	World Climate Research Program
WDC	World Data Center
WDN	World Deltas Network
WEB	Water Earth Biota
WGA	Western Governors' Association
WKB	Wickenburg special upper-air observing site
WLG	Mt. Waliguan Observatory
WMO	World Meteorological Organization
WRF	Weather Research and Forecasting
WSA	Wang-Sheeley-Arge
WSR-88D	Weather Surveillance Radar 88 Doppler
WW2BW	White Water to Blue Water
WWA	Western Water Assessment
XML	Extensible Markup Language
XRS	X-Ray Sensor