Climate Diagnostics Center

Center for Limnology

Center for Science and Technology Policy Research

National Snow and Ice Data Center

Earth Science and Observation Center

Cryospheric and Polar Processes

Ecosystem Science

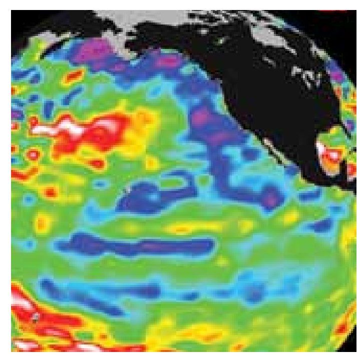
Environmental Chemistry

Environmental Observations, Modeling, and Forecasting

Solid Earth Sciences

Weather and Climate Dynamics



2009 CIRES Annual Report

COOPERATIVE INSTITUTE FOR RESEARCH IN ENVIRONMENTAL SCIENCES

Colorado
University of Colorado at Boulder

COOPERATIVE INSTITUTE FOR RESEARCH IN ENVIRONMENTAL SCIENCES

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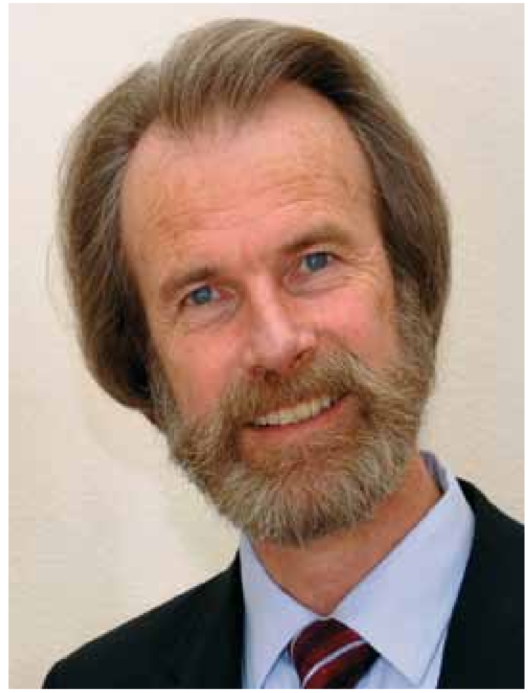
From the Director

Our forward-thinking scientists are improving the monitoring and assessment of climate variability and change, the development of models, and the prediction of environmental changes.

Our world is changing fast, under pressure from climate change, growing demands for finite resources, and the extinction of many plants and animals. In this period of unparalleled global change, CIRES occupies a critical intersection.



We are a world leader in environmental sciences committed to identifying and pursuing innovative research in Earth system science for a sustainable world and to fostering public awareness of this research. Our research is essential for understanding the processes and feedbacks in many Earth science disciplines, and to foster cross-disciplinary understanding of the cryosphere, biosphere, atmosphere, geosphere, and hydrosphere. CIRES scientists are identifying and quantifying changes in a warming climate, providing baseline data against which to measure change, and informing the public and the policy makers about these changes. Our forward-thinking scientists are improving the monitoring and assessment of climate variability and change, the development of models, and the prediction of environmental changes.

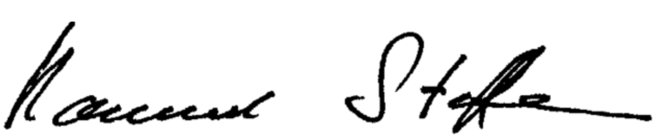
The CIRES research budget continues to grow and has surpassed $53 million, supporting 651 employees, including 20 faculty lines, 427 scientists, 36 administrative support personal, 95 graduate and 73 undergraduate students. Even in a time of international fiscal contraction and uncertainty, we were able to grow our research support by 4.7 percent last year.

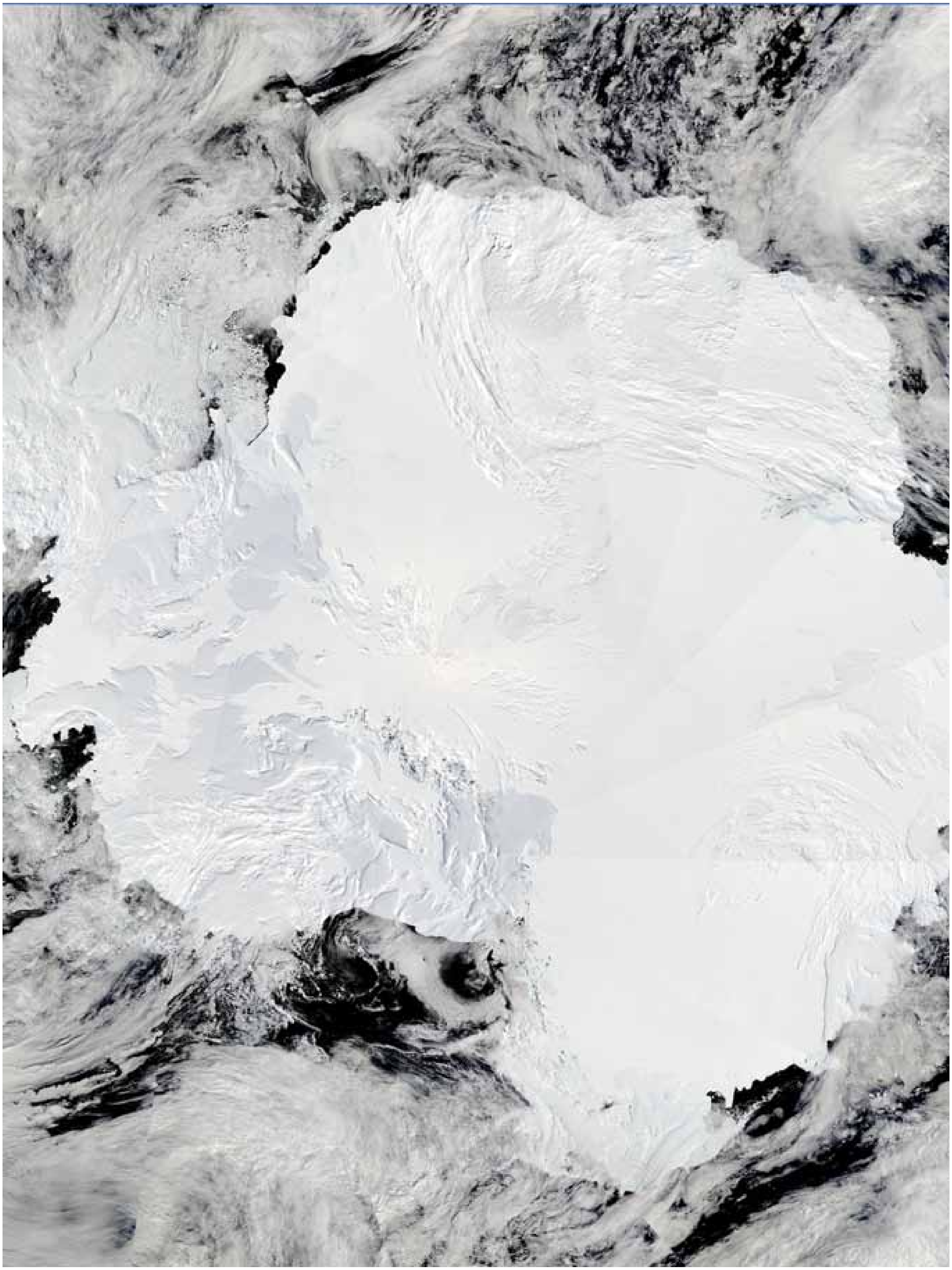
We published 594 papers in peer-reviewed journals, 27 percent more than last year, which indicates increased productivity and improved dissemination of our research findings in the open literature. CIRES researchers and staff received a large number of honors and awards in the past year, ranging from the American Geophysical Union Robert Horton medal (Dr. Vijay Gupta), the Humboldt Research Fellowship (Dr. Roger Barry), Fellow of the American Geophysical Union (Dr. Steven Nerem), the Outstanding Women Scientist Award (Tilottama Ghosh), Fellow of the American Meteorological Society (Dr. Henry Diaz), and the Astellas Foundation Prize from the American Chemical Society (Dr. Robert Sievers)—to name just a few.

We welcome two new CIRES tenure-track faculty researchers: Dr. Mark Serreze, Professor in the Department of Geography, and Dr. Max Boykoff, Assistant Professor in the Environmental Studies Program. Dr. Serreze was also appointed as the new director of CIRES' National Snow and Ice Data Center (NSIDC).

This report summarizes ongoing research in six research themes: advanced modeling and observation systems, climate system variability, geodynamics, planetary metabolism, regional processes, and integrating activities. Further, it provides a brief overview of research conducted by CIRES Fellows, the research activities of five CIRES scientific centers, the Western Water Assessment, and education and outreach. In my view, the breadth, depth, and innovation of this research is outstanding—but I let you be the judge.

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





NASA

Antarctica.

Executive Summary and Research Highlights

CIRES: Science in Service to Society

The Cooperative Institute for Research in Environmental Sciences (CIRES) at the University of Colorado at Boulder has been a world leader in environmental sciences since 1977. CIRES researchers pursue science in service to society, applying both established and innovative techniques to pressing problems around the globe. In 2009, CIRES, the oldest and largest of NOAA's cooperative institutes, completed the fifth year of its current cooperative agreement (Agreement) with NOAA. This summary highlights many of the past year's activities and research accomplishments, demonstrating how CIRES continues help NOAA meet its strategic goals.

During fiscal year 2009 (FY09), 1 July 2008 to 30 June 2009, CIRES supported 182 research scientists, 199 associate scientists, 30 visiting scientists, 16 postdoctoral researchers, 36 administrative staff, 95 graduate students, and 73 undergraduate students. CIRES is particularly proud of its 20 faculty lines. In total, CIRES supported 651 scientists, administrative staff, and students, with an overall extramural research budget of nearly $50,000,000 (4.7 percent more than FY08). Including university faculty support, CIRES' total budget is more than $53,500,000 and NOAA funds account for about $25,500,000 (48 percent).

New Leaders

CIRES is a dynamic institute, and in FY09 four of its centers had a planned change in leadership. In September 2008, Dr. William Travis, CIRES Fellow and Associate Professor of Geography, became the new director of the Center for Science and Technology Policy Research. Dr. Travis is an expert in natural hazards, land use, and human ecology. Also in September, 2008, Dr. Prashant Sardeshmukh, CIRES Fellow and senior research scientist, became the new director of the Climate Diagnostics Center. His area of expertise is the effects of rising ocean temperatures on land temperatures.

The former Center for the Study of Earth from Space has a new director, Dr. Waleed Abdalati, CIRES Fellow and Associate Professor of Geography, and a new name, the Earth Science and Observation Center (ESOC). Prior to joining CIRES in July 2008, Dr. Abdalati was the head of National Aeronautics and Space Administration (NASA) Cryospheric Sciences Branch at the Goddard Space Flight Center. In February, he developed a new strategic plan with a new mission and vision for ESOC. Dr. Richard Spinrad was among the many guests who attended the center's open house, held to encourage NOAA and university-wide collaboration with ESOC's six faculty members on a broad range of activities from in situ observations to unmanned aircraft systems deployment and satellite mission design.

CIRES Earth Science and Observation Center: New name, new mission

"We advance scientific and societal understanding of the Earth System based on innovative remote-sensing research. Through our research, we provide fundamental insights into how the Earth system functions, how it is changing, and what those changes mean for life on Earth, for the benefit of human kind."

New this year, Dr. Mark Serreze was selected to lead the CIRES' National Snow and Ice Data Center (NSIDC), following a highly competitive international search for a new director. Dr. Serreze will succeed Distinguished Professor Roger Barry, who stepped down as director in 2008 after 31 years of service. Dr. Serreze, CIRES Fellow and senior research scientist at NSIDC since 2005, will officially become the new director and Professor of Geography in August 2009. He brings to the position internationally recognized expertise in Arctic climate change, especially his research into the environmental implications of the rapidly declining Arctic sea ice cover. Dr. Serreze has authored more than 90 scientific publications, including an award-winning textbook, The Arctic Climate System, coauthored with Dr. Barry.

A junior faculty search by the Center for Science and Technology Policy Research was also successful. Dr. Maxwell Boykoff will join CIRES in the fall of 2009 as CIRES' newest fellow and Assistant Professor of Environmental Studies. Dr. Boykoff's research interests include environmental governance, science and policy interactions, and political economics and the environment, with a focus on the transformations of carbon-based economies and societies. Prior to joining CIRES, he was a research fellow in the Environmental Change Institute and department lecturer in the School of Geography at the Oxford University Centre for the Environment.

The CIRES Council of Fellows is also pleased to welcome Dr. Rainer Volkamer, Assistant Professor in Chemistry and Biochemistry. Dr. Volkamer studies atmospheric chemistry in the context of air quality and climate, using a combination of in situ and remote-sensing measurement techniques. His current projects include ocean-atmosphere interactions over the tropical Pacific Ocean, coastal atmospheric chemistry affecting mercury levels, and the dynamics of ozone and secondary organic aerosol precursor gases. In 2009, Dr. Volkamer was awarded the Faculty Early Career Development Program, the National Science Foundation's most prestigious award in support of junior faculty who exemplify the role of teacher-scholars.

Successful Programs

CIRES is very pleased to continue support of its established competitive programs that provide research and education opportunities to visiting scientists, innovative CIRES scientists, and graduate students. This past year, six visiting fellowships were awarded to postdoctoral and sabbatical scientists conducting diverse research on ice, clouds, mountain-building, and more.

The Innovative Research Program funded nine novel, inventive proposals to support exploratory research. Supported projects ranged from the use of mini-gliders for making high-resolution atmospheric measurements to climate change impacts on ocean productivity and the effect of mountain pine beetles on emissions of volatile organic compounds from the soil.

The CIRES Distinguished Lecture Series featured five notable speakers: Dr. Susan Solomon, Dr. Gerard Roe, Dr. Alan Robock, Dr. Greg Carmichael, and Dr. Raymond Bradley. The invited speakers gave engaging presentations on climate change prediction, geoengineering as a possible solution to a warming climate, the globalization of air pollution, and deglacierization of the tropics. Researchers at NOAA's David Skaggs Research Center have the opportunity to meet and collaborate with CIRES' newest fellows, center directors, and senior scientists at an on-site seminar series, established in early 2008.

CIRES is a strong supporter of its graduate students and is working closely with its Graduate Student Association, recently created to provide a venue for students to discuss their research in organized seminars and to enjoy social events with colleagues. The ESRL-CIRES Graduate Student Research Fellowship, started in the last fiscal year, awarded one master's and two doctoral fellowships to new CIRES graduate students, who will complete their coursework in a CIRES-affiliated department or program at the university while conducting research at ESRL. In a separate program, seven new and current students advised by a CIRES fellow were awarded research assistantships.

New Events and Awards

CIRES participated in, organized, and sponsored numerous events in FY09. Highlights include a special briefing in August by CIRES' climate scientists for a group of Italian delegates interested in understanding climate change impacts on ice sheets, sea ice, permafrost, and sea level, and in policy research on mitigation and adaptation. Fred Fehsenfeld, one of the first NOAA scientists to be appointed as a CIRES fellow, was honored at a symposium and luncheon in September 2008 for 46 years of scientific achievement. Dr. Fehsenfeld is among the most-cited geoscientists in the world, with more than 300 published papers, and he has received dozens of scientific awards and honors. Also recognized for his achievements was CIRES Fellow and former Director Robert Sievers, who is developing a patented inhalable measles vaccine. Dr. Sievers received the Governor of Colorado's Award for Research Impact in February 2009.

CIRES Education and Outreach held two climate change workshops on teaching and effectively communicating climate science. The Western Water Assessment held four workshops on tree-ring reconstruction and projections of streamflow, agriculture-to-urban water transfers, and climate change modeling for water providers. CIRES was also an active contributor to the University's Renewable and Sustainable Energy Initiative and the founding of the new Center for Research in Wind Energy, part of the Colorado Renewable Energy Collaboratory comprised of three academic institutions and three federal labs, including NOAA.

CIRES

CIRES' Robert Sievers and Colorado Governor Bill Ritter.

NOAA's Priorities

This annual report is an accounting of collaborative research goals described in the *CIRES-NOAA FY09 and FY10 Scientific Workplan*, year one. The report is organized by NOAA's six scientific themes identified in the Agreement—advanced modeling and observing systems, climate system variability, geodynamics, planetary metabolism, regional processes, and integrating activities. Select research highlights from each of the scientific themes are presented below.

Advanced Modeling and Observing Systems

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

Instruments to measure the chemical composition of the atmosphere are critical for understanding how atmospheric chemistry relates to climate and air quality. Atmospheric

NOAA

A research jet takes off during the HIPPO mission.

chemistry is governed by trace quantities of several gases, as well as liquid and solid particles. These occur in minute amounts and are often ephemeral. State-of-the-art techniques, customized to measure these hard-to-measure species, often enable the discovery of new areas of chemistry important in the atmosphere. CIRES has made several technical advances in instrumentation this fiscal year: Development of a scanning aerosol lidar system to measure plume dispersion, rise, and particle mass emission rates from jet engines; development of an aircraft-based lidar for measuring wind and turbulence; and an improved version of a single-particle albedo instrument that will help scientists understand the radiative effects of aerosol particles as well as the optical properties of dust.

CIRES also contributed to NOAA's atmospheric research goals by improving environmental modeling and prediction using data collected in focused observational campaigns as well as from space-borne measurements. Such improvements enable researchers to better understand tropical storm and other hazardous weather development, regional climate prediction, and air quality. CIRES focused particularly on models that 1) predict atmospheric river events responsible for winter floods along the West Coast, 2) improve our understanding of how physical processes influence sustained precipitation, and 3) simulate how low-elevation winds, the main conveyer of water vapor and anthropogenic pollution, are shaped by complex topography—a notoriously difficult task. For example, CIRES researchers were able to identify sensitivity in the Weather and Research Forecasting (WRF)-modeled low-level winds in the Central Valley of California to uncertainties in atmospheric forcing and soil initialization. This low-level wind research represents a new paradigm in atmospheric modeling, with researchers working directly on the model used operationally at NOAA National Centers for Environmental Prediction. Findings are being used in planning efforts for future air quality research in California.

The detailed processes occurring within cloud systems are difficult to study, but critical in understanding and forecasting precipitation. The dynamic and microphysical processes of cloud systems influence the number and size of raindrops, so by studying the vertical structure of raindrop size distribution, CIRES researchers are beginning to understand the processes taking place within cloud systems. In FY09, scientists studied raindrop distribution and cloud dynamics with Doppler radars and other custom instrumentation. One comparison showed that two instruments—a C-band polarimetric scanning radar and a vertically pointing profiler—produced comparable measurements, both with relatively small estimated errors.

FY09 was a productive one in the development, planning, and use of unmanned aircraft systems (UAS) for scientific research. Researchers worked with the U.S. Federal Aviation Administration, NOAA, NASA, and Advanced Ceramics Research to develop properly equipped aircraft, to test them, and to establish the international relationships that make this research possible. UAS are taking researchers into environments and weather too hostile to otherwise access to bring back valuable new data that are helping improve weather and climate predictions. UAS are advancing accurate and reliable data sampling, in particular, in places such as the Arctic, inside hurricanes, and in remote oceanic areas, filling critical data gaps in climate research. Flights over meltponds on the Greenland Ice Sheet in July 2008 collected data on the depth and volume of lakes, at a level of detail never previously attained.

CIRES scientists also took climatology modeling beyond the atmosphere and into outer space this year. Understanding space weather is vital for the advancement of science, including the engineering and planning of satellite missions and better understanding of how the space environment affects Earth's atmosphere. CIRES is working with the U.S. Department of Defense's Air Force Weather Agency, NASA's Living with a Star Program and NOAA's Space Weather Program to assess the current state of the space environment. Through this partnership, scientists are archiving data, evaluating physical space environment models, constructing data assimilations to drive the best models, generating gridded databases, supporting virtual observatories, and building the first climatology of the space environment. CIRES space climate modeling is approaching real-time, with global coverage.

Climate System Variability

Climate directly influences agriculture, water quantity and quality, ecosystems, and human health. Understanding and predicting climate system variability is of critical interest to the public and to a broad array of decision makers within federal and state government, industry, natural resources management, and hazard mitigation. CIRES

CIRES

Vegetation ready for experimental burning, and the burn.

research on this theme addresses climate change that occurs on time scales from seasons and decades to millennia. The scope of research efforts includes the study of climate trends and predictions of climate variability, mechanisms and forcings of climate variability, climate and cryosphere interactions, atmospheric ozone, and extreme events and rapid climate change.

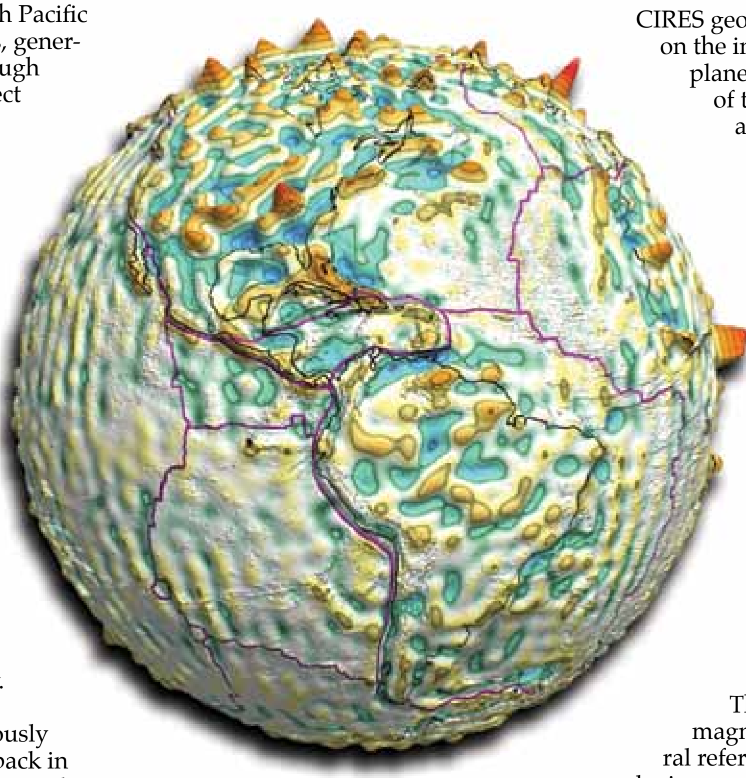
One of the greatest challenges in climate science research is understanding how anthropogenic forcing may modify natural variability. This knowledge is essential for reducing the uncertainty in climate projections during the next several decades, and for predicting the risks of extreme weather and climate events. Toward this goal, CIRES has been working to explain the relationship between recent multi-decadal changes in tropical ocean temperatures and the global atmospheric circulation. Techniques include the use of atmospheric models forced by sea-surface temperatures, ocean models forced by wind stresses and heat fluxes, and hierarchies of coupled ocean-atmosphere general circulation model simulations. One project analyzed the relative contributions of El Niño-Southern Oscillation (ENSO)-related and ENSO-unrelated tropical sea-surface temperature variations on global climate change during the past 130 years. CIRES research revealed that previously identified multi-decadal variations in the Pacific, Indian, and Atlantic oceans all had substantial ENSO components, and their long-term warming trends also had appreciable ENSO components. ENSO-unrelated events were attributed to a combination of anthropogenic, naturally forced, and internally generated coherent multi-decadal variations. Two surprising aspects of these ENSO-unrelated variations are worth noting. First, there is a strong cooling trend in the eastern equatorial Pacific Ocean, and second, a nearly zonally symmetric multi-decadal Tropical-Extratropical seesaw has amplified in recent decades, which may play a major role in modulating sea-surface temperature over the Indian Ocean.

One of the most highly publicized research findings during the past year is a hallmark example of the collaboration between CIRES and NOAA researchers. Analyses of commercial ship emissions revealed the unexpected finding that tugboats emit more black carbon per kilogram of fuel burned than any other type of vessel, and large cargo ships emit twice as much as previously estimated. On a global scale, black carbon currently traps about 30 percent as much heat as does carbon dioxide. These small dark particles absorb sunlight, affect how clouds and precipitation form, and have been linked to impairment of cardiac and respiratory function in humans. Tugboats may disproportionately impact human health because they emit potentially harmful contaminants near densely populated urban areas. However, the release of black carbon and other particles into remote regions, which are likely to experience increased ship traffic as sea ice diminishes and new shipping routes expand, may compound ice melt by radiative forcing.

Two decades after an international treaty first restricted the production of many substances that deplete stratospheric ozone, atmospheric burdens of several ozone-depleting substances are in decline. However, stratospheric ozone depletion remains a global environmental concern. Stratospheric ozone levels in some regions are unlikely to return to pre-1980 values. The 22-year ozonesonde record at South Pole shows that up to the year 2007, there have been no definitive signs of springtime stratospheric ozone recovery.

Central to our current understanding and prediction of ozone depletion is the continued monitoring of stratospheric ozone and the key constituents that deplete it. It is also critical to determine the impacts of ozone depletion on climate change, and vice versa. CIRES contributed to these efforts in many ways. CIRES researchers helped update NOAA's annual Ozone-Depleting Gas Index, which showed a sustained overall decline in the atmospheric abundance of ozone-depleting substances, despite more rapid increases of hydrochlorofluorocarbons (substitute compounds that have less impact on ozone). CIRES staff helped validate satellite ozone profiling and total column ozone measurement systems with ozone profile information derived from ground-based instruments. The continuity of ground-based profile instruments is critical in validating data obtained from satellite instruments that have a limited lifetime. CIRES staff also collaborated with international colleagues to make measurements of the latitudinal, longitudinal, and vertical distributions of ozone-depleting substances during different seasons above a large region of the Pacific Ocean. This produced a unique dataset that is extremely valuable in studies of tropospheric dynamics, and in quantifying oceanic fluxes of these substances and other climate-related gases. Airborne measurements of trace gases in the tropopause region provide important insights into transport and mixing between the stratosphere and troposphere, and are important for climate and stratospheric ozone calculations. A novel, global cross-section of latitude versus altitude distributions of SF_6 and CO_2 was developed and offers a multitude of useful information, including preferred altitudes for transport of air between the Northern and Southern hemispheres.

CIRES scientists and colleagues also sought to understand—using models and historic data—the extent to which tropical climate variability is forced from the North Pacific through oceanic pathways, generated locally, or forced through the atmosphere. This project uncovered two distinct patterns: A slow effect of wind stress and surface heat anomalies in the subtropical North Pacific, triggered during spring, which reaches the equator four to five years after forcing and excites tropical variability efficiently. Less efficient is a fast signal, triggered from November-March, which affects tropical variability within a year. These findings revealed a significant effect of extratropical forcings on tropical variability. In other modeling work, CIRES discovered a previously unreported spurious feedback in atmospheric general. Such simulations have grossly underestimated the observed magnitude of the North Atlantic Oscillation trend during the last 50 years.



A representation of Earth's lithospheric magnetic field.

Other efforts to detect and monitor trends of gases and particles in the atmosphere include the collaborative expansion of NOAA's North American Carbon Observing System (Carbon America). The Boulder Atmospheric Observatory tower, operated since the 1970s, was instrumented for monitoring of urban and industrial sources of CO_2 and CO from the nearby Denver metropolitan area. Three new tower sites were also established, including the tallest tower with continuous CH_4 measurements (Sacramento, CA) and the first tower located within an urban center (San Francisco, CA). Both California tower sites provide daily measurements of a variety of greenhouse gases, carbon isotopes, halocarbons, and other compounds. A new tall-tower site was also established in Iowa to monitor agricultural ecosystems in the nation's corn belt, where CO_2 concentrations are expected to vary seasonally and annually depending on crop uptake.

In addition, CIRES researchers and NOAA collaborators created a consistent, gridded emissions dataset of gaseous and particulate species from anthropogenic activities and biomass burning from 1850-2000. These data will support modeling studies that are part of the Intergovernmental Panel on Climate Change's Fifth Assessment Report. Projections of future emissions will use the 2000 emissions as a starting point to ensure continuity in emissions between historical and future distributions. CIRES researchers also added significantly to an online glacier photograph database, and to several other datasets in high demand by researchers and the public, from an Arctic Sea Ice Index to long-term records of temperature and precipitation in Central Asia.

Geodynamics

CIRES geodynamics research focuses on the internal processes of the planet, including the properties of the core-mantle boundary, convection within the Earth's mantle, and the effects of convection on the surface of the planet. The convective process plays an indirect but fundamental role in determining the Earth's climate by affecting surface topography. Advances in geodynamic research can help to predict and mitigate natural hazards including earthquakes, volcanoes, floods, storm surges, and global sea-level rise.

The direction of Earth's magnetic field provides a natural reference frame for orienting devices on the surface, underground, and in the oceans, atmosphere, and near-Earth space. Magnetic direction is translated into geographic direction using magnetic reference models. To maintain precision, these models are regularly updated with the latest magnetic field observations. Using six years of satellite magnetic measurements from the CHAMP satellite, CIRES and NOAA released the Equatorial Electric Field Model (EEFM1), which provides the mean and variance of the equatorial electric field as a function of longitude, local time, season, solar flux, and lunar local time.

An Earth Magnetic Anomaly Grid (EMAG2) was also compiled from satellite, ship, and airborne magnetic measurements to provide insights into the subsurface structure and composition of Earth's crust. This year, CIRES researchers and colleagues improved grid resolution to

NCAR

An Arctic river valley seen from a research aircraft during the HIPPO mission.

2-arc minutes (previously 3-arc minutes) and included additional grid and trackline data over land and oceans.

Planetary Metabolism

Planetary metabolism encompasses the complex web of biochemical and ecological processes that occur within the biosphere and their interaction with the lithosphere, atmosphere, and hydrosphere. Both natural and anthropogenic disturbances drive the structure and dynamics of natural systems, therefore, a thorough understanding of these complex processes is essential to protect the biosphere from the adverse effects of pollution, destruction of natural landscapes, and climate change. Research within this theme focuses on biogeochemical cycling, biosphere-atmosphere interactions, the response of natural systems to perturbations, and the transport and fate of chemicals in the biosphere.

To better understand the role that gas exchange between the biosphere and atmosphere plays in shaping regional climate and air quality, CIRES researchers made ultra-sensitive measurements of gases that are emitted by vegetation or that are the result of biomass burning (natural or anthropogenic). Vegetation naturally emits terpenes, which undergo oxidation and can affect human health, regional haze, and climate. CIRES researchers measured particle nucleation following the gas-phase oxidation of the atmospherically most abundant sesquiterpenes. Even at low concentrations (less than 100 ppt), the scientists learned, new particle formation was efficient. The new data were interpreted with a molecular-level nucleation model, and the nucleation process will be parameterized for input into regional aerosol and air quality models.

CIRES researchers measured the emissions of acidic and other trace gases from biomass burning in work conducted at the Fire Sciences Laboratory in Missoula, MT. A new, CIRES-developed chemical ionization mass spectrometry (CIMS) method picked up very large emissions of nitrous acid. Atmospheric nitrous acid is a direct source of radicals and could lead to rapid chemical changes in forest fire plumes. Interestingly, this project also identified isocyanic acid as a large component of emissions from burning vegetation—isocyanic acid has not been observed in the atmosphere, so the implications of this finding are currently being researched.

Anthropogenic light pollution is an increasing global ecological concern because of its negative impacts on critical animal behaviors, including foraging, reproduction, and communication. CIRES researchers and colleagues around the world developed a mission concept for a near-synchronous orbit satellite that could collect moderate-resolution nighttime light data with increased spatial and spectral resolution. An example dataset was obtained from the International Space Station, revealing a multitude of features not visible in current nighttime satellite imagery. These products will be used in mapping urban growth and modeling the density of impervious surface areas, global economic activity, national level gas flaring volumes, and trends in fishing activity.

Regional Processes

Climate variability and extreme weather events are influenced by topography, watersheds, vegetation, and other geographical features that often impact very specific populations, economic systems, and ecosystems. CIRES researchers are working to better understand regional scales of forcing in order to improve forecasting tools and to manage local impacts of weather extremes and natural resource use.

In FY09, CIRES evaluated natural and anthropogenic ozone and fine-particle precursors in key regions of the United States from air, ship, and ground-based sites. These regional air quality studies focused on natural emission sources, anthropogenic emission sources (e.g., power plants and refineries), coastal meteorological influences on ozone production, the regionality of ozone production, and the chemical makeup of fine particles.

Research on the distribution and transport of ozone and aerosols in the Front Range urban corridor during Summer 2008 may help the greater Denver area address some of its most urgent air quality problems, such as the 2007 violation of the national ozone standard and future violations that are likely to occur with a new, lowered ozone standard. CIRES made observations using NOAA's airborne ozone lidar on a Twin Otter aircraft and a with small network of Doppler wind profilers, and found that high-ozone air from the Denver metro area was transported west by easterly winds, with highest levels typically found over the western suburbs and along the eastern slope of the mountains. If the mixed layer was deep enough, the ozone plume was pushed further west across the Continental Divide, resulting in high ozone levels and reduced visibility in Rocky Mountain National Park. Ozone was also vented into the free troposphere and transported back east by predominantly westerly winds above the boundary layer. In the Houston area, analyses of data from the 2006 Texas Air Quality Study field study showed that fluxes of volatile organic compounds and other trace gases that contribute to rapid ozone formation exceed the inventory emissions by approximately an order of magnitude. These results help to explain why models cannot reproduce the rapid ozone formation that is often observed in petrochemical plumes.

Data from the 2006 Texas Air Quality study were also used to determine the ratio of black carbon to carbon monoxide in the boundary layer—that ratio is important in global climate and regional air quality modeling. The compact linear relationship CIRES uncovered should be of value in estimating black carbon mass loadings from the more widely available carbon monoxide measurements in other urban regions. CIRES also evaluated the size distribution and coating of individual black carbon particles in fresh emissions from urban and biomass burning in the Dallas and Houston areas. Compared with carbon particles originating from burning biomass, urban-generated black carbon particles were smaller, had fewer, thinner coatings, and less absorption per unit mass. These results suggest that urban black carbon may have a longer lifetime in the atmosphere and could interact with cloud and ice particles differently than biomass black carbon—information that is useful for constraining climate and aerosol models.

The radiative forcing of clouds, and the modification of this forcing due to aerosol, is one of the largest unknown variables in climate change. Based on observations and modeling associated with the 2006 Gulf of Mexico Atmospheric Composition and Climate Study mission, CIRES researchers conducted a rigorous test of the ability of a model to simulate the effect of aerosol on cloud radiative forcing by using both macroscale properties (cloud fraction, cloud depths, water content) and microscale properties (cloud drop size distributions). CIRES found good agreement between the observations and model, provided the aerosol residing between the clouds was included in the calculations. These results demonstrate the importance of cloud-enhanced scattering by aerosol residing between clouds.

Understanding regional emissions of climatically important aerosols and gases is critical for assessing and mitigating global impacts, and for informing international policy makers. CIRES researchers published work in FY09 showing that in the Alaskan Arctic, a large amount of black carbon, which can enhance sea ice melting by direct radiative forcing, is transported from forest fires in the Lake Baikal region of Siberia and agricultural biomass burning further west in Kazakhstan. The United States also receives smoke plumes from fires in Central America, dust from Africa, and large-scale pollution and dust transported at mid-latitude across the Pacific Ocean from Asia. To understand the regional sources and distribution of gases originating in Asia, CIRES deployed instruments in the Anhui Province of China from May to December 2008, to measure aerosol optical and cloud forming processes. In addition, a CIRES analysis of comprehensive ozone profile data from western North America indicates that ozone in the free troposphere has increased. Tropospheric background ozone entering the West Coast of the United States, as measured at Trinidad Head, CA, makes it harder for inland parts of the state to meet air quality standards.

The development of wind energy may help to mitigate air quality impairment by fossil fuels, provided it can be a reliable source of energy. CIRES researchers are working to reduce uncertainty in wind power production by developing techniques to accurately estimate the stable boundary layer depth, thereby helping to understand and predict high variations in wind and turbulence conditions that affect taller modern turbines.

Integrating Activities

CIRES is committed to working across conventional disciplinary boundaries to produce rigorous, cutting-edge science and technology and to share that knowledge with a broad audience. The Institute's wide range of integrating activities in research, education, and outreach encompass each of its research themes. CIRES' integrating activities include K-12; interdisciplinary education and outreach; undergraduate, graduate and post-graduate education; scientific assessments; interdisciplinary research; and science and technology policy research.

Scientific synthesis and assessment products provide an essential link between research and policy. CIRES researchers contributed to the U.S. Climate Change Science Program's Synthesis and Assessment Product 2.4, Trends in Emissions of Ozone-Depleting Substances, *Ozone Layer Recovery, and Implications for Ultraviolet Radiation Exposure*. The Western Water Assessment released *Climate Change in Colorado*, a synthesis of observed and projected data that connect climate science with issues of greatest concern to the water management and drought mitigation communities. The report received extensive media coverage and was selected as a finalist for the Governor's Research Impact award. Researchers at the Western Water Assessment gave more than 30 public presentations on the findings of this report alone, and authored several chapters in the *Citizen's Guide to Colorado Climate Change*. These efforts, ongoing work to develop a Colorado Climate Roadshow and a Climate 101 training workshop, and the continuation of the hugely popular Intermountain West Climate Summary, demonstrate CIRES' commitment to communicate our research to decision makers and the public to ensure a sustainable future environment.

New CIRES research on predictors for the Upper Colorado River Basin streamflow and the role management could play in mitigating the risk of Lake Mead water depletion also received wide media attention. CIRES Fellow and Western Water Assessment team member Balaji Rajagopalan led a study that reported a 52 percent risk of reservoir depletion in 2057, assuming a 20 percent reduction in streamflow due to climate change—that extremely high depletion risk could be reduced to 32 percent with aggressive management, Dr. Rajagopalan and his colleagues found.

Contributions to NOAA's Vision

CIRES research reflects NOAA's commitment to address many of the nation's most challenging environmental needs and supports NOAA's four mission goals: Ecosystems, Climate, Weather and Water, and Commerce and Transportation.

Mapping anthropogenic lighting will help inform studies of light stress on ecosystems.

Supporting NOAA's Strategic Mission

CIRES' fundamental research priority—to enhance the understanding and prediction of Earth's environment—compliments NOAA's priorities, articulated in *New Priorities for the 21st Century: NOAA Strategic Plan FY05–FY10*. CIRES' cross-cutting, interdisciplinary research supports the four Mission Goals identified in the *NOAA Strategic Plan*: Ecosystems, Climate, Weather and Water, and Commerce and Transportation. The following are examples of CIRES research in support of these goals.

Ecosystem Mission Goal: Protect, restore, and manage the use of coastal and ocean resources through an ecosystem approach to management.

CIRES contributes to NOAA's ecosystem mission goal by developing new datasets and other information products that can help assess coastal hazards and the vulnerability of U.S. communities. CIRES staff and NOAA colleagues are developing precise, high-resolution digital elevation models (DEMs) of at-risk U.S. coastal communities, for example. DEMs are used to support tsunami modeling, coastal inundation mapping, and scientific research. Other efforts include enhancing the Hurricane Weather Forecasting model (HWRF) to improve forecasts for tropical cyclone intensity, wave and storm surge, and hurricane-related inland flooding. CIRES is conducting instrumentation and forecasting research leading to better prediction of coastal flood and debris flow risk, notably in parts of California that are vulnerable because of wildfire risk or deficiencies in conventional observing systems. CIRES is also providing spatial and temporal depictions of anthropogenic lighting associated with human settlements, biomass burning, gas flares, and brightly lit fishing boats. These products are helpful for assessing sensitive ecosystems at risk from human disturbances (e.g., water pollution, intense tourism, bomb fishing) and direct impacts of light (e.g., the disruption of normal, endogenous circadian rhythms; failed or altered migration of birds, fish and insects; disorientation of sea turtle hatchlings; impaired reproduction in coral, reptiles, and amphibians; alterations in the food web; and bird and bat mortality from collisions with lighted structures). These data can inform the identification of high-priority areas requiring restoration or preservation.

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

CIRES is a world leader in climate science research relevant to NOAA's climate mission goal, contributing significantly to all three categories of NOAA's climate-related programs: 1) climate observations and monitoring, 2) climate research and modeling, and 3) climate service development.

In the observation and monitoring arena, CIRES scientists have inventoried, scanned, and made available online dozens of climate databases, many of them focused on Earth's poles and glaciers. At the National Snow and Ice

Data Center, CIRES staff added more than 4,000 glacier photographs to an online database in FY09 alone, and updated several other databases, from the Sea Ice Index and melt pond maps to historic temperature and precipitation data from Central Asia. CIRES staff also continued long-term work to measure trends in atmospheric constituents that contribute to greenhouse warming and stratospheric ozone depletion, and conducted research to understand the atmospheric dynamics that affect those trends.

In climate research and modeling, CIRES staff and NOAA colleagues have released the 20th Century Reanalysis dataset, representing 1908-1958, produced by assimilating sparse historic observations with an ensemble Kalman filter. Researchers here also conduct innovative research on the effects of oceanic dynamics on atmospheric variability; interactions between clouds, the boundary layer and heat budgets; and the dynamics of ozone layer recovery and its effects on climate—continuing to push scientific boundaries in these fields.

In support of NOAA's goal to serve society with climate products, CIRES researchers serve as authors, reviewers, and coordinating editors of national and international scientific assessments, designed to help decision makers understand scientific findings. Two examples are CIRES' contributions to the U.S. Climate Change Science Program's Synthesis and Assessment Product 2.4—on chemistry related to the stratospheric ozone layer—and CIRES' Western Water Assessment (WWA)'s *Climate Change in Colorado* report for the Colorado Water Conservation Board and the Governor of Colorado, which was a finalist for the Governor's Research Impact Award.

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

CIRES researchers support NOAA's mission to provide essential information on weather in several ways, including by developing and maintaining a version of HWRF and the experimental Flow-following finite-volume Icosahedral Model (FIM), used by the weather research modeling community. CIRES science advances numerical weather model forecasting, both through model improvements and evaluation and improved assimilation of data collected in focused observational campaigns, ongoing monitoring, and from satellite missions. CIRES serves society's needs for water information though the WWA annual workshops and web site on tree-ring reconstructions of streamflow for use in water management; through a project to reconcile scientific estimates of the effect of climate change on the Colorado River flow; and through publications that translate science for decision makers. WWA recently conducted a survey of readers of its flagship publication, the monthly *Intermountain West Climate Summary*, and found that the water-management community highly values the publication, as an assessment and translation of technical climate information and forecasts for the decision-making community. WWA also plays a valuable role in the drought task force organized by the Colorado Water Conservation Board for Colorado's governor, and in the production of regional analyses and forecasts of drought conditions. Related efforts by other CIRES water researchers include the design of innovative measurement systems, such as ground-, ship-, and aircraft-based instruments to increase our understanding of water-cycle processes; and analysis of satellite data to better understand the global water cycle. Better data and

The Western Water Assessment report, 'Climate Change in Colorado,' was a finalist for the Governor's Research Impact Award.

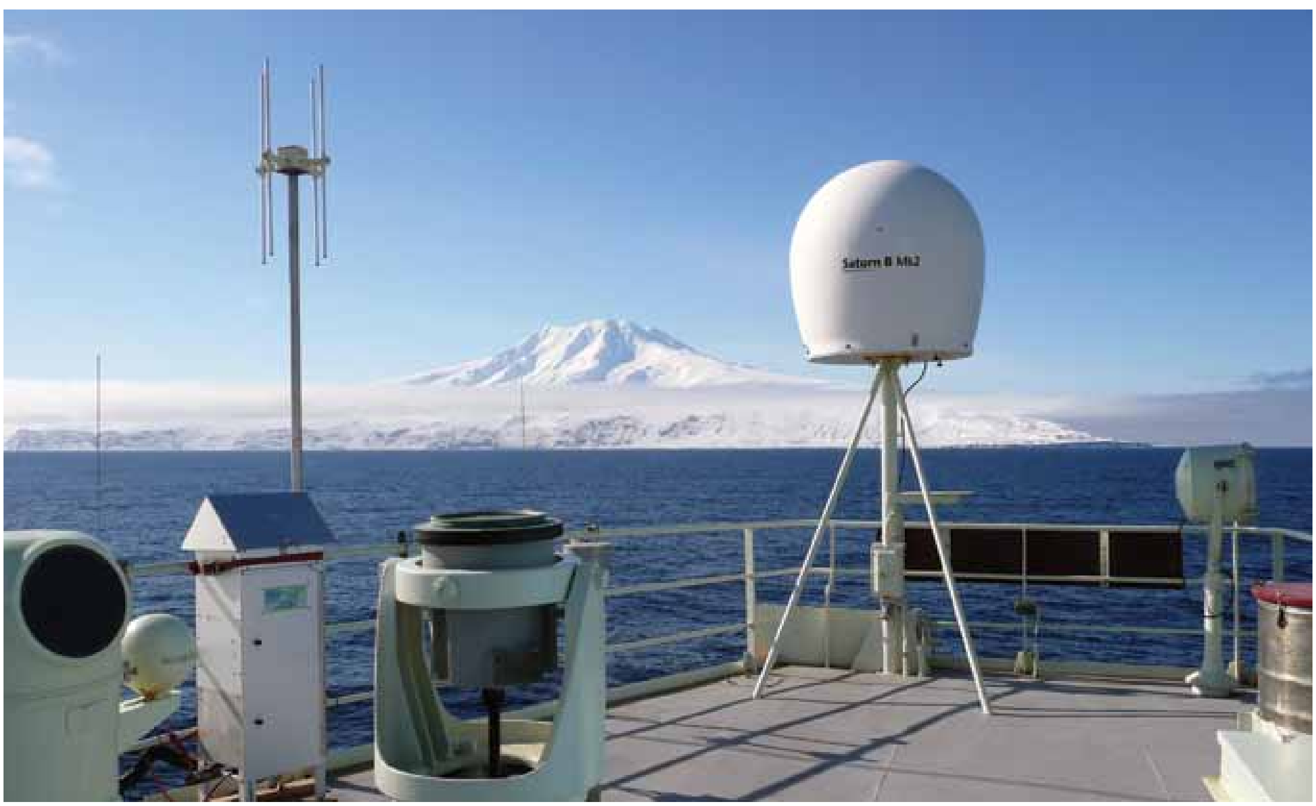
CIRES enhances marine transportation safety by developing marine geophysical data that are critical for hazard mapping.

understanding lead to improvements in weather and climate forecast models.

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

Researchers at CIRES are enhancing aviation transportation safety by improving regional-scale numerical weather forecasts and verification approaches for aviation parameters including icing, turbulence, convection, and oceanic weather. CIRES enhances marine transportation safety by developing and making public marine geophysical data that are critical for hazard mapping and for understanding ocean circulation patterns. CIRES has also made significant contributions to the understanding of the environmental impact of ships, contributing to NOAA's goal of environmentally sound transportation. CIRES published the definitive work on particulate emissions from ships, which can affect air quality and human health in ports and coastal areas, and can also affect radiation balance, including in relatively pristine regions such as the Arctic. CIRES ship emissions research has resulted in a database larger than all other publications on the subject combined, and staff are continuing the research, by designing sensitive new instrumentation and planning new missions. CIRES researchers also contribute to GPS navigational precision and radio wave communication, by developing and improving the analysis of Earth's geomagnetic field, which is a natural reference frame for orientation on Earth's surface, underground, and in the oceans and the atmosphere.

In support of NOAA's goal to serve society with climate products, CIRES researchers serve as authors, reviewers, and coordinating editors of national and international scientific assessments, designed to help decision makers understand scientific findings.

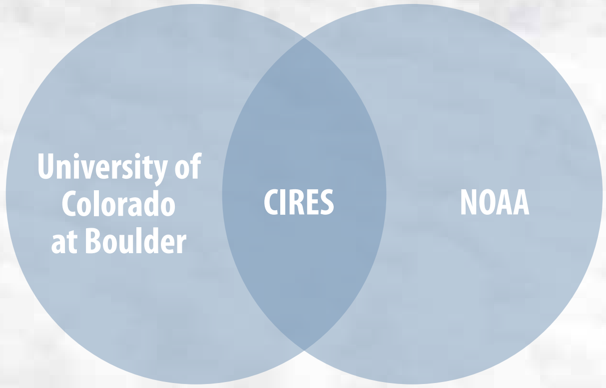


ERIC WILLIAMS

Clouds ring Jan Mayen, a volcanic island in the Greenland Sea, during an expedition to investigate the processes involved in the intercontinental transport of photochemical pollution.

Year in Review

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



This is CIRES

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

University Departments and Programs

Aerospace Engineering Sciences

Atmospheric and Oceanic Sciences

Chemistry and Biochemistry

Civil, Environmental, and Architectural Engineering

Ecology and Evolutionary Biology

Electrical and Computer Engineering

Geography

Geological Sciences

Molecular, Cellular, and Developmental Biology

Physics

Environmental Studies Program

Geophysics Program

Hydrologic Sciences Program

CIRES Divisions

Cryospheric and Polar Processes

Ecosystem Science

Environmental Chemistry

Environmental Observations, Modeling, and Forecasting

Solid Earth Sciences

Weather and Climate Dynamics

Interdisciplinary Centers

Climate Diagnostics Center

Center for Limnology

Center for Science and Technology Policy Research

National Snow and Ice Data Center

Earth Science and Observation Center

NOAA Earth System Research Laboratory (ESRL)

Chemical Sciences Division

Global Monitoring Division

Global Systems Division

Physical Sciences Division

NOAA Centers

National Geophysical Data Center

Space Weather Prediction Center

Administration and Funding

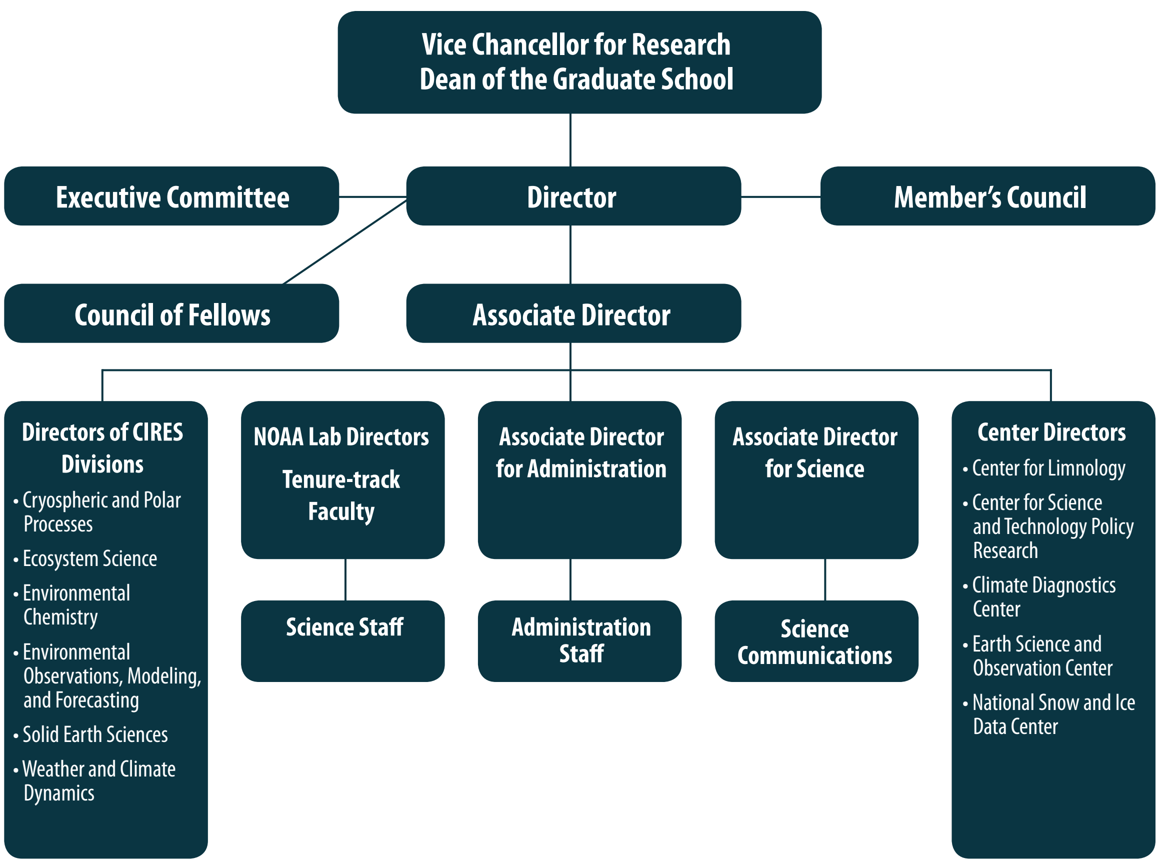
The Cooperative Institute for Research in Environmental Sciences (CIRES) is a scientific research institute established in 1967 between the University of Colorado at Boulder and the National Oceanic and Atmospheric Administration. CIRES maintains an interdisciplinary environment for research on the geosphere,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

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

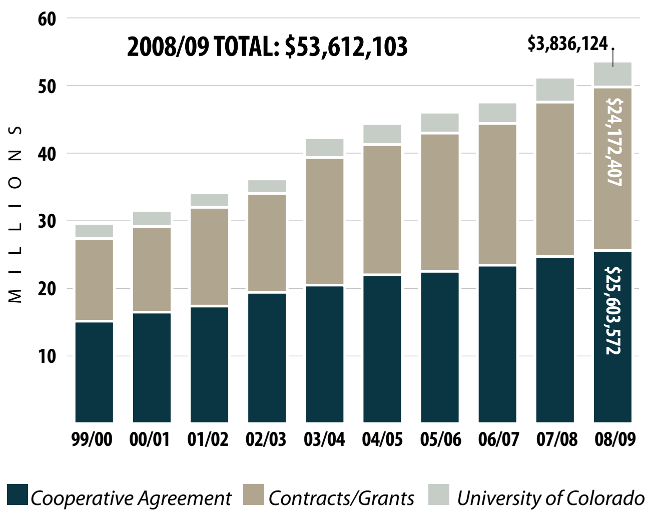
CIRES' campus affiliation links NOAA to 13 university departments and programs (see previous page). Communication is facilitated through the Fellows, Members' Council, scientific retreats, research symposiums, regular town meetings, and outreach programs. Career progression and excellence are promoted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

Vision and Mission

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



Expenditures by NOAA cooperative agreement, individual awards and CU funds



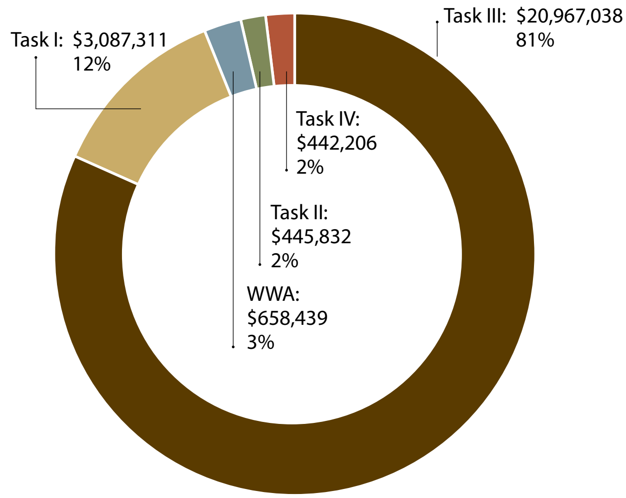
In recent years, CIRES has maintained modest and steady growth. The largest portion of CIRES' funding (48 percent) is provided by the Agreement with NOAA, and expenditures in this category have increased every year for the last decade. CIRES researchers have also had continuing success in obtaining external research awards (45 percent of CIRES' total funding). The university's monetary contribution to CIRES primarily covers faculty salaries, and it varies with year-to-year changes in the CIRES-affiliated university faculty roster.

Agreement expenditures by task for FY09 are shown in the top figure at right. Task I expenditures include CIRES administration and internal scientific programs, such as the Visiting Fellows program. Task II provides partial funding for the National Snow and Ice Data Center, the largest of CIRES' five interdisciplinary scientific centers. Task III funds CIRES' collaboration with NOAA's Earth System Research Laboratory, National Geophysical Data Center, and Space Weather Prediction Center. Task IV was created to serve as an efficient administrative mechanism for directing NOAA research grants and awards, which would otherwise be stand-alone projects outside the Agreement, to university researchers in fields aligned with CIRES' mission. CIRES has one such 'shadow' award, NA08OAR4320914, Dynamical Downscaling: Global Climate Models' Seasonal Predictions Using Regional Atmospheric Modeling System (RAMS). The report for year one was submitted on 5 June 2009. Task IV also includes NA17RJ1229, Reconstruction of Global and Southern Hemisphere Variability and Regional Connectivity from Synthesis of Ice Core Isotope Records with Process Modeling (not a shadow award.) The report for year two was submitted 8 May 2009.

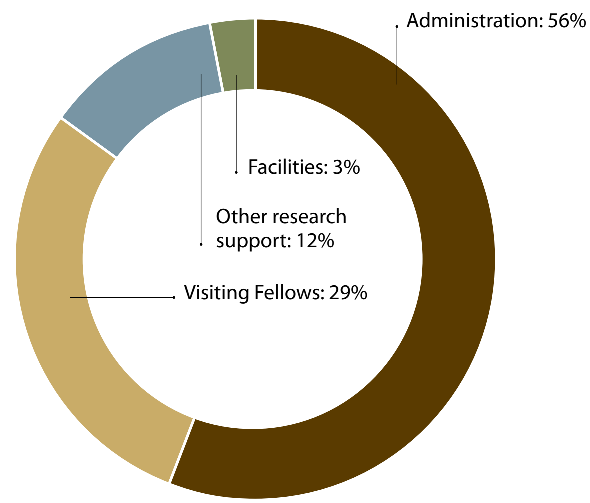
The largest share (56 percent) of Task I supports CIRES administration, primarily salaries and benefits for the administrative staff (middle figure at right). The Visiting Fellows program receives the second largest share (29 percent) of Task I expenditures, and is supported by other funding as well. Task I also provides partial support of CIRES' Education and Outreach program, other research, and the physical plant facilities.

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

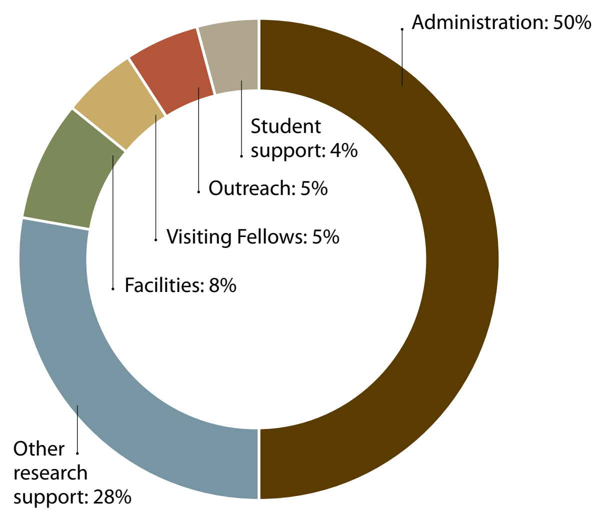
Cooperative agreement expenditures by Task



CIRES Task 1 base fund expenditures



CIRES Task 1 base and ICR-supported expenditures



CREATING A DYNAMIC RESEARCH ENVIRONMENT

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

Western Water Assessment

The Western Water Assessment (WWA) is CIRES' signature integrating activity, relying on multidisciplinary teams of experts in climate, water, law, and economics to work with decision makers across the Intermountain West and produce useful information about natural climate variability and change. In the West, many of the impacts of climate change will be delivered through changes in the hydrologic cycle that have affected, and will continue to affect, water resources. WWA has focused on building relationships and networks of water-resource decision makers, and has used these relationships to develop practical research programs and useful informational products.

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

■ **wwa.colorado.edu**

Western Water Assessment. ***Page 72***

Innovative Research Projects. ***Page 79***

Education and Outreach

The research conducted at CIRES provides knowledge that helps society to build a sustainable future. The CIRES Education and Outreach (EO) group builds bridges between CIRES research and educators, communicators, students, and scientists. Our work emphasizes scientific inquiry, links to current research, and foundational concepts in geosciences education.

Programs for educators include professional development related to cutting edge research. Programs for students include the National Ocean Sciences Bowl, after-school activities for students underrepresented in science, and fellowships for graduate students who participate in the National Science Foundation-funded K-12 project. Programs for scientists include climate communications workshops, support for education activities, and geosciences research proposal preparation assistance.

CIRES EO workshops reached diverse audiences in FY09, and we began to serve remote audiences through video-conference and webinar technology. Research on Colorado classroom practices around controversial topics such as evolution and climate change was concluded. Several new projects were initiated such as a new climate-related workshop series for teachers, an after-school geomagnetism unit, and a Teacher at Sea experience documented through the Quake Cruise blog.

■ **cires.colorado.edu/education/k12**

Visiting Fellows Program

CIRES annually conducts a competitive Visiting Fellows program that promotes collaborative research at the forefront of scientific knowledge. One-year fellowships are made to Ph.D. scholars and university faculty planning sabbatical leave to continue their education in research positions that may foster interdisciplinary training and exposure to scientific assessments and policy research. Since 1967, CIRES has awarded approximately 250 Visiting and Sabbatical Fellowships. Recipients have included previous CIRES Director Susan Avery and current Director Konrad Steffen. Selections are based in part on the likelihood of stimulating academic interactions and the degree to which both parties will benefit from the exchange of new ideas. To further this goal, the competition is open to scientists from all countries, and priority is given to candidates with research experience at institutions outside the Boulder scientific community. Fellowships are offered to scientists with research interests in the following areas: 1) physics, chemistry, and dynamics of the Earth system including the atmosphere, biosphere, hydrosphere, lithosphere, and cryosphere; 2) global and regional environmental change, 3) climate system monitoring, diagnostics, and modeling, remote sensing, and in situ measurement techniques for the Earth system; and 4) interdisciplinary research.

■ **cires.colorado.edu/collaboration/fellowships**

Innovative Research Program

The purpose of the CIRES-wide competitive Innovative Research Program is to stimulate a creative research environment within CIRES and to encourage synergy between disciplines and research colleagues. The program encourages novel, unconventional, and / or fundamental research that may quickly provide concept viability or rule out further consideration. Activities are not tightly restricted and can range from instrument development, lab testing, and field observations to model advancement. Funded projects are inventive, often opportunistic, and do not necessarily have an immediate practical application or guarantee of success. Each year, an interdisciplinary team selects the award recipients, and the results of their research are presented the following year at a poster reception. The 10th annual Innovative Research Program in 2008 funded nine projects, including research into small-scale atmospheric turbulence, development of a new technique for measuring channel erosion rates, and the application of Sony PlayStation technology for precipitation research. In 2009, the 11th annual Innovative Research Program funded nine more projects, including the effect of pine beetles on forest soil emissions, analysis of historic and current photographs to measure glacier loss, and use of a mini-glider to gather elusive atmospheric data.

■ **cires.colorado.edu/science/pro/irp**

Performance Awards at Rendezvous!

Graduate Research Fellowships

CIRES supports two prestigious student fellowship programs: the ESRL-CIRES Fellowship, begun in 2008 with the support of NOAA's Earth System Research Laboratory, and the long-established CIRES Graduate Student Research Fellowships, GSRFs. The ESRL-CIRES Graduate Student Fellowship allows students to pursue a master's or doctoral degree in a CIRES-affiliated department or program at CU-Boulder, while working with world-class researchers at NOAA ESRL. In 2009-2010, the second year of the ESRL-CIRES program, ESRL-CIRES Fellowships were awarded to three students. CIRES GSRFs, which support Ph.D. students advised by a CIRES Fellow, or prospective and students likely to be advised by a Fellow, were awarded to seven students in 2009-2010. Recipients of the two fellowships are exploring topics ranging from the effects of pine beetle infestation on watershed dynamics in Colorado, to surface-atmosphere interactions on Mars, and a survey of the composition of airborne microbial communities in different land-use types across the Colorado Front Range.

■ **cires.colorado.edu/education/cu/gsrf**
■ **cires.colorado.edu/education/cu/esrl**

Rendezvous!

More than 300 people attended the CIRES Members' Council's fourth annual Rendezvous! research symposium on 1 April 2009. This half-day, institute-wide symposium featured 95-plus posters showcasing the depth, breadth, and quality of the pacesetting science being conducted at CIRES.

Director Konrad Steffen spoke about the "State of CIRES," and presented 20 awards for outstanding performance, years in service, and other scientific achievement.

The CIRES Awards Committee, comprised of CIRES Members' Council representatives, annually reviews nominations and recommends awards for outstanding professional achievement. Five awards of $2,000 each were given this year, three in the science and engineering category, and two in the service category. The awards were presented to each individual or research team at the CIRES Members' Council Rendezvous symposium. This year, CIRES recognized John Holloway (ESRL Chemical Sciences Division), Sergey Matrosov (ESRL Physical Sciences Division) and a team of Sonja Wolter, Doug Guenther, and Fred Moore (all ESRL Global Monitoring Division) for outstanding performance in the science and engineering category. Adriana Bailey and Molly Heller (ESRL Global Monitoring Division) were recognized for outstanding achievements in the service category.

■ **cires.colorado.edu/events/rendezvous/contacts**

DISTINGUISHED LECTURE SERIES

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

26 SEPTEMBER 2008

Susan Solomon

Earth System Research Laboratory, National Oceanic and Atmospheric Administration

A world of change: Climate yesterday, today, and tomorrow

31 OCTOBER 2008

Gerard Roe

Department of Earth and Space Sciences, University of Washington

The shape of things to come: What are the limits to global climate predictions?

30 JANUARY 2009

Alan Robock

Department of Environmental Sciences, Rutgers University

Smoke and mirrors: Is geoengineering a solution to global warming?

6 MARCH 2009

Greg Carmichael

Department of Chemical and Biochemical Engineering, The University of Iowa

What goes around comes around: The globalization of air pollution and the implications for the quality of the air we breathe, the water we drink, and the food we eat

17 APRIL 2009

Raymond Bradley

Climate System Research Center, Department of Geosciences, University of Massachusetts, Amherst

Recent climatic change and deglacierization of the tropics

SYMPOSIA/CONFERENCES AND WORKSHOPS

■ **Climate debriefing with political delegates from Italy** (Francesco Rutelli and Gianni Vernetti) Luncheon and conference (08/08)

■ **CIRES' staff appreciation picnic** (08/08)

■ **Water and science engineering workshop** (08/08)

■ **Fred Fehsenfeld symposium and luncheon** (09/08)

■ **Architecture and Data Committee, Group on Earth Observations, Institute of Electrical and Electronics Engineers, Inc. workshop** (09/08)

■ **Making climate hot: Effectively communicating climate change workshops** (throughout FY09)

■ **CIRES Graduate Students Association kickoff and symposia** (09/08 and throughout FY09)

■ **CU-Boulder Energy and Climate Challenge Activities:**

• ***Solar conversion workshop,*** in collaboration with the CU-Boulder Energy Initiative, the U.S. Department of Energy, the CU-Boulder Chemistry Department, and Colorado State University (08/08)

• ***Have we underestimated the size of the challenge?*** Panel discussion by Roger Pielke, Jr., CIRES; Tom Wigley, National Center for Atmospheric Research; and Frank Laird, University of Denver; with moderation by Carl Koval, CU-Boulder Renewable and Sustainable Energy Initiative (09/08)

• ***Energy Initiative Leadership Council meeting*** (10/08)

• ***Do we need a "Manhattan/*****Apollo Project" to solve the energy/climate problem?** Panel discussion by Rad Byerly, Jr., CIRES; Craig Cox, Interwest Energy Alliance; Pete Geddes, Foundation for Research on Economics and the Environment; Chuck Kutscher, National Renewable Energy Laboratory; Gregory Nemet, University of Wisconsin; with Moderation by Paul Komor, CU-Boulder Renewable and Sustainable Energy Initiative (10/08)

• ***Energy Initiative Fall Symposium,*** in collaboration with the CIRES Center for Science and Technology Policy's Energy Initiative (10/08)

• ***Policy advice for the new president,*** a seminar kicking off the Fall Symposium, by Daniel Kammen, Distinguished Professor of Energy at University of California-Berkeley (11/08)

■ **Teaching climate change: Impacts in Colorado workshop** (10/08)

■ **CIRES Innovative Research Program reception and poster session** (11/08)

■ **Jose Jimenez and Margaret Tolbert award celebration.** Jose Jimenez won the Kenneth T. Whitby Award from the American Association for Aerosol Research and Margaret Tolbert won the American Chemical Society's Award for Creative Advances in Environmental Science and Technology (11/08)

■ **Technical workshop on tree-ring reconstructions of streamflow,** sponsored by the Western Water Assessment (11/08)

■ **Reconciling streamflow projections on the Colorado River workshop,** sponsored by the Western Water Assessment (11/08)

■ **Evolving regional frameworks for ag-to-urban water transfers workshop,** sponsored by the Western Water Assessment (12/08)

■ **CIRES staff appreciation and holiday celebration** (12/08)

■ **Earth Science and Observation Center open house** (01/09)

■ **Mountain Mariner National Ocean Sciences Bowl** (02/09)

■ **CIRES director's coffee** (02/09)

■ **Climate change modeling for Front Range water providers workshop,** sponsored by the Western Water Assessment (02/09)

■ **CIRES Members' Council Rendezvous! science symposium** (04/09)

■ **Reflections on the Copenhagen international scientific congress meeting,** a discussion with the Center for Science and Technology Policy Research staff and several Copenhagen participants, to reflect on climate change findings from the international scientific congress meeting (04/09)

■ **Centers for Ocean Sciences Education Excellence West Colorado collaborative lecture series and workshops** (4/09–6/09)

■ **Civilian applications for unmanned aircraft systems,** 2009 steering committee planning (05/09)

Presentations by Other Guest Speakers

■ **Mary Tyszkiewicz:** Venture capital concept analysis (08/08)

■ **Frank Laird:** Changing technological systems: Comprehensive policy for renewable energy (10/08)

■ **David Cherney :** Non-governmental organizations in environmental policy: An overview of Yellowstone (10/08)

■ **Barbara Farhar:** On the path to zero carbon homes: The comparative San Diego case study (10/08)

■ **Marilyn Averill:** Climate litigation: The role of the judiciary in U.S. climate policy (10/08)

■ **Jerry Peterson:** A nuclear physicist in the Department of State (11/08)

■ **Deane Little:** Profitable air capture of CO_2 (01/09)

■ **Matthew Newman:** How important is air-sea coupling in ENSO and MJO evolution? (02/09)

■ **William Lewis, Jr.:** Dam removal: Advocacy, resistance, and feasibility (02/09)

■ **Ila Cote:** Risk assessment at the Environmental Protection Agency: Science, policy and politics (02/09)

■ **Nicole Peterson:** Decisions, opportunities, and obstacles in organizational decision-making (02/09)

■ **Melissa Kenney:** Coupling scientific predictions with decision analysis (02/09)

■ **Lisa Dilling:** Governing the carbon balance: Land-use, decision-making, and opportunities for usable science (02/09)

■ **Konrad Steffen:** Changes in the Arctic ice cover (02/09)

■ **Maxwell Boykoff:** Transformations of carbon-based economies and societies (02/09)

■ **Jason Delborne:** The practice of scientific dissent in agricultural biotechnology (03/09)

■ **Elizabeth Albright:** Local-level response to extreme flood events in the Central Danube River Basin (03/09)

■ **Steve Vanderheiden:** Food politics: Cultivation or conservation? Competing imperatives for land use (04/09)

■ **Melanie Roberts:** Grant writing 101: Tips for success (04/09)

■ **Eugene Turner:** The aftermath of Hurricanes Katrina and Rita—doubt and restoration: Coastal Louisiana (04/09)

■ **Erik Fisher:** The 'Two Cultures' in science policy today (06/09)

■ **David Hofmann:** Increase in background stratospheric aerosol since 2000: Is it related to increased coal burning in China? (06/09)

People&Projects

NOAA Scientists

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

CU-Boulder Teaching Faculty

Waleed Abdalati	Baylor Fox-Kemper	Anne Sheehan
Ben Balsley	Vijay Gupta	Robert Sievers
Roger Barry	Jose Jimenez	Konrad Steffen
Roger Bilham	Craig Jones	Margaret Tolbert
John Cassano	William Lewis Jr.	Greg Tucker
Tom Chase	Peter Molnar	William Travis
Xinzhao Chu	Russell Monson	Veronica Vaida
Shelley Copley	Steven Nerem	Ranier Volkamer
Lisa Dilling	David Noone	John Wahr
Lang Farmer	Roger Pielke Jr.	Carol Wessman
Noah Fierer	Balaji Ragagopalan	

CIRES Scientists

Richard Armstrong	Prashant Sardeshmukh	Tingjun Zhang
Joost de Gouw	Mark Serreze	

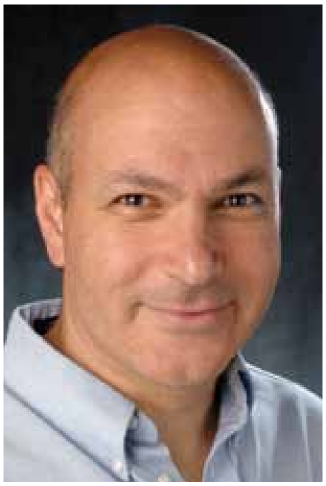
CIRES starts with people. Researchers here all seek to better understand the planet, and they do so from different perspectives that reflect diverse areas of expertise. Fellows, CIRES scientists, students, and outreach professionals work together, forming a network that stretches from the Institute across the globe.

The following pages highlight the diversity of research conducted at CIRES, beginning with those CIRES Fellows who are University of Colorado at Boulder faculty or CIRES senior scientists. Following are brief descriptions of CIRES' five centers, CIRES' signature integrating activity—the Western Water Assessment—and the Institute's Education and Outreach program. We also describe our prestigious visiting fellowships, pioneering research funded by CIRES' Innovative Research Program, and graduate and undergraduate research and fellowships. A more exhaustive description of CIRES projects, involving CIRES Fellows at NOAA and hundreds of other scientists and staff, can be found in the Themes Reports (page 102).

Waleed Abdalati

Studying Ice from Space

FUNDING: NASA

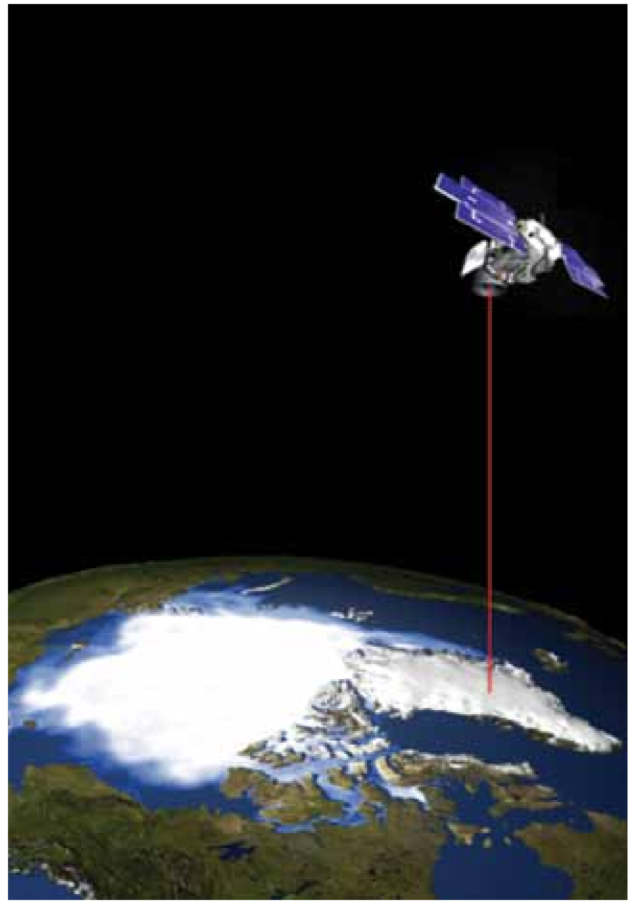


NASA's planned Ice Cloud and land Elevation Satellite-2 (ICESat-2) mission is designed to significantly improve upon measurements begun by its predecessor, ICESat, to map changes in ice sheet elevation using space-based laser altimetry. Abdalati is lead of the ICESat-2 Science Definition Team, which is carrying out extensive analyses in support of the mission.

The objectives of ICESat-2 are to a) quantify the contributions of the Greenland and Antarctic ice sheets to sea-level rise, and provide key insights into the underlying mechanisms; b) assess the thickness of the Earth's sea ice cover to improve our understanding of the exchanges of moisture and energy among the oceans, ice, and atmosphere; and c) map global land biomass to quantify its carbon storage.

Satellite observations of recent dramatic changes in the Earth's polar ice cover have transformed our thinking about polar ice since the original ICESat mission was developed. As a result, the ICESat-2 mission must be designed to capture the very rapid changes of outlet glaciers, observe the impacts of summer speedup of ice flow due to the penetration of surface melt water to the ice sheet bottom, and examine the detailed character of the rapidly thinning Arctic sea ice cover. All of these require new observations and rigorous analyses of various observation strategies. Maximizing the capabilities of the mission to achieve these multiple objectives poses significant challenges to optimal design.

Among the parameters under study are: mission duration, laser pulse-repetition frequency (PRF, or along-track sampling rate), spatial density of sampling in the cross-track direction, required laser energy for cloud penetration, footprint size, etc. The optimal values for each of these variables is determined by the geometric structure of the ice and vegetation surfaces observed, and the nature of the interaction of the laser's photons with that surface. The primary tradeoffs are between observing strategies that maximize sampling (high PRF with small footprints, multiple beams in the cross-track direction, and high laser energy levels) and those that maximize laser life to enable meaningful change detection (low PRF with larger footprints, minimal use of multiple lasers, and low energy levels).



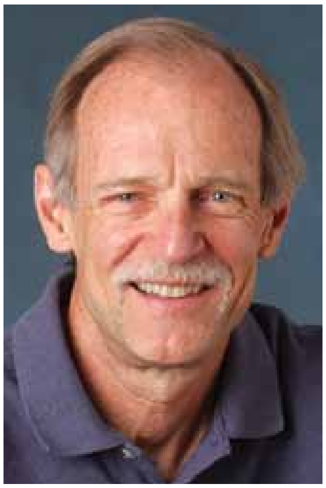
COURTESY OF WALEED ABDALATI USING NASA IMAGES

The work of the ICESat-2 Science Definition Team has already led to a well-defined set of mission parameters that are guiding NASA's development of ICESat-2, so that the mission can provide key information for understanding how and why the Earth's polar ice cover is changing, and what the implications are for global sea-level rise.

Richard Armstrong

The GLIMS Glacier Project: An Example for Nepal

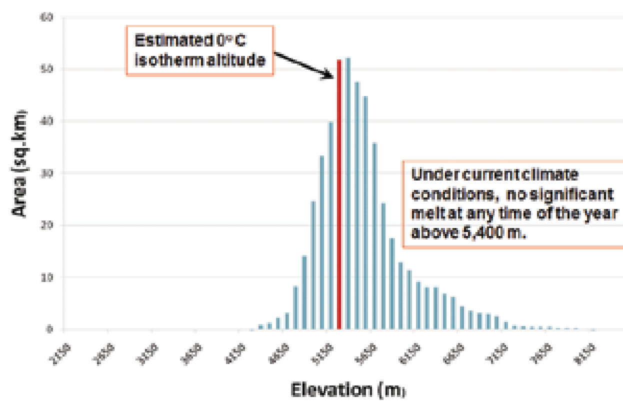
FUNDING: NASA EARTH SCIENCE



The Global Land Ice Measurements from Space (GLIMS) project is a baseline study that systematically quantifies the areal extent of past and present glaciers to allow accurate assessment of the rate and magnitude of glacier changes occurring worldwide. The GLIMS project is creating an inventory of the majority of the world's estimated 160,000 glaciers, and mapping their extent and rate of change. GLIMS is an international project, coordinated by CIRES' National Snow and Ice Data Center (NSIDC) and the University of Arizona, with participation from more than 60 institutions in 28 countries worldwide. Data are submitted to the GLIMS database at NSIDC, accessible at http://nsidc.org/glims. The NSIDC GLIMS project has created a geospatial and temporal database of glacier outlines and various scalar attributes. These data are derived from high-resolution optical satellite imagery, primarily the Advanced Spaceborne Thermal Emission and Reflection Radiometer instrument aboard the NASA EOS Terra satellite, as well as Landsat and the Satellite Pour l'Observation de la Terre, operated by the French Space Agency. Historic data (maps and photographs) are also used to document changes from earlier periods. The database currently contains outlines for more than 83,000 glaciers. This work is being undertaken in direct collaboration with the World Glacier Monitoring Service (WGMS), Zurich, Switzerland, and is a logical extension of the WGMS World Glacier Inventory.

The Armstrong research group is using GLIMS data to assess the role of glaciers in the hydrologic regime of Nepal. The methodology developed for this new study involves establishing a relationship between the area-altitude distributions of catchment basins and glaciers, and associated water and energy exchange gradients. A glacier melt model is based on melt from 100 meter area-altitude belts for the glacierized portion of each catchment. We define a "vertical mass balance gradient" (the rate of increasing specific ice melt with decreasing altitude in the ablation zone, 0.7 to 1.4 m/100 m for this region); define the mean maximum altitude of the 0°C isotherm during the ablation period (about 5,400 m); and determine the volume of ablation as the product of specific ice melt values taken from the balance gradient and the area-altitude values of corresponding belts in the glacier ablation zone. Topography is defined by digital elevation datasets acquired from the NASA Shuttle Radar Topography Mission for both models, glacier outlines were provided by the International Center for Integrated Mountain Development, Kathmandu, Nepal and streamflow data are from the Department of Hydrology and Meteorology, Nepal.

Dudh Kosi: One of 9 glacierized basins with runoff gauging stations selected for this study.

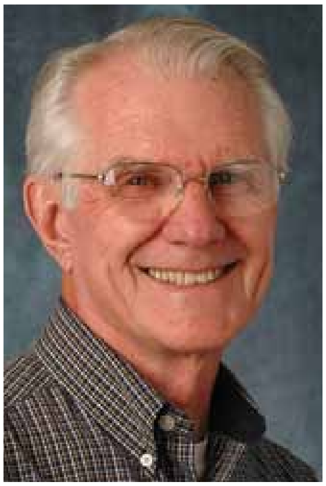


Area/altitude histogram for the Dudh Kosi Basin, Nepal (representative of all nine basins studied.

Preliminary results indicate that the annual contribution of glacier melt water to streamflow in the Nepal Himalayas varies among catchment basins, but is not likely to exceed 2-13 percent of the total annual flow volume measured at lower altitude hydrometric stations. This represents approximately three percent of the total annual streamflow volume of the rivers of Nepal. Preliminary results also suggest that neither the timing nor the volume of the streamflow of rivers of Nepal will be significantly affected in the near future (next several decades) by a continued retreat of the glaciers.

Ben Balsley

Fine-Scale Atmospheric Dynamics and Overturnings Using High-Resolution In Situ Measurements



We are beginning to examine fine-scale atmospheric dynamic processes using in-house-developed in situ measurement techniques. Specific dynamic properties include non-linear processes associated with atmospheric gravity waves, Kelvin-Helmholtz instabilities, and 'overturnings' in the potential temperature profile in the first 10-20 km of the atmosphere. These new techniques evolved from earlier studies of the lower atmosphere using tethered lifting system measurements that were also developed in-house. We are currently developing a slow-rise-rate radiosonde technique that will enable 1-meter vertical resolution measurements from 0-20 km altitude by reducing conventional balloon inflation procedures. Figure 1 shows balloon rise rate as a function of lift, and indicates that radiosonde rise rates of about 1 m/s can be achieved with a nominal lift (balloon plus sensor) of about 50 grams.

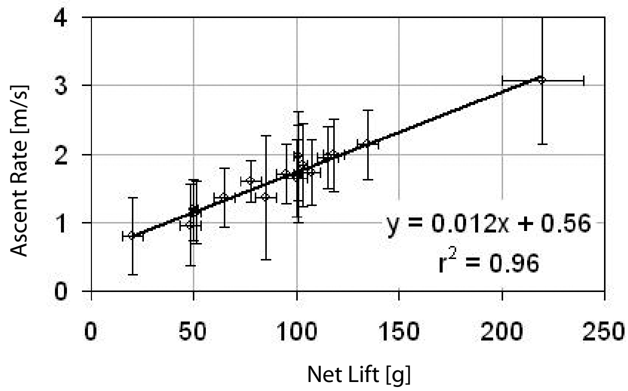


Figure 1: *Balloon rise rate as a function of lift.*

Our second development involves the use of balloon-launched, unmanned, autonomous, GPS-controlled, mini-gliders that can carry a conventional radiosonde. The mini-glider was developed in New Zealand and is being modified at CIRES to provide onboard archiving of temperature, humidity, pressure, wind speed and direction, and GPS flight coordinates (Figure 2). Pertinent characteristics include a wingspan and length of 60 cm, a forward speed of about 14 m/s, and a descent rate of 2-3 m/s. One of the first measurements will be made around a high-resolution radar beam in Peru to examine fine-scale temperature profiles in conjunction with the radar measurements of small-scale turbulence structure.

One of the surprising early results of these studies is the occurrence of myriad 'overturnings' in the potential temperature profiles provided by the slow-rise-rate radiosonde data. Basically, in the absence of external forcing, potential temperature profiles should increase steadily with height. In practice, however, the high-resolution data exhibit narrow regions where the temperature decreases with height, indicating the presence of external forcing. Preliminary analysis of these regions suggests that they may be associated with gravity-wave activity, and the breakdown of the waves into fine-scale turbulence.

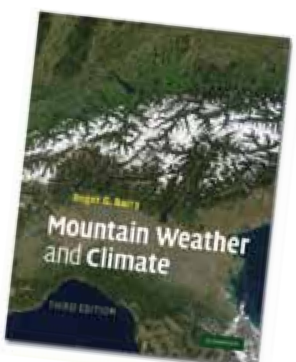
Figure 2: *The mini-glider was developed in New Zealand and is being modified at CIRES to provide onboard archiving of temperature, humidity, pressure, wind speed and direction, and GPS flight coordinates.*

Roger Barry

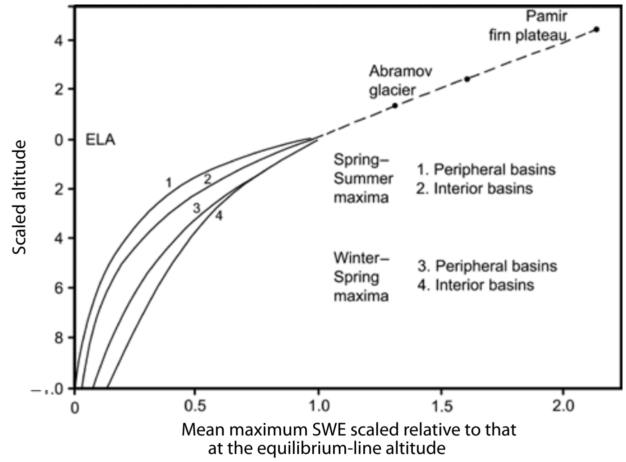
Mountain Meteorology and Climate

Barry completed and published the third edition of *Mountain Weather and Climate* (Cambridge University Press, Cambridge, 506 pp.). First published in 1981 and updated in 1992, the work is an advanced text. It is the only comprehensive book describing and explaining mountain weather and climate processes. It presents the results of a broad range of studies drawn from across the world.

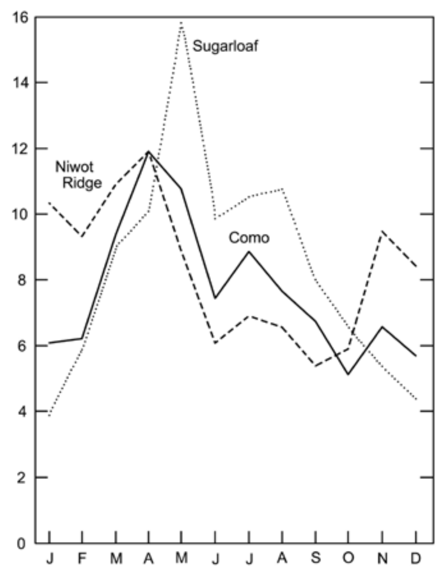
Following an introductory survey of the historical aspects of mountain meteorology, three chapters deal with the latitudinal, altitudinal, and topographic controls of meteorological elements in mountains; circulation systems related to orography; and the climatic characteristics of mountains. The author supplies regional case studies of selected mountain and high plateau climates from New Guinea to the Yukon, including the ice plateaus of Greenland and Antarctica. The next chapter on bioclimatology, weather hazards, and air pollution in mountains is followed by the concluding chapter on the evidence for and the significance of changes in mountain climates.



Since the first edition of this book appeared more than two decades ago, several important field programs have been conducted in mountain areas. Notable among these have been the European Alpine Experiment and related investigations of local winds, studies of air drainage in complex terrain in the western United States, and field and laboratory experiments on air flow over low hills. Results from these investigations and other research are incorporated in this new edition and all relevant new literature is referenced.



Typical vertical gradients of maximum snow water equivalent (SWE) on macro-scale slopes in the Tien Shan and Pamir ranges (adapted from Getker 1985).



Precipitation regimes on the east slope of the Front Range, Colorado (408˚ N, 105.58˚W) expressed as monthly percentages of the annual total (based on Niwot Ridge long-term ecological research data). Niwot Ridge (3,743 m) is 2.5 km east of the Continental Divide, Como (3022 m) is 9.5 km and Sugarloaf (2,591 m) 22.5 km east of the Divide. The Niwot Ridge and Como data are for 1952–2004, and Sugarloaf data span 1952–1991.

Figures excerpted from
Mountain Weather and Climate

Roger Bilham

Shaky History

In 2008, my students and I worked on a database of more than 8,000 earthquake intensity observations of historical earthquakes in India; evaluated the tsunami hazard in the Mediterranean; installed a tiltmeter array in the Pozzuoli region of Italy; analyzed incoming tilt and creep data from California and GPS data from 88 points in Indian and Pakistan Kashmir, Sindh, NW Frontier Province and Baluchistan; and worked on archaeological aspects of historical seismicity in the Sindh and Kashmir provinces of Pakistan and India.

Our macroseismic earthquake work has produced new findings for the rate of attenuation of shaking intensity with distance in ancient cratons (central India, North America, and Australia) and in deformed sediments such as the Himalaya. Our tiltmeters in Oregon, Mammoth Lakes, and Pozzuoli consist of horizontal water pipes up to 500 m long, installed in shallow trenches or in tunnels. They are sensitive to sub-micron vertical displacements of the subsurface related to the inflation of magma chambers and the slip of the plate interface in slow earthquakes. The GPS data captured the October 2008 Pishin/Mach earthquake sequence and its afterslip, and provide new constraints on the deformation of the India/Asia collision zone along the western edge of the Indian plate in Baluchistan and Afghanistan.

We have determined that the ancient Arabic capital of Sindh (Mansurah c. 725-1000 AD) was destroyed by an earthquake c. 980 AD. We further report that we have probably found the lost Mughal town of Samawani, in which 30,000 houses were reported to have subsided in 1668, presumably as a result of sediment liquefaction during a severe earthquake. Mughal accounts rank it the third largest city in Nassirpur province, which narrowed the search to a region near a town of that name. A village-by-village search led to the discovery of ruins, which oral tradition held were those of a town called Samawani, not mentioned on maps. We hypothesize that relatively modest earthquakes can cause the abandonment of cities in the Indus valley—a result of changes in the course of river, in turn caused by the breach of their natural levées. A study of the 1897 Assam earthquake reveals that levée collapse can accompany Mercalli Intensity VII shaking.

The "Thul" at Mansurah in 2008. This masonry tower is all that remains of fortified town of Mansurah, the ancient capital of Sindh province that was destroyed by an earthquake c. 980 AD. In 19th century archaeological excavations, skeletons were found crushed by bricks. Recent excavations revealed four massive bronze door knockers buried deep beneath the ruins of the largest building, objects that had escaped looting in the past millennium, which would surely have been removed if the city had, instead of being shaken by an earthquake, been sacked by an invading army.

These 50-kg bronze door knockers were once attached to massive doors on one of the largest civic structures in Mansurah, the ancient Arabic capital of Sindh (7th to 10th century). They are thought to have been buried by an earthquake c. 980 AD. Kufic inscriptions surround the raised-relief heads of a pattern copied from traditional Roman designs.

John Cassano

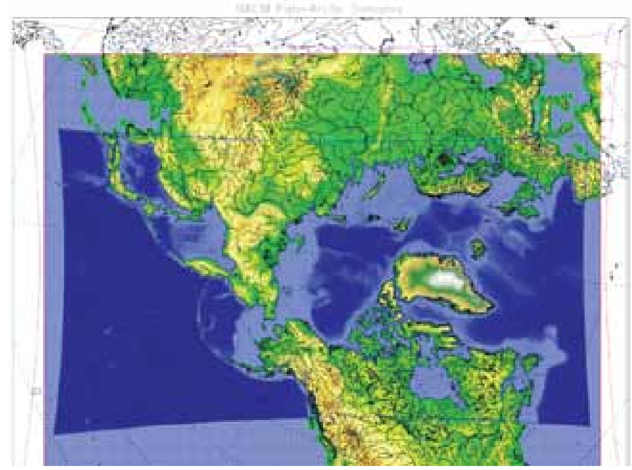
Polar Climate and Meteorology

FUNDING: NSF,
DEPARTMENT OF ENERGY

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

Our motivation to develop a high-resolution Arctic climate system model comes from the limitation of current generation global climate system models lacking the horizontal and vertical resolution to adequately resolve key processes in the Arctic climate system. In addition to the improved resolution possible in a regional model, we use model physics tailored to the unique aspects of the polar climate system, ensuring that all key processes in the climate system are sufficiently represented in the model. We use a pan-Arctic model domain, which includes all of the sea-ice-covered regions of the Northern Hemisphere and all terrestrial watersheds that drain to the Arctic Ocean (top right). One question we plan to address with our Arctic climate system model is why global climate models have failed to simulate the recently observed rapid decline in Arctic sea ice cover. We hypothesize that processes acting at scales below the resolution of global models are, in part, responsible for this failure.

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



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

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

Cassano in Antarctica.

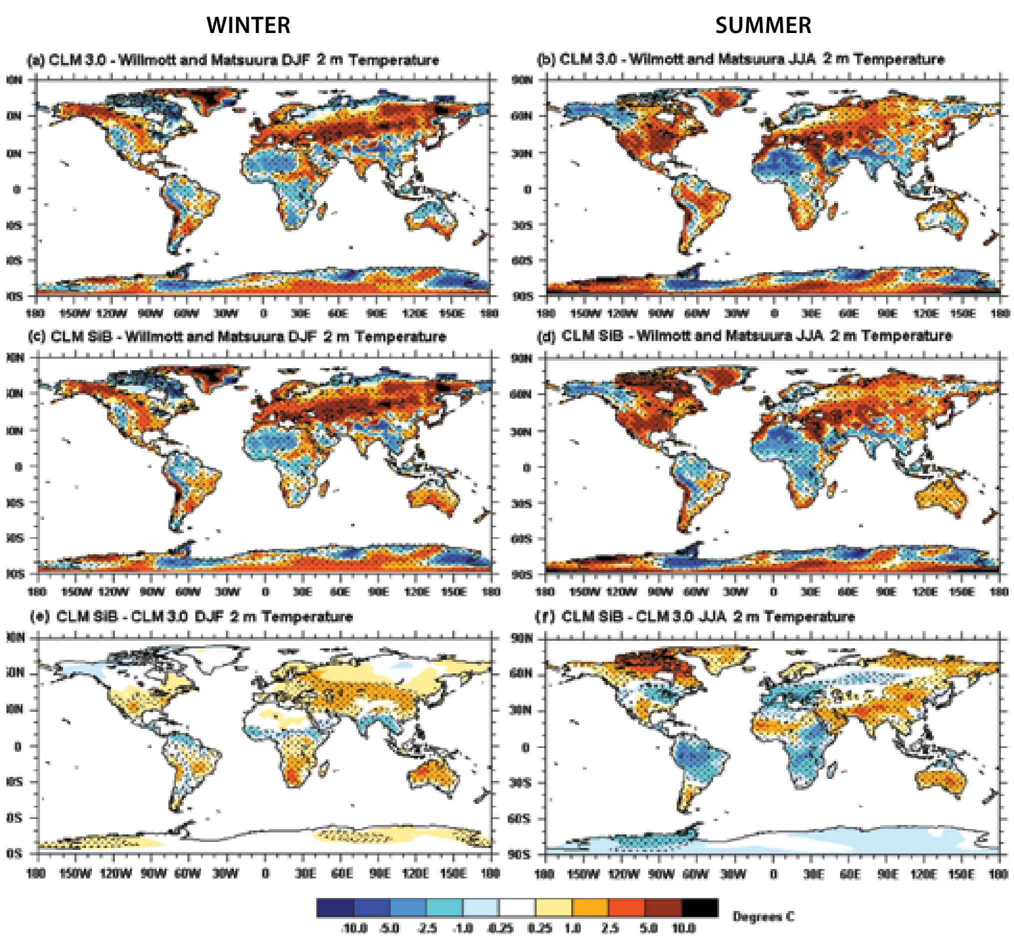
Tom Chase

Modeling Climate Better

Our work in the past year involved climate modeling simulations and observational work related to the effects of the land surface on climate and climate change. We showed that East Asian monsoon precipitation prediction can be vastly improved by including antecedent vegetation characteristics in the forecasting algorithm. Most monsoon prediction in the past has used ocean characteristics, particularly sea-surface temperatures, as the main indication of future precipitation. By including the land surface, we effectively doubled the predictive power of our forecast models, demonstrating the important role the land surface and changes in the land surface have on climate. This work received a "Research Highlight" discussion in *Nature*.

We also published a modeling study in which we improved the land surface hydrology in the NCAR Community Climate System Model (CCSM). CCSM had large errors in globally-averaged transpiration, and we used a combination of theoretical results, empirical analysis, and guidance from other models to greatly reduce the overall errors in the model. Beyond getting more realistic values out of the land surface parameterization, this work also highlighted the role of the land surface on the climate system. The figure below shows the changes in near-surface air temperature in winter (left panels) and summer (right panels) for the old model hydrology (CLM3.0) and new hydrology (CLM SiB), compared with observations and with each other. The two bottom panels indicate that the change in land surface hydrology was responsible for changes in the model temperature of more than 5°C in many parts of the globe. This magnitude of temperature change is towards the upper limit suggested by a doubling of carbon dioxide, indicating the importance of correctly simulating the land surface in any model of climate change.

Other work continues on trends in low–level inversions, which may have an impact on near-surface temperature trends that have been recently observed, and in the area of damage to coastal cities due to landfalling hurricanes.



Differences in average seasonal near surface air temperature between Willmott and Matsuura, (2000) 1970-1999. Observed Climatology and Current CLM 3.0 hydrology experiment (a and b) and with new CLM SiB hydrology experiment (c and d), and differences between experiments (e and f). Differences with statistical significance greater than 95% are stippled.

Xinzhao Chu

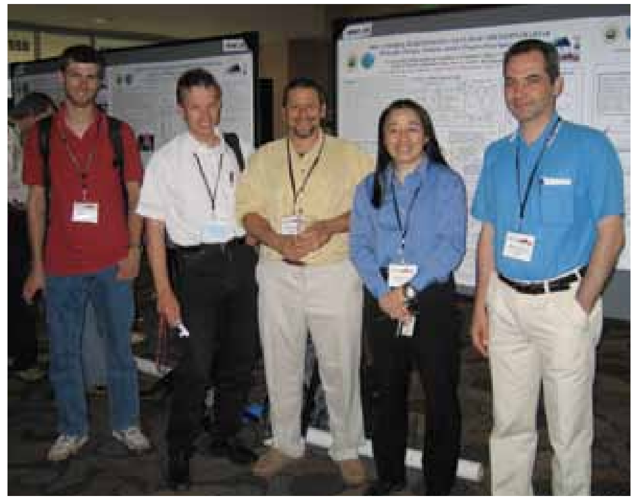
LIDAR Technology Innovation and Study of Middle Atmospheric Sciences

FUNDING: NSF'S MRI, CAREER, AERONOMY, AND CEDAR PROGRAMS; EUROPEAN SPACE AGENCY

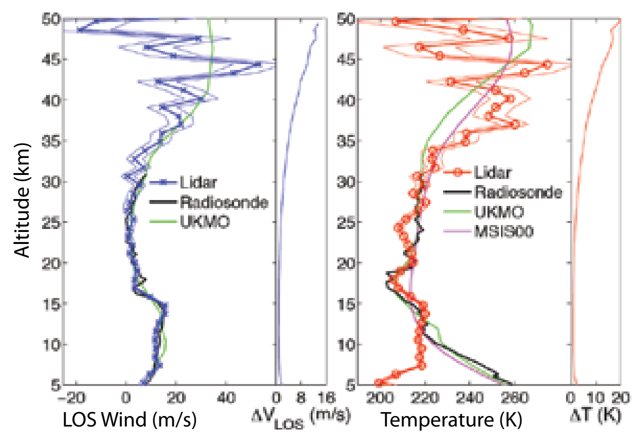
In FY09, the Chu Research Group published six papers in the *Journal of Atmospheric Solar-Terrestrial Physics*, the *Journal of Geophysical Research*, *Optics Letters*, and *Optical Engineering*, with lead authors Chu, Yamashita, Friedman, Huang, and Smith. The contents covered polar and tropical middle atmospheric cloud physics and wave dynamics, sodium double-edge magneto-optic filter technique (Na-DEMOF), and laser frequency locking for Doppler lidar. Additional papers are in progress.

Highlights of Chu Group research include three major activities: lidar development for Major Research Instrumentation, the Innovative Research Program-funded exploration of Na-DEMOF technology, and a European Space Agency feasibility study of space-borne mesosphere lidar. 1) We are working with Light Age, Inc. to develop a unique pulsed alexandrite ring laser for the Major Research Instrumentation Fe-resonance / Rayleigh / Mie Doppler lidar. With help from Mike Hardesty's group at NOAA's Earth System Research Laboratory, we are borrowing the optical heterodyne detection technique from coherent lidar to measure and control the frequency of each lidar pulse. This will lead to a revolution in resonance Doppler lidar. 2) In collaboration with Colorado State University and Colorado Research Associates, we developed and implemented a Na double-edge magneto-optic filter into the receiver of a 3-frequency Na Doppler lidar, and successfully demonstrated its capability in simultaneous measurements of wind and temperature from 5-50 km (figure). This moves us one step closer to achieving a whole atmosphere lidar. 3) In light of the needs of a mesosphere lidar in space, we are participating in a feasibility study of putting a resonance-fluorescence Doppx-raler lidar into space, hosted by the European Space Agency. Our "although challenging but doable" results were presented at the European Space Agency workshop held in Noordwijk, the Netherlands in April 2009.

CIRES hosted the 24th International Laser Radar Conference, and the Chu Group joined the Earth Science and Observation Center. At the laser conference, Chu chaired a session on "Middle atmosphere physics and chemistry," and presented an invited review titled "Advances in middle atmosphere research with lidar." Chu group members and CIRES staff, who helped with the conference, significantly increased the visibility of CU-Boulder lidar programs.



Lidar experts gathered at the 24th International Laser Radar Conference held at the CU-Boulder campus.



Line-of-sight wind and temperature measured with the Na-DEMOF and CSU Na Doppler lidar.

Students and postdocs in Chu's laboratory had major successes this year. Our first Ph.D., Jonathan Fentzke, successfully defended his dissertation in May 2009, and John A. Smith, who earned his Master of Science degree, published two journal papers, won a NASA Earth and Space Science Fellowship, and will continue his Ph.D. study at CIRES. Doctoral student Chihoko Yamashita published two journal papers, passed her Ph.D. comprehensive exam, and has a third paper ready for submission. This year's star was Wentao Huang, who developed a new lidar technology, Na-DEMOF, and published two papers in *Optics Letters*, under the support of a CIRES Innovative Research Program award.

Shelley Copley

The Evolutionary Potential of Promiscuous Enzymes

FUNDING: NATIONAL INSTITUTES OF HEALTH

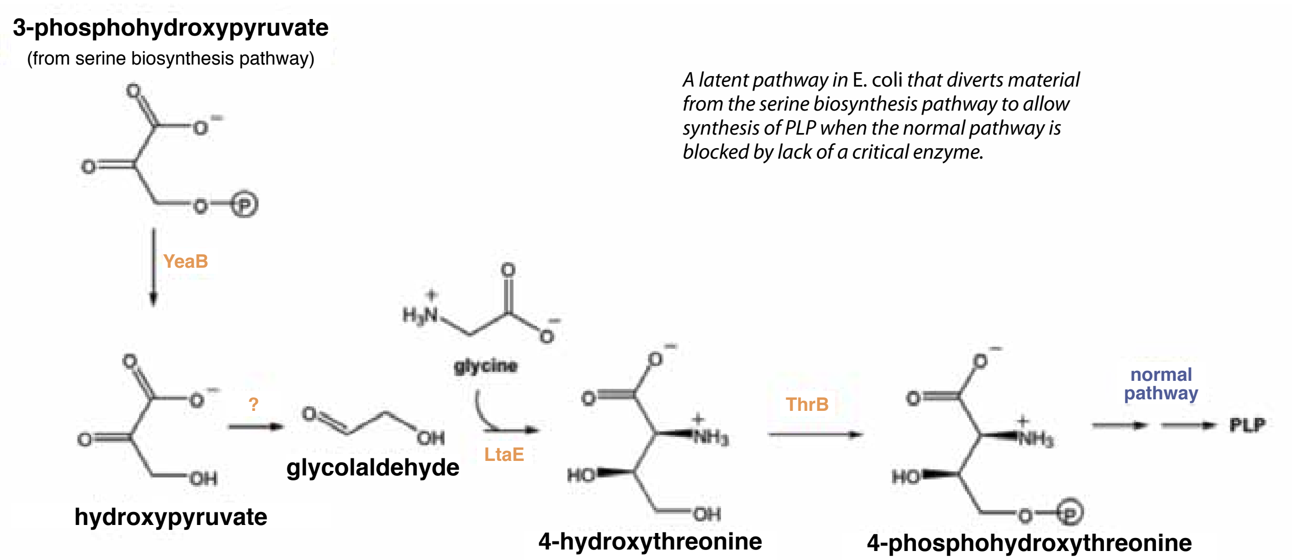
We are interested in the evolution of new catalysts, both in nature and in the laboratory, including catalysts that could assist in the degradation of pesticides and industrial pollutants or in the "green" synthesis of pharmaceuticals, specialty chemicals, and biofuels.

Enzymes are superb catalysts. They accelerate reactions by up to 17 orders of magnitude. With few exceptions, they catalyze reactions with extremely high regioselectivity and enantioselectivity. In addition, enzymes are environmentally benign. The conditions required to produce and to use enzymes are "green"—they do not require toxic organic solvents and/or extremely high temperatures and pressures that are costly in terms of energy usage.

Many enzymes are understood to have "promiscuous" characteristics, promoting, at low levels, reactions other than primary ones. New enzymes can emerge from these promiscuous activities, which exist fortuitously as a consequence of the assemblage of reactive catalytic residues and cofactors at active sites. Although promiscuous activities are accidental and normally of no particular use to the organism, they provide an expanded catalytic repertoire from which enzymes may be recruited under novel environmental conditions. However, the potential of promiscuous enzymes goes beyond just catalysis of a single reaction. Promiscuous activities can be assembled into novel combinations to allow microbes to synthesize a useful metabolite or degrade a novel carbon source.

We are currently studying three pathways that can be patched together from promiscuous enzymes to allow *E. coli* to bypass a metabolic block. A strain of *E. coli* lacking the enzyme erythronate 4-phosphate dehydrogenase cannot grow on glucose because it cannot make the critical cofactor pyridoxal phosphate (PLP). We have identified seven enzymes that, when over-expressed, allow this strain to grow on glucose. Genetic analyses suggest that these enzymes facilitate three latent pathways patched together from promiscuous enzymes that allow *E. coli* to produce a metabolite downstream of the block in the pathway for synthesis of PLP. We have identified enzymes capable of catalyzing three of the four steps in one of the latent pathways (see below).

The identification of three different latent pathways that allow formation of PLP demonstrates the remarkable evolutionary potential of catalytically promiscuous enzymes residing within the proteome of *E. coli*, which contains about 2,000 enzymes. This project will enhance our understanding of the potential for assembling novel metabolic pathways by patching together enzymes that normally serve other functions in the cell. Such pathways could be engineered to allow degradation of novel anthropogenic chemicals such as pesticides and industrial pollutants or to allow "green" synthesis of pharmaceuticals, specialty chemicals, and biofuels.



A latent pathway in E. coli *that diverts material from the serine biosynthesis pathway to allow synthesis of PLP when the normal pathway is blocked by lack of a critical enzyme.*

Joost de Gouw

with Carsten Warneke, Jerome Brioude, Jessica Gilman, Patrick Veres, Paul Goldan, and NOAA colleagues

Understanding Arctic Haze

The Arctic region has witnessed relatively large increases in average temperatures and the retreat of sea ice has accelerated in recent years. In 2008, our research was focused on the transport of atmospheric emissions to the Arctic and their impact on climate. These activities were undertaken in the framework of the International Polar Year.

Measurements of trace gases and aerosol were made in April 2008 from the NOAA WP-3D aircraft during flights in the Alaskan Arctic. Numerous plumes with strongly enhanced trace gas and aerosol concentrations were observed. The chemical composition of the plumes, notably the presence of acetonitrile (CH_3CN) measured using mass spectrometry, revealed that these plumes were emitted from biomass burning. Satellite observations of fire hot spots, land-use data, and an atmospheric transport model were used to determine the source of these plumes and it was found that forest fires in Russia and agricultural fires in Kazakhstan were largely responsible for the presence of these plumes in the Alaskan Arctic. Work is in progress to determine what the impact of biomass burning plumes is on Arctic climate and how commonly such events occur.

Measurements of trace gases were made in the northern Atlantic using the research vessel *Knorr* from the Woods Hole Oceanographic Institution. In the vicinity of Svalbard, the *Knorr* encountered air masses with strongly depleted ozone levels. Such ozone depletion events at the surface have been observed previously in the Arctic and are attributed to the activation of halogen radicals over sea ice in the spring. This chemistry also manifested itself in the concentrations of different hydrocarbon species measured by gas chromatography-mass spectrometry. For example, acetylene (C_2H_2) reacts efficiently with various halogen radicals and was markedly lower during this event, whereas benzene does not react with halogen radicals and remained relatively constant. Closer inspection of the hydrocarbon data revealed that halogen chemistry determined the variability in ozone over a large part of the springtime northern Atlantic Ocean, in stark contrast with ship-based observations in other regions.

COURTESY OF DEREK COFFMAN/NOAA

Rough weather made for a choppy ride on the U.S. Navy's research vessel Knorr *during the ship-bound portion of the 2008 Arctic missions.*

JULIE COZIC/NOAA/CIRES

NASA's P-3, captured from NOAA's P-3 during a 2008 mission instrument comparison flight above Alaska. Haze is visible.

Lisa Dilling

with Bill Easterling, Penn State University, and research assistant Betsy Failey

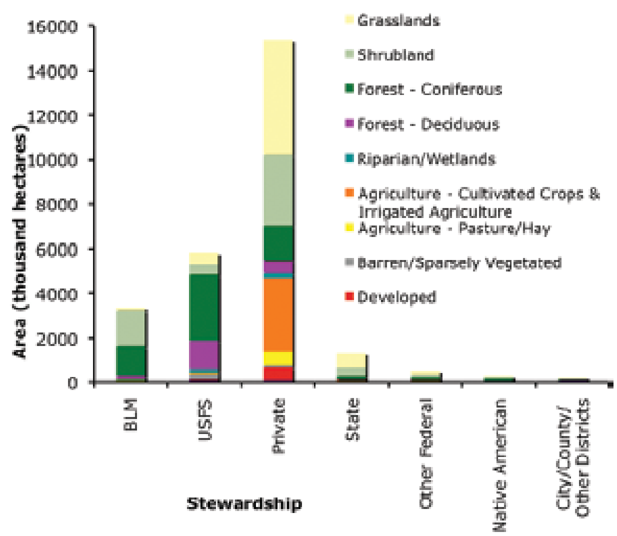
Scales of Decision-Making and the Carbon Cycle

FUNDING: NOAA CLIMATE PROGRAM OFFICE

Carbon management is increasingly a topic of interest in policy circles and among business entrepreneurs alike. In the United States, while no binding regulatory framework exists, carbon management is nonetheless being pursued both by voluntary actions—at a variety of levels, from individual to national—and through mandatory policies at state and local levels. Controlling the amount of carbon dioxide in the atmosphere for climate purposes will ultimately require a form of governance that will ensure that the actions taken and being rewarded financially are indeed effective with respect to the global atmosphere on long time scales. Moreover, this new system of governance will need to interface with existing governance structures and decision criteria that have been established to arbitrate among various societal values and priorities. These existing institutions and expressed values will need to be examined against those proposed for effective carbon governance, such as the permanence of carbon storage; the additionality of credited activities; and the prevention of leakage, or displacement, of prohibited activities to another region outside the governance boundary. The latter issue suggests that interactions among scales of decision-making and governance will be extremely important in determining the ultimate success of any future system of carbon governance.

The goal of our study is to understand the current context of land-use decision-making in different sectors, and examine the potential for future carbon policy to be effective given this context. This study examined land-use decision-making in Colorado from a variety of ownership perspectives, including federal land managers, individual private owners, and policy makers involved in land use at a number of different scales. We have found, through analyzing GIS data and interviews, that decisions on the land are influenced by policies at a wide variety of scales. There are clear differences in the main influences for decision-making for public and private land managers. Federal law governs the process for land-use decision-making on federal lands, but there is nonetheless some degree of autonomy at the local scale, where decision makers must balance competing interests in the use of the land. The decisions of private land managers are influenced by markets; federal, state and non-governmental incentive programs; and cultural heritage. Interestingly, neither group is yet particularly aware or interested in managing land for carbon or climate change purposes. This may change as incentives change, but for the moment, concerns about natural resource management, fire and beetle risks, and profitability dominate the decision process. Future policy to encourage carbon sequestration on land will need to take into account these other drivers of decision-making.

LISA DILLING



The distribution of land cover type by land management category. In Colorado, much of the grassland and agricultural land is privately owned, whereas forested land is predominately managed by two Federal agencies, the Forest Service and Bureau of Land Management.

Lang Farmer

Sources of Glacial and Glacimarine Sediment in the North Atlantic

FUNDING: NSF EARTH SCIENCES

The Farmer laboratory in 2008 conducted research to assess the past stability of the Greenland ice sheet. Marine sediments, deposited at the Greenland continental margin, contain the signatures of ice-rafted sedimentary detritus (IRD), delivered to the margin of southeast Greenland during the past 50,000 years. We used radiogenic isotope data to characterize the IRD sources.

We assessed the neodymium and strontium isotopic compositions of Quaternary glacial and glacimarine sediments deposited along the margin of southeast Greenland to determine the roles of the Greenland, Iceland, and more distal ice sheets in delivering detritus to this portion of the northern North Atlantic.

Fine-grained IRD deposited along the southeast Greenland margin over the past 50,000 years from Blosseville Basin, in the north, to the southern Irminger Basin show regular spatial isotopic variations. These variations correspond to changes in the isotopic compositions of southern Greenland continental crust and reveal that much of this sediment was eroded from the adjacent southern Greenland margin.

However, along the entire southeast Greenland margin, locally-derived detritus is intermixed with isotopically distinct sediment that was most likely delivered by icebergs from the Eurasian ice sheets. Deposition of glacial sediment from both local and distal (Eurasian) sources occurred adjacent to southeast Greenland throughout the past 50,000, with periodic increases in IRD deposition at various times including those of Heinrich events 1, 2, and 4 (Heinrich events are times of major instabilities in Northern Hemisphere ice sheets.)

Our data reveal that shelf-based ice streams along the east southeast margin of Greenland were unstable during the last glacial cycle and that instabilities that led to marked increases in IRD depositions along the east Greenland coast occurred in concert with instabilities in other circum-North Atlantic sheets. The latter observation suggests that ice sheet collapses in the North Atlantic may share a common forcing mechanism, such as regional North Atlantic-wide atmospheric/ocean perturbations.

An ice cap in central Iceland. Such ice is responsible for delivery of Iceland sediment to the North Atlantic.

LANG FARMER

Eastern Peru, in the Amazon Basin.
NOAH FIERER

Noah Fierer

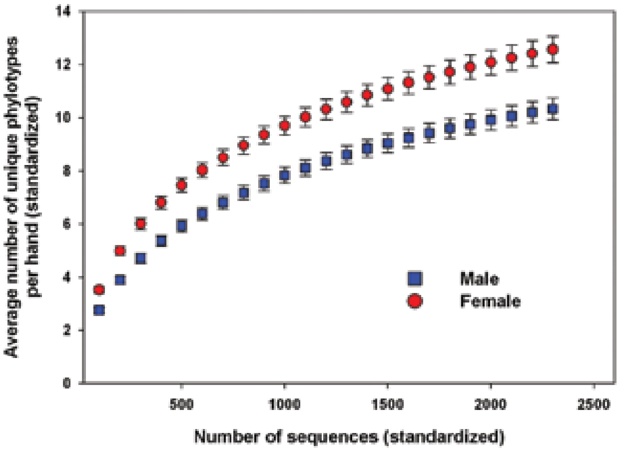
Airborne Microorganisms and Microorganisms on Leaf Surfaces

FUNDING: A.W. MELLON FOUNDATION, NSF, NATIONAL GEOGRAPHIC SOCIETY, USDA

Bacteria and fungi are ubiquitous in the atmosphere and represent a large proportion of total airborne particulates. Atmospheric transport is a key mode of microbial dispersal, and the transmission of airborne plant and animal pathogens can significantly affect ecosystems, human health, and agriculture.

In addition, recent evidence suggests that airborne microorganisms may be able to alter precipitation events by facilitating atmospheric ice nucleation and cloud condensation. There have been few studies examining the validity of this hypothesis, or the overall diversity of microbial diversity in the atmosphere. To address these key knowledge gaps, we used a cultivation-independent molecular approach to identify the bacteria and fungi present in air samples collected during 12 days from a single site at the Storm Peak Laboratory in northern Colorado (shown above, 3,200-m elevation).

The air samples were dominated by a diverse array of bacteria, including types commonly found in air samples across the globe. Snow samples had distinct microbial communities compared with aerosol samples. Bacteria with ice nucleation capabilities were more common during periods of high humidity than in periods of low humidity, suggesting that bacteria alter their physiologies in response to humidity levels. We are expanding on this work to further understand how airborne microorganisms vary across space and time, so we can better predict how airborne microorganisms respond to—and potentially influence—atmospheric conditions.



In other, nationally-noted research, Fierer found higher bacterial diversity on women's than men's hands. The reason may be that men generally have more acidic skin—other research has shown microbes are less diverse in more acidic environments.

Microorganisms are common inhabitants of leaf surfaces and these leaf-associated bacteria and fungi represent one of the major sources of bacteria to the atmosphere. However, few studies have assessed the full extent of microbial diversity on leaf surfaces, and we do not know if distinct plant species harbor distinct microbial communities. We have been conducting a series of projects examining leaf-associated microbial communities, sampling more than 60 tree species in Colorado. We find that unique species harbor unique bacterial communities, and many of the leaf-associated bacteria are similar to those found in the atmosphere. These findings suggest that changes in vegetation could have an important influence on microorganisms present in the atmosphere, with subsequent effects on human health. In addition, we recently completed a study documenting changes in leaf-associated bacterial communities across a tropical elevation gradient in eastern Peru. We found that bacterial communities, unlike plant and animal communities, do not exhibit a decrease in diversity at higher elevations.

Baylor Fox-Kemper

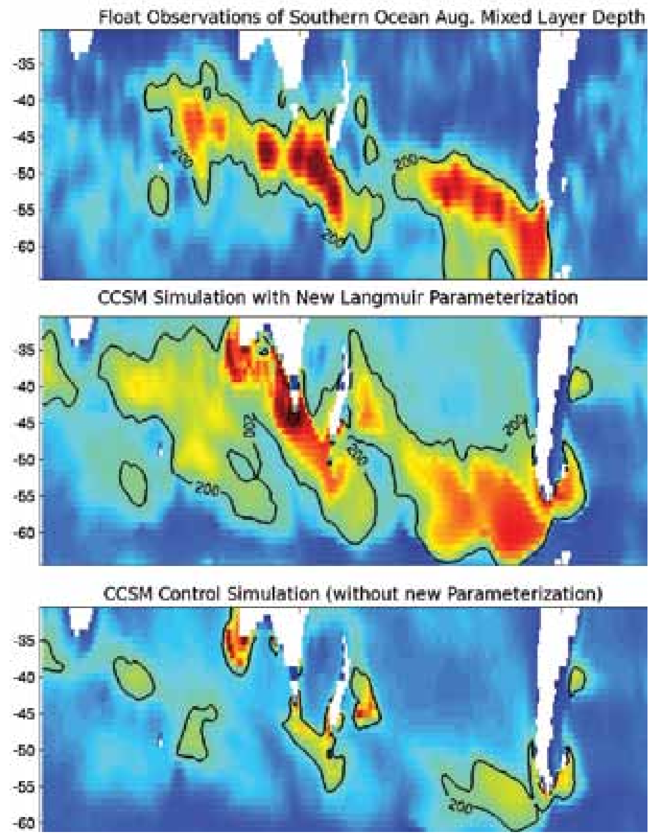
Improving Subgridscale Physics in Ocean Climate Models

FUNDING: NSF, NASA,
CIRES INNOVATIVE RESEARCH PROGRAM

The ocean is vast and diverse. Ocean motion at the largest scales (>1,000 km) combines with cryospheric, atmospheric, and biospheric processes to provide a habitable climate. However, the largest ocean movements depend on smaller-scale features. For example, the Gulf Stream (100 km) plays a crucial part in transporting heat from the equator to the northern midlatitudes. Smaller features (e.g., mesoscale eddies (10-100 km) and deep convection (1-10 km)) allow the Gulf Stream to function as it does. Even smaller features affect the way the atmosphere, ice, and ocean communicate through the ocean surface (e.g., submesoscale eddies (100 m-10 km), Langmuir circulations (10-100 m), and finescale turbulence (1 cm-10 m)).

Even the world's fastest computers cannot simulate the global ocean with a fine enough model grid to capture these small features directly. Thus, something must be done to handle, or parameterize, the effects of these unresolved, subgridscale phenomena on the larger resolved scales. The small-scale phenomena interact so strongly with the global scale that without these parameterizations, an ocean model cannot be used to simulate climate realistically.

Fox-Kemper and colleagues have developed a parameterization of the effects of submesoscale eddies (<10 km) that inhabit the near-surface ocean. The submesoscale heat transport rivals the ocean surface forcing by radiation and exchange with the atmosphere, so these eddies have a global climate impact. A theory was developed—and confirmed against numerical experiments—that allows the vertical fluxes of these eddies to be incorporated into climate scale models. This parameterization reduces climate model biases, and it is now being used internationally in the majority of the ocean models for the upcoming Intergovernmental Panel on Climate Change's fifth assessment report.



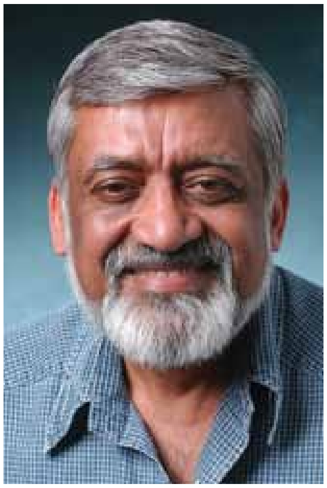
Southern Ocean mixed layer depth in observations and models with and without the Langmuir parameterization.

This year, the Fox-Kemper group collaborated with National Center for Atmospheric Research scientists to implement a rough parameterization of mixing by Langmuir turbulence into a global climate model. For the first time, the global-scale effect of these wind and wave-driven roll vortices (10-100 m) can be studied. These vortices, like the submesoscale eddies, affect the near-surface ocean. The figures above illustrate the substantial improvement in simulated Southern Ocean mixed layer depth when the new Langmuir parameterization is used. These improvements warrant future parameterization efforts, and with NASA support, the Fox-Kemper group will work with collaborators at CU-Boulder, University of California, Berkley, and the University of New Hampshire to use simulations and satellite observations to develop and validate a robust parameterization.

Other projects, including global simulations of mesoscale eddies and long-timescale and paleoclimate variability of the El Niño/Southern Oscillation are germinating within the Fox-Kemper group.

Vijay Gupta

Tests of Multi-Scale Dynamics of Statistical Scaling in Floods on River Networks: the Iowa Floods of June 2008

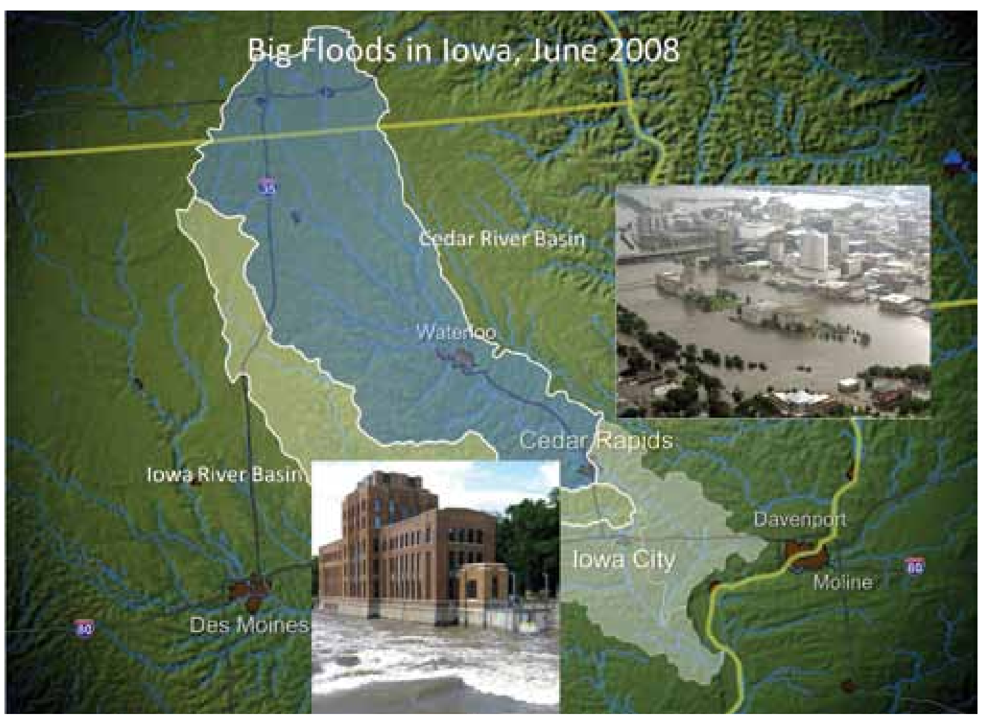


When water topped the Upper Mississippi's banks in June 2008, the soaked Iowa City, Cedar Rapids, and surrounding communities suffered some $2 billion in damages, and more than 30,000 people were evacuated. Recovery efforts are still ongoing.

Mother Nature's experiments in Iowa provided a unique opportunity to put to the test the central hypothesis of a multi-scale dynamical theory of floods that has been developing for the past 20 years. The motivation to develop the theory came from the long history of flood research in engineering hydrology. It pointed to a fundamental question: How can we understand regional (spatial) annual flood statistics (for example, the "100-year flood") in terms of physical mechanisms producing floods on hourly and daily time scales? An answer to this question has remained elusive, but could greatly improve current engineering methodologies used for real-time flood forecasting and floodplain management.

The flood theory requires mass and momentum conservation equations for channel segments (links) between junctions and attendant hillslopes draining into them. Therefore, a river basin is decomposed into a large number of hillslope-link pairs as they exist on a terrain. Solutions of the conservation equations are obtained on a channel network that gives flow hydrographs at every junction over the entire network. Real networks are endowed with spatial variability and heterogeneity, but also self-similarity, meaning that each part is a tiny version of the whole. So when the size of the study area is magnified, the pattern of network remains similar. This leads to the central hypothesis—that floods exhibit spatial scaling (power laws). Scaling is an emergent property of the system, not one that is built into the conservation equations. Random self-similarity is a mathematical characterization of high-level spatial organization in the presence of spatial variability and heterogeneity in real channel networks. The Gupta research team and collaborators tested random self-similarity on 28 medium-sized river basins (about 3,000 km^2) in the United States, and results are being written-up for publication in a scientific journal.

University of Iowa collaborators analyzed the U.S. Geological Survey streamflow data from multiple spatial locations on the Iowa River Basin and the Cedar River Basin, and confirmed the presence of power laws supporting the hypothesis of the flood theory. This is the first time that the theory has been put to test on such large basins (>10,000 km^2), which has given a major boost to 20 years of basic research on floods. The results are being written-up for publication in a scientific journal. The findings above add a very important new dimension to the Hydro-Kansas research that was reported in the 2008 CIRES annual report. Practical applications of this theory in the future will range from development of new methods to improve real-time flood forecasting to estimation of annual flood frequencies for the management of flood plains in a changing climate.



The Iowa floods of 2008 caused some $2 billion in damages. But they represented a unique opportunity to test theories that could greatly improve current engineering methodologies used for flood forecasting and floodplain management.

Jose-Luis Jimenez

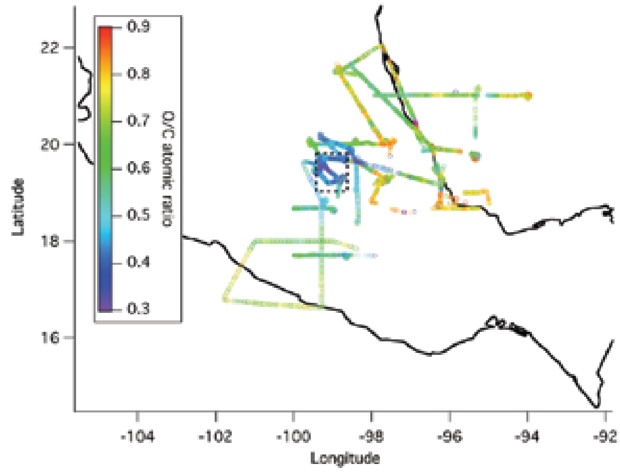
Quantifying Atmospheric Aerosol Sources and Processing from Mexico City to the Arctic

FUNDING: NASA EARTH SCIENCES, NSF ATMOSPHERIC CHEMISTRY, AND THE DEPARTMENT OF ENERGY OFFICE OF BIOLOGICAL AND ENVIRONMENTAL RESEARCH/ ATMOSPHERIC SCIENCE PROGRAM

The Jimenez group at CIRES focuses on the development and application of advanced instrumentation for measurements of atmospheric aerosols. We care about atmospheric aerosols for many reasons, including their effect on radiation balance (climate forcing), severe short-term and long-term effects on human health, reduced visibility, and deposition of acids, toxics, and nutrients to ecosystems and crops. Most of these effects are not well understood, in good part due to limitations of the instrumentation available. Advanced instrumentation can be used to make much faster scientific progress in these areas.

Our group focuses on the development and application of aerosol mass spectrometers, which can determine the size and composition of aerosols in real time. Two field studies have been the focus of much of our work during 2008. The MILAGRO international field study (Megacity Initiative: Local and Global Research Observations) took place in March 2006, with the goal of studying the sources and evolution of aerosols from the Mexico City region. During 2008, we published six journal papers with results from this study. The top figure shows example data, collected in high time resolution as the NSF/NCAR C-130 aircraft flew over and around Mexico City. These data represent the first characterization of the oxidation state of organic species in submicron aerosols. Organic species are less oxidized over the city and more oxidized on the regional air. This finding is consistent with expectations, given the influence of sources of combustion aerosols (such as cars, trucks, and forest fires) around Mexico City. However the degree of oxidation of the aerosol over the city is surprisingly high, as is the rate of increase of oxidation as the air is transported over regional scales. Neither of these features is captured by current aerosol models. We are pursuing further analyses of this rich dataset using factor analysis methods, comparing with state-of-the-art models, and comparing with studies at other locations.

Our group also took part in the 2008 NASA ARCTAS field study (Arctic Research of the Composition of the Troposphere from Aircraft and Satellites), which was conducted under the umbrella of the International Polar Year.



Map of the oxidation state of submicron organic aerosols over central Mexico (dashed square represents the Mexico City region). Data were acquired by the CIRES Aerosol Mass Spectrometer onboard the NSF/NCAR C-130 aircraft. Published in DeCarlo et al. 2008.

Some of the Canadian forest fires whose smoke we sampled extensively during ARCTAS.

During spring and summer, we performed 20 research flights onboard the NASA DC-8 aircraft, focusing on the sources of Arctic haze during the spring, and on boreal forest fires in Northern Canada during the summer. We have presented results from this study at four international conferences (including the American Geophysical Union and European Geosciences Union annual meetings), and we are collaborating with several groups to further analyze the physical and chemical evolution of the haze and smoke and their impact on Arctic and mid-latitude regions.

Craig Jones

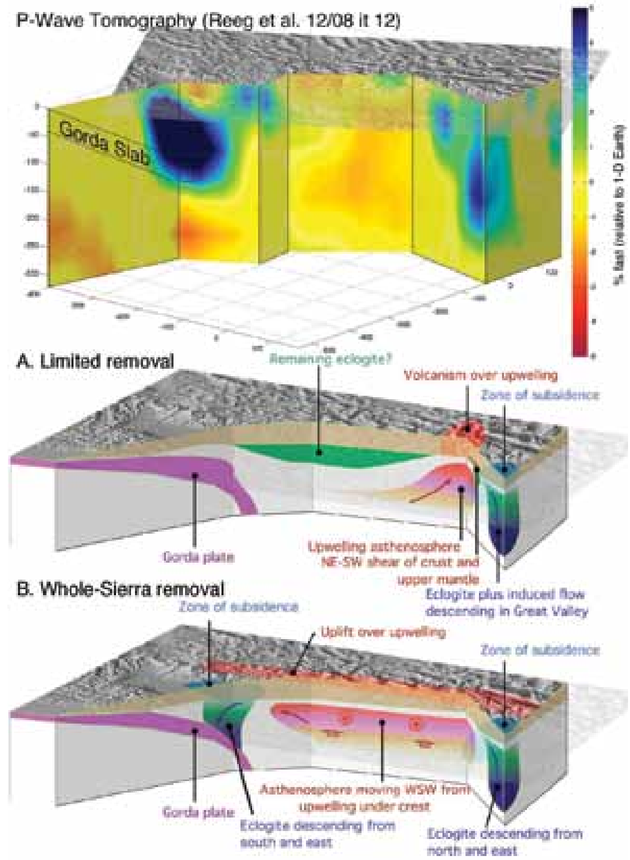
Tectonics of Foundering Lithosphere, Sierra Nevada, California

FUNDING: NSF EARTHSCOPE AND
CONTINENTAL DYNAMICS PROGRAMS

In contrast with oceanic 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. Jones and colleagues at the CU-Boulder and several other universities are analyzing data from the Sierra to understand the dynamics of this process.

Heidi Reeg, a CIRES graduate student, has constructed a tomographic image of the Sierran upper mantle and crust. All project scientists met in November 2008 to discuss early results and to plan on publications. A special issue of *Geosphere* will house many of the papers from this project. CIRES graduate student Will Levandowski has worked from several datasets—tomography, images of the Moho from collaborators at the University of Arizona, surface topography, and recent subsidence—to estimate the density variations required in the mantle.

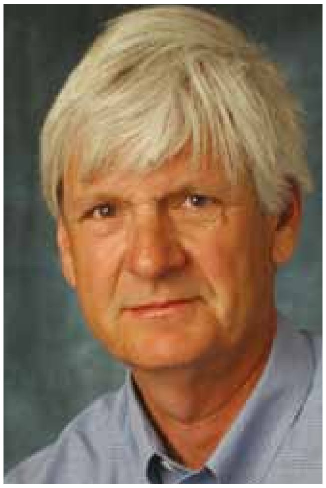
The removal of mantle lithosphere may drive enigmatic deformation in continents, but hypotheses for the impacts of such an event were largely based on theory. Previous geophysical data allowed for two possibilities in the Sierra: that uplift of the range was caused by convective removal of a dense layer at the base of the crust (B in the figure), or that only some of the dense layer was removed from part of the range, leaving explanation for most of the elevation of the Sierra to another cause (A in the figure). Inversion of the arrival times of P-waves from distant earthquakes were used to image variations in seismic wavespeed under the Sierra and much of surrounding California (top panel), revealing elements of both ideas. To the right (south), low-speed material (oranges) appears under the southern Sierra to the northeast of the high wavespeed “drip” under the San Joaquin Valley, consistent with case A. Far to the north, high-wavespeed material with a subducting slab is also tied to shallow high-wavespeed material under the Sierra, suggesting some Sierran material being entrained with the downgoing slab, as in B. (The bulk of the slab does not show up in this section, owing to coverage from available seismometers). The analysis of density variations indicates that the high-wavespeed bodies (in blue) are denser than if the seismic variation was solely due to temperature. This indicates that some or all of the garnet-rich lithologies are still present under the Sierran foothills and in the ‘drip’ seen at the right of the image, indicating that the process is still underway.



Cutaway views of the Sierra Nevada from the west and southwest showing observed variations in P-wave speed and pre-experiment hypotheses for Sierran structure.

William Lewis, Jr.

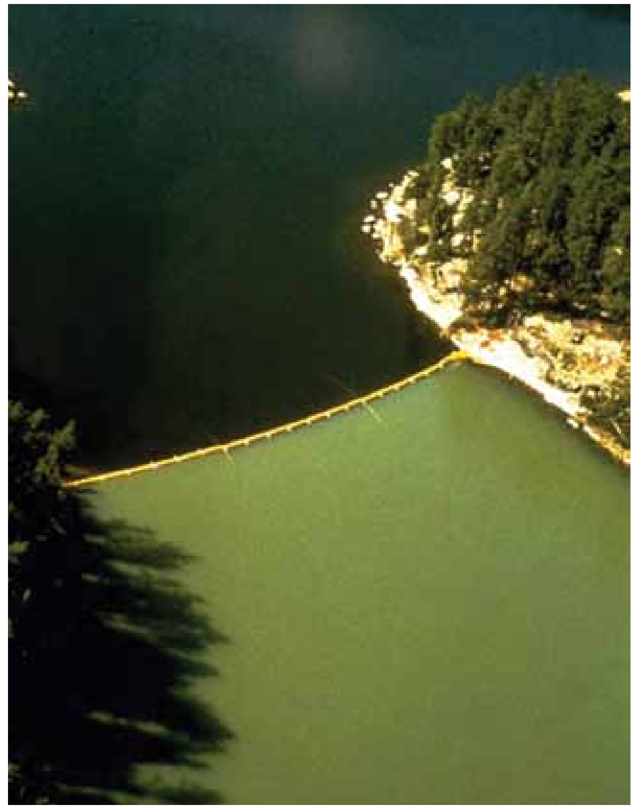
Aquatic Nutrients



Algae provide the organic basis for support of aquatic food webs in marine and inland waters. Algae may grow in suspension (phytoplankton), or they may coat illuminated surfaces (periphyton). The abundance of algae has long been known to vary enormously from one water body to another. It is also well known that the abundance of plant nutrients explains a large amount of the variation in algal abundances worldwide. Waters that contain abundant plant nutrients are designated as eutrophic (e.g., Lake Erie), whereas lakes that contain scarce plant nutrients are designated as oligotrophic (e.g., Lake Superior).

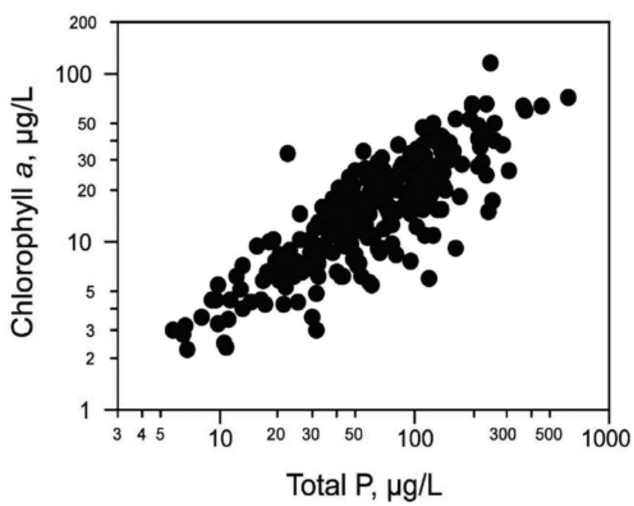
Although any of the 25 elements needed by algae could hypothetically explain variations in abundance of algae, extensive experimental work shows that the only two elements likely to be in such short supply as to cause cessation of growth by algae are phosphorus and nitrogen. During the 1970s, limnologists focused intensively on phosphorus as the key element controlling algal populations. Studies in the Experimental Lakes Area of Canada were particularly influential in substantiating the key role of phosphorus and seemed to show that nitrogen is much less important than phosphorus. Since the 1970s, much new information of great geographic breadth has accumulated on nutrient limitation as determined experimentally. This evidence indicates strongly that nitrogen is at least as often limiting to algal growth as phosphorus, rather than being secondary as earlier supposed. In a recent review, Lewis and Wurtsbaugh (2008) argued that the phosphorus paradigm for control of algal growth must be supplanted by a new paradigm involving dual limiting nutrients: nitrogen and phosphorus.

The proposal that nitrogen is at least as important as phosphorus in limiting algal growth in inland waters is meeting with great resistance in some corners, but it also is being endorsed by some limnologists. The mechanisms of nutrient limitation for algae have great practical importance in preserving the quality of inland waters. To be realistic, limnologists will need to revise their prescriptions for nutrient control to include nitrogen as well as phosphorus.



CANADIAN EXPERIMENTAL LAKES AREA

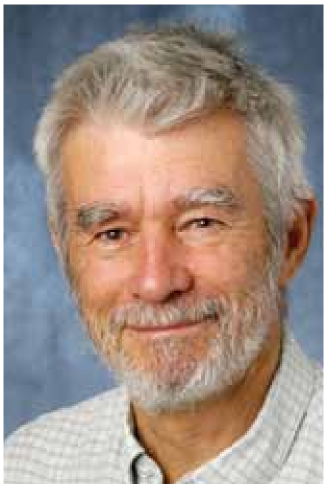
A lake divided, with natural (low nutrient conditions) above, and fertilization with nitrogen and phosphorus below.



Simulation showing that the correlation between phosphorus (P) and chlorophyll a (which indicates algal biomass) is a tautology rather than an indicator of casual relationship because both P and chlorophyll are mandatory components of algal biomass. The simulation is for lakes controlled by nitrogen rather than phosphorus (Lewis and Wurtsbaugh 2008).

Peter Molnar

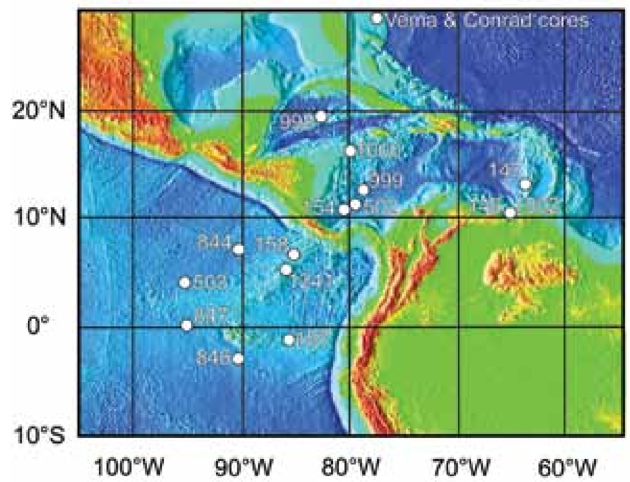
The Closing of the Central America Seaway and the Ice Ages?



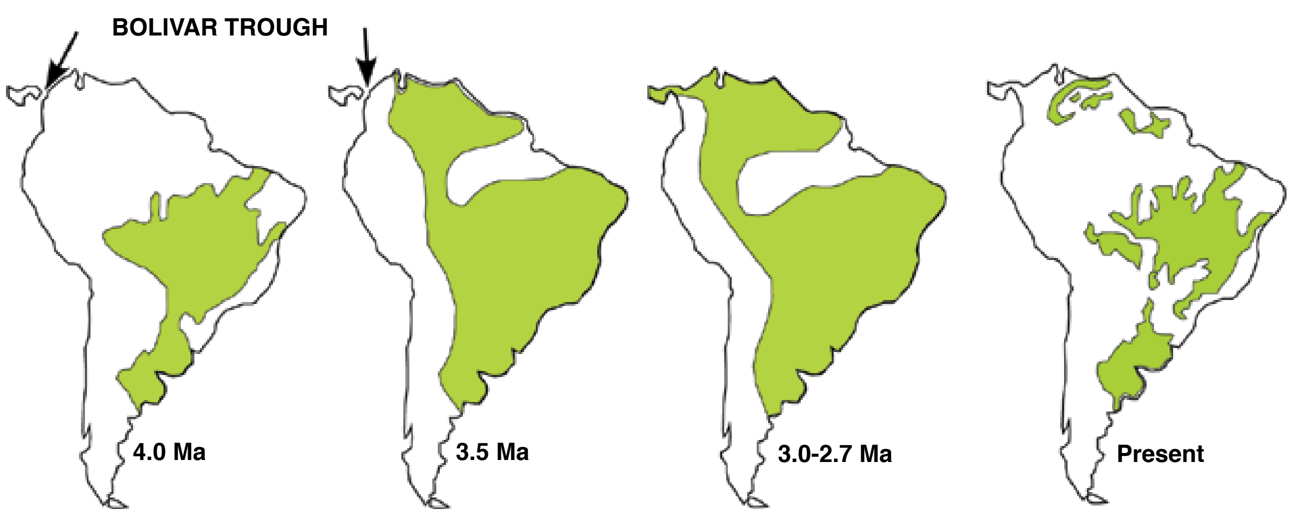
Peter Molnar devoted a part of his research effort in 2008 to synthesizing evidence commonly used to infer that the closing of the Central American Seaway altered Atlantic Ocean circulation and stimulated the change from warm mid- and high-latitude climates to ones characterized by recurring ice ages (Molnar 2008).

This review considered the geologic history of Central America; paleoceanographic data, both globally and from the region near Central America (map); paleontological data from both the land and littoral environments of Central America; and general circulation model calculations of ocean circulation with different configurations of the Central American Seaway. The most compelling evidence for a role of this closing comes from its concurrence with the first ice age. In fact, the tightest constraint on when the Isthmus of Panama formed comes from the Great American Exchange at about 2.6 Ma, not only when mammals of South America suddenly crossed into North America, and vice versa, but also when the first large ice sheet covered Canada and part of the United States (and sea level dropped tens of meters to perhaps 100 m). As vertebrate paleontologists (e.g., L.G. Marshall and S.D. Webb) have recognized for 30 years, however, those animals, which commonly inhabit savannas, could not possibly cross the rain forests and swamps of Panama today. As the tropics became arid during ice ages (figure below), one of the strongest arguments relating the closing of the Central American Seaway to climate change becomes inverted: climate change, with ice sheets, not only lowered sea level and facilitated a land-bridge, but it also created arid tropical climates that allowed the Great American Exchange of savanna-inhabiting animals to take place.

This suggests that the permanent Pre-Ice-Age El Niño state may owe its existence to the emergence of the islands in the Maritime Continent.



Map of the eastern equatorial Pacific, Central America, the Caribbean region, and northern South America showing locations of drill sites from which much of the paleoceanographic data has been obtained.

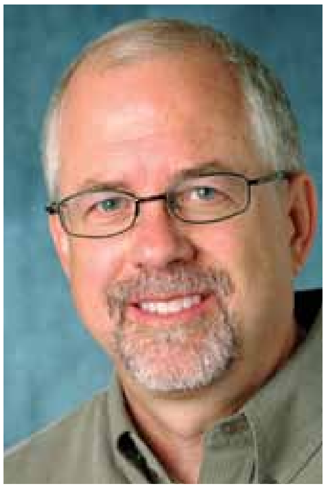


Maps of South America showing suggested regions of savanna-grasslands in green shading (redrawn from maps in Marshall 1985).

Russell Monson

Carbon Sequestration in a Front Range Forest

FUNDING: DOE, NSF



For the past 10 years, we have been monitoring the exchange of carbon dioxide from the top of a 27-m tower at the Niwot Ridge AmeriFlux site, near the C-1 NOAA site. Our aims are to understand the principal controls over, and magnitude of, the exchange of carbon dioxide from the trees and soils of the ecosystem, as well as their response to interannual climate variation. Our site is one of more than 200 worldwide that function in an integrated network known as Fluxnet, which aims to provide fundamental insight and data to modelers using regional and global carbon budgets, particularly in response to future climate change.

We have focused on the question of how this mountain forest ecosystem responds to an acceleration of the onset of spring. In this forest, the transition from winter to spring has occurred two to three weeks earlier, on average, during the past five decades, compared with 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.

In previous years we had shown that earlier spring warming causes this mountain ecosystem to absorb less carbon from the atmosphere. During this past year we discovered the cause for this effect. We used the stable isotope signals in winter snow versus summer rain to show that the trees of this forest rely on snowmelt water to drive their photosynthetic productivity well into autumn. Summer rain water was less effective in supporting carbon uptake, probably due to its failure to penetrate deeply into the soil. During years with earlier spring warming, the trees have access to less snowmelt water and thus less support for photosynthesis. Given the widespread distribution of mountain forests in the western United States, their dominant role in sequestering atmospheric carbon in this part of the country, and the persistent decadal-scale drought that has occupied the West for the past several years, we can expect the terrestrial carbon sink in the western United States to continue to weaken in the face of future climate warming.

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

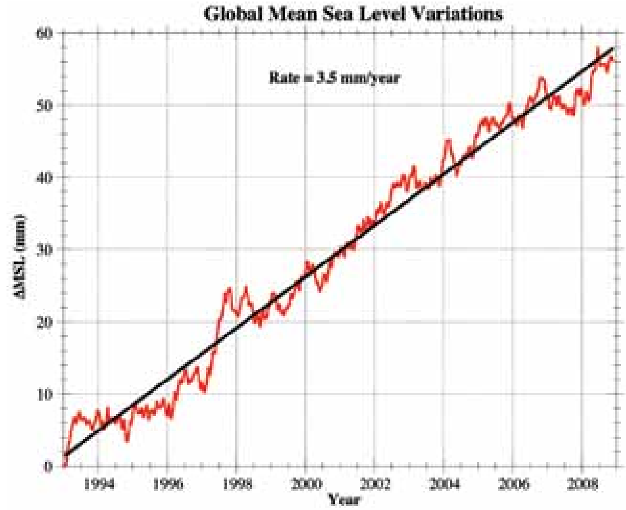
Steven Nerem

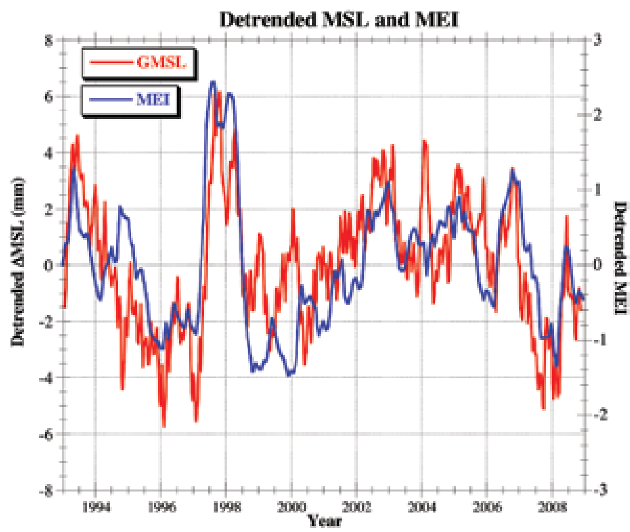
Satellite Observations of Present Day Sea-Level Change

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

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

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





The 2007 anomaly in global mean sea level appears to be related to the extended La Niña that was ongoing, as opposed to a change in the Earth's response to climate change.

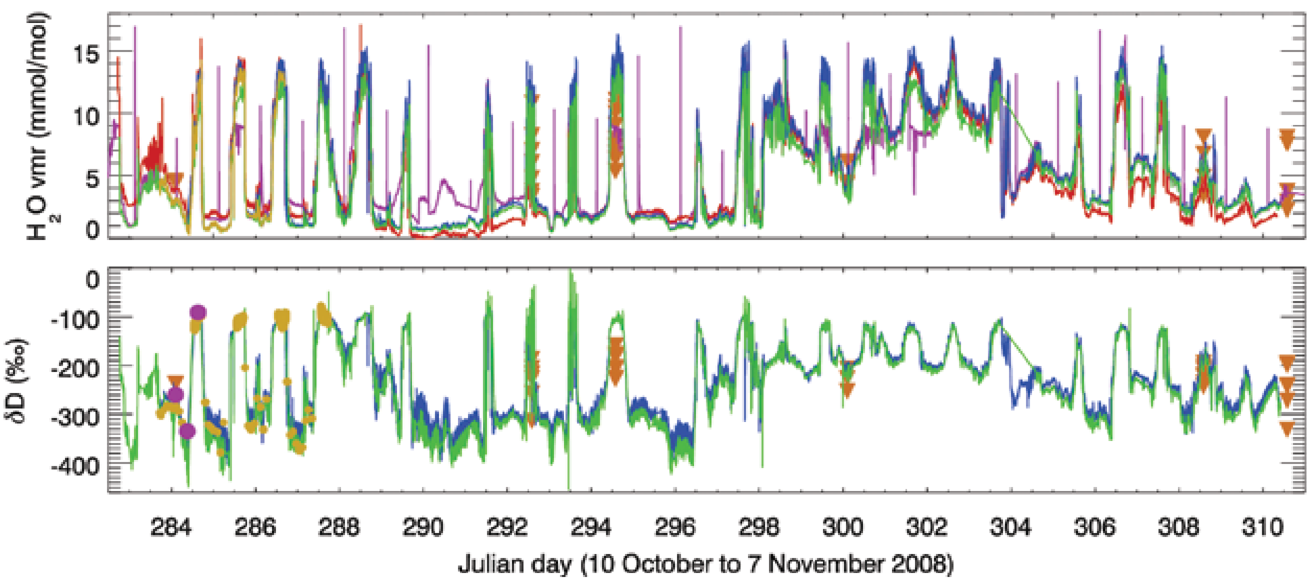
As shown in the figures, sea level did not rise quite as fast in 2007 and early 2008 as in previous years. While much was made of this temporary "slowing" of sea-level rise, sea-level change returned to the decade-long trend by the end of 2008. As the bottom figure shows, there are large interannual variations in global mean sea-level change that appear to be correlated with El Niño-Southern Oscillation. The 2007 anomaly appears to be related to the extended La Niña that was ongoing at that time, as opposed to a change in the Earth's response to climate change. As a result, we do not believe the recent "slowing" should be viewed as a significant change in the Earth's response to climate change.

David Noone

Monitoring the Hydrological Cycle with Water Isotopes at Mauna Loa

Water vapor is by far the most abundant greenhouse gas in the atmosphere, and the changing distribution of water in the atmosphere has significant implications for water resources as climate changes. Our ability to accurately evaluate and predict changes in climate is limited by our understanding of the movement of water vapor and characteristics of clouds. Measurements of the isotopic composition of water are useful for understanding the water cycle because the abundance of heavy isotopologues (HDO and $H_2{}^{18}O$) relative to normal water ($H_2{}^{16}O$) changes during evaporation and condensation. Lighter H_2O molecules preferentially evaporate, heavier HDO and $H_2{}^{18}O$ molecules preferentially condense, and lighter molecules diffuse faster than the heavier ones. As such, measurements of the isotopic composition of water vapor allow assessment of hydrological processes relevant to climate change. Because water is so important in the climate system, knowledge of the isotopic composition of water vapor can build understanding of factors controlling the water and energy balance of the atmosphere, inform development of improved climate models, and guide new studies of clouds and the atmospheric hydrology.

We made continuous measurements of H_2O, $H_2{}^{18}O$ and HDO at the NOAA Mauna Loa Observatory for four weeks in October 2008, using three laser-based spectroscopic analyzers. The figure below shows that at Mauna Loa, isotopic composition data capture the dramatic diurnal transition between air influenced by the marine boundary layer during day and free troposphere air at night. Closer examination shows that this transition is almost reversible, yet the isotopic signature of clouds is evident and suggests cloud processes play a role in the energy budget that maintains the regional marine boundary layer. The very dry and isotopically depleted free-troposphere air indicates that the humidity is set though ice cloud processes either in the mid latitudes or in the upper troposphere within the Inter-Tropical Convergence Zone. Moistening of the troposphere near Mauna Loa occurs in association with detrainment from warm convection, as is exemplified by an "atmospheric river" event that was observed during our experiment. This work establishes that isotopic vapor analyzers are capable of monitoring the isotopic composition at NOAA baseline stations, that the calibrated measurements are of remarkably high precision, and that the data can be used to establish new understanding of the atmospheric water cycle.

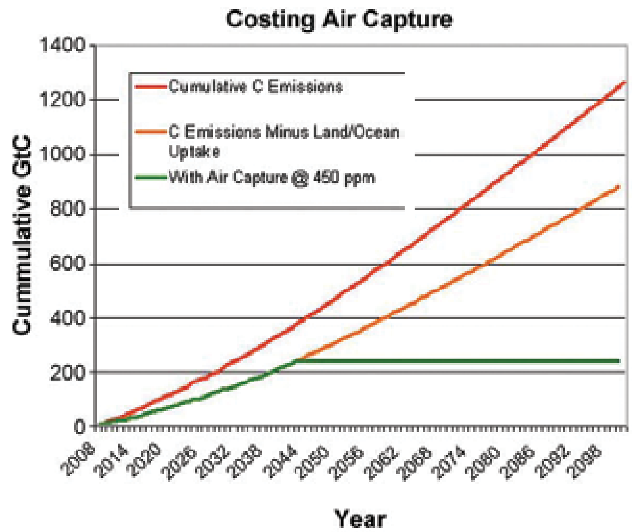


Time series of water vapor volume mixing ratio (upper) and isotopic δD of water vapor (lower) at Mauna Loa from 10 October to 6 November 2008. Observations were made by different instruments and include the station's meteorological dew point hygrometer (magenta), a Licor 7000 infrared gas analyzer (red), an LGR water vapor isotope analyzer (blue), a Picarro isotopic water vapor analyzer (green), the Jet Propulsion Laboratory's Tropospheric Water Instrument (orange circles), TES satellite infrared spectrometer (orange triangles), and three flasks (magenta circles).

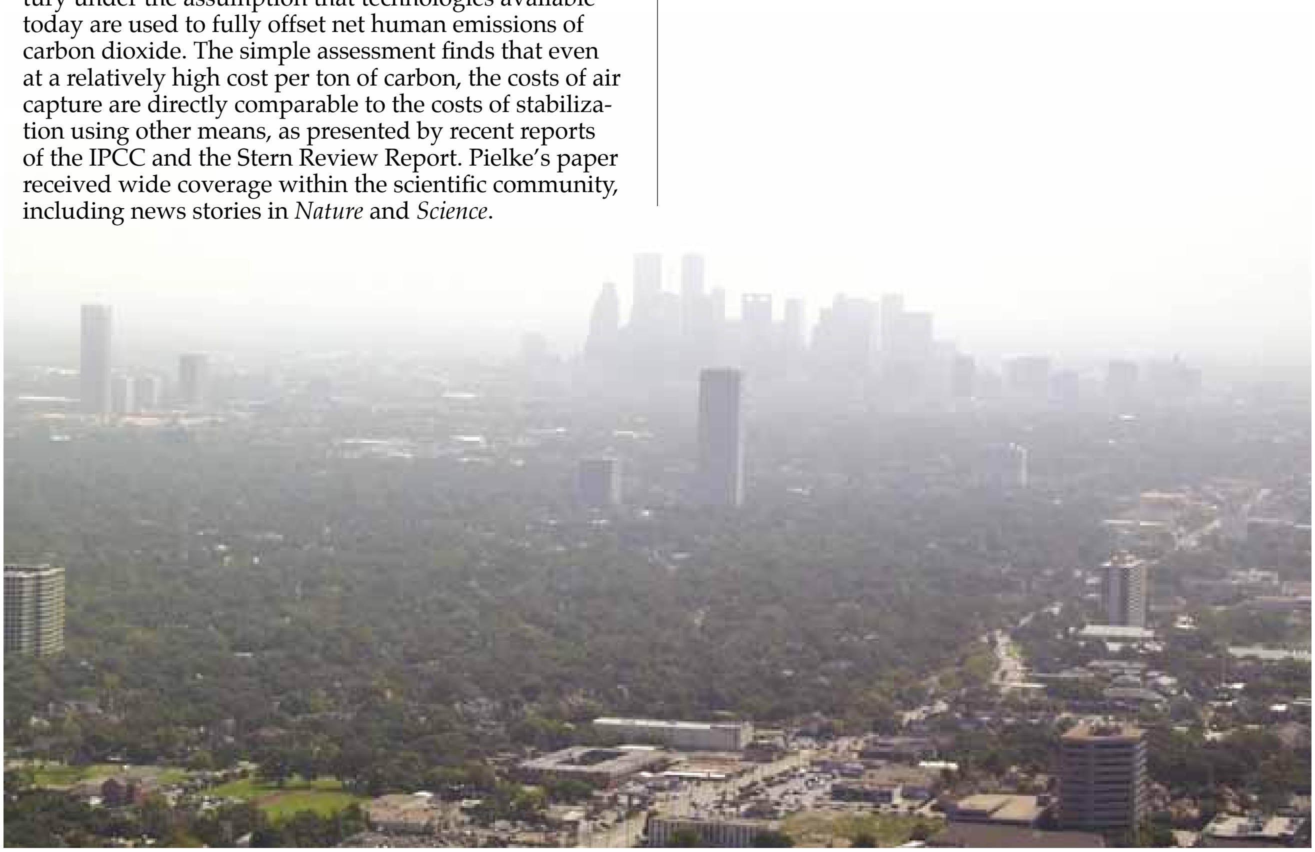
Roger Pielke, Jr.

An Idealized Assessment of the Economics of Air Capture of Carbon Dioxide in Mitigation Policy

In a paper published online 11 February 2009 in *Environmental Science & Policy*, and then in the May issue of the journal, Roger Pielke, Jr. argues that the technology of direct capture of carbon dioxide from the atmosphere—air capture—is something that cannot be ignored. The paper develops a simple arithmetic description of the magnitude of the challenge of stabilizing atmospheric concentrations of carbon dioxide as a cumulative allocation during the 21st century. This approach, consistent with and based on the work of the Intergovernmental Panel on Climate Change (IPCC), sets the stage for an analysis of the average costs of air capture during the 21st century under the assumption that technologies available today are used to fully offset net human emissions of carbon dioxide. The simple assessment finds that even at a relatively high cost per ton of carbon, the costs of air capture are directly comparable to the costs of stabilization using other means, as presented by recent reports of the IPCC and the Stern Review Report. Pielke's paper received wide coverage within the scientific community, including news stories in *Nature* and *Science*.



The cumulative cost of air capture calculated as the difference between the orange and green curves at a point in time multiplied by the cost per ton of carbon of air capture. The green curve reflects full offsetting of net human emissions of carbon dioxide begining in 2043.



Balaji Rajagopalan

Water Supply Risk on the Colorado River: Can Management Mitigate?

FUNDING: NOAA/CIRES-WWA, NCAR VISITING FELLOWSHIP

Tropical weather and climate have a major impact on global weather and climate. In particular, the quasi-periodic Madden-Julian Oscillation (MJO) with dominant power in the 30- to 70-day period band, and the El Niño-Southern Oscillation (ENSO) with dominant power in the 2- to 7-yr period band, have been shown to exert important influences around the globe. Yet these phenomena are poorly represented in state-of-the-art numerical weather and climate models. It is widely thought that the difficulty arises partly from an inadequate treatment of air-sea coupling in MJO dynamics, which not only causes errors in the MJO, but then also leads, through a distorted "MJO-ENSO connection," to errors in ENSO.

In a recently published study, we investigated the effect of air-sea coupling on tropical climate variability in a coupled Linear Inverse Model (LIM) derived from observed fluctuation-dissipation relationships between the tropical atmospheric circulation and sea-surface temperature (SST) variations. Specifically, we used the simultaneous and 1-week lag correlations of the system variables to construct the model. We first demonstrated that the model successfully captures the power spectra of these variables (see figure below). We then investigated the importance of air-sea coupling on the MJO and ENSO dynamics by shutting off the appropriate interaction terms in the model's time evolution operator. Our conclusion was surprisingly clear: air-sea coupling has a very small effect on the MJO, but a profound effect on ENSO. In other words, ENSO is a strongly coupled phenomenon, whereas the MJO is an almost uncoupled, "internal atmospheric" phenomenon. Consistent with this, the eigenvectors of the system's dynamical evolution operator also cleanly separate out into two distinct but nonorthogonal subspaces: one governing the nearly uncoupled MJO dynamics, and the other governing the strongly coupled ENSO dynamics.

An important implication of such a remarkably clean separation of the uncoupled and coupled tropical dynamics is that erroneous air-sea coupling in general circulation models may cause substantial errors in ENSO simulations and predictions, but not in MJO simulations and predictions. It also suggests that the "MJO-ENSO connection" often claimed to be important in ENSO dynamics is largely illusory, in that the same initial perturbation that sets off an ENSO event also tends to set off an MJO event, but without any direct interaction between them. This is a classic example of an observed correlation (here, between the MJO and ENSO) not implying causation, or even interaction.

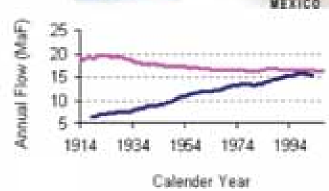


Figure 1: *Colorado River Basin including major dams. Inset shows a nine-year moving average water demand and losses (purple) and supply (pink).*

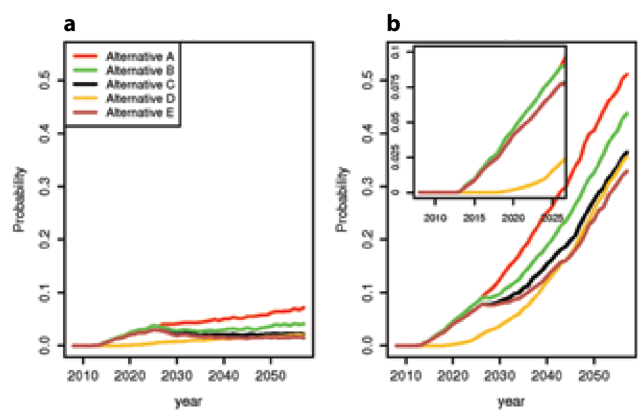


Figure 2: *a) Risk of drying for five management alternatives under assumptions of no climate change-induced average flow reduction. b) Same as a), but from natural climate variability and a superimposed 20-percent reduction in the annual average inflow during 50 years. Inset shows the risk in the near term for the period 2008-2026.*

Prashant Sardeshmukh

Using Observed Fluctuation-Dissipation Relationships to Understand Multi-Scale Climate Interactions in Tropical Regions

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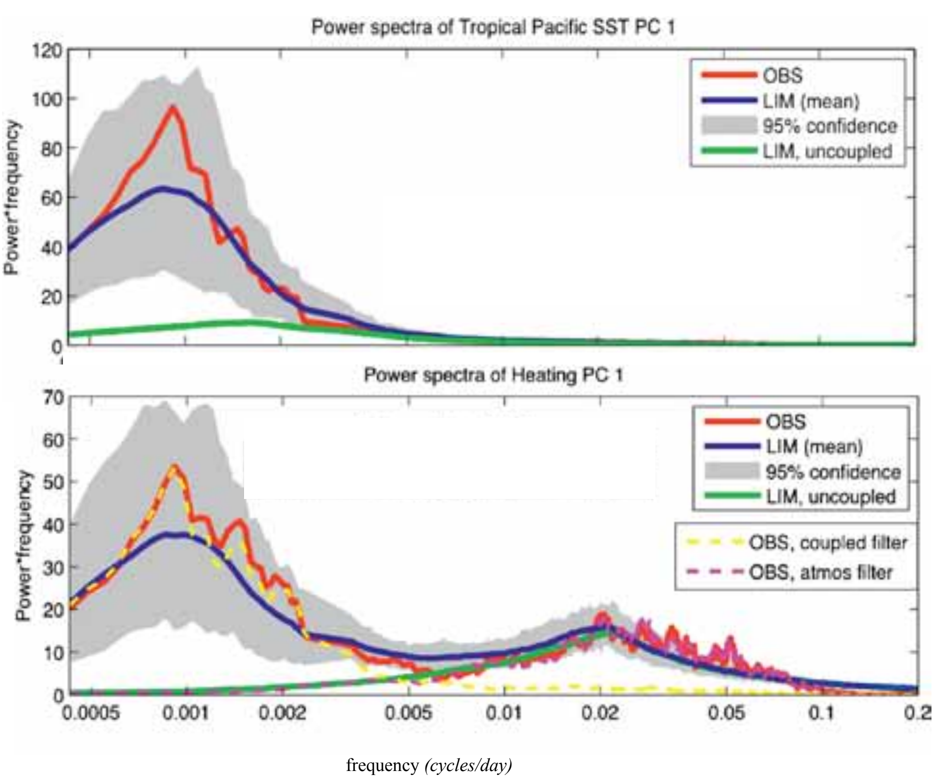


Observed power spectrum (red curves) of the amplitude of the dominant pattern of tropical SST (upper panel) and atmospheric diabatic heating (lower panel) variability based on data for 1982-2005. Enhanced power at ENSO periods in the SST spectrum, and at ENSO and MJO periods in the diabatic heating spectrum, are clearly evident. The dark blue curves show the corresponding spectra given by the Linear Inverse Model (LIM), with 95% confidence intervals shaded gray. The green curves show the spectra obtained when air-sea coupling is disabled in the LIM. Note how the power on ENSO time scales is greatly diminished, but the power on MJO time scales is almost unaffected by the decoupling. As further corroboration of this point, the dashed yellow and purple curves in the lower panel show the spectra obtained by projecting the observed data only the coupled and uncoupled eigenmodes, respectively, of the LIM's evolution operator. (from Newman et al. (2009), J. Clim., doi: 10.1175/2008JCLI2659.1.

Mark Serreze

with Julienne Stroeve, Andrew Barrett , David Kindig, and Andrew Slater

Environmental Impacts of a Shrinking Arctic Sea Ice Cover

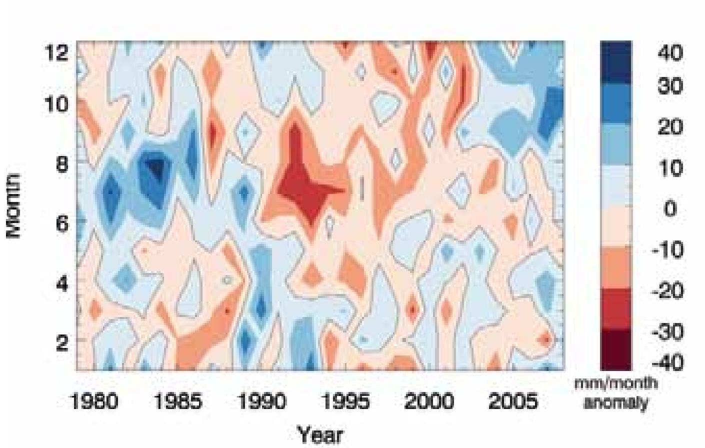
Arctic sea ice extent is declining in all months, but is strongest at the end of the melt season in September. The September trend during the satellite record (1979-present) stands at 11.8 percent per decade. Compared with conditions in the 1970s, September ice extent has retreated by 40 percent. September 2007 and 2008, respectively, saw the lowest and second lowest ice extent ever recorded.

The trend reflects responses to both natural climate variability, including changes in the circulation of the atmosphere and ocean, and a general warming trend consistent with rising concentrations of atmospheric greenhouse gases. As exampled by the extreme September sea ice minima of 2007 and 2008, positive feedbacks that act to accelerate melt are gaining strength. It is quite possible that we will lose the summer sea ice cover by the year 2030.

While much remains to be learned about the relative roles of different ice loss mechanisms, attention by our group has increasingly turned to the environmental impacts of a shrinking ice cover. For most of the year, the ice cover insulates a cold Arctic atmosphere from the underlying and much warmer Arctic Ocean. With less sea ice, there is less insulation, meaning that heat from the ocean escapes to warm a considerable depth of the atmosphere. Evaporation from open water in turn moistens the atmosphere. These process, which will be most pronounced in autumn and winter, will affect vertical temperature gradients and cloud conditions in the Arctic atmosphere, and the temperature difference between the Arctic and lower latitudes. As the ice cover continues to shrink, we should start to see resulting influences on patterns of atmospheric circulation and precipitation both within and beyond the Arctic. Our group is looking at this problem from observational and modeling perspectives.

Strong warming over the Arctic Ocean linked to declining sea ice extent is already well underway. Data from the Japanese Meteorological Agency's next-generation atmospheric reanalysis (JRA-25) shows above-average precipitation over the Arctic for about the past five years during autumn and winter. Is this simply an expression of natural climate variability, or are we starting to see influence of declining sea ice extent? Experiments with a regional climate model initiated in 2008 will help to answer this question.

Anomalies in monthly precipitation for the region north of 60˚N by year (x axis) and month (y axis) from 1979 through 2008, based on data from the Japanese Meteorological Agency's JRA-25 reanalysis.



Anne Sheehan

New Zealand Ocean Bottom Seismology Project

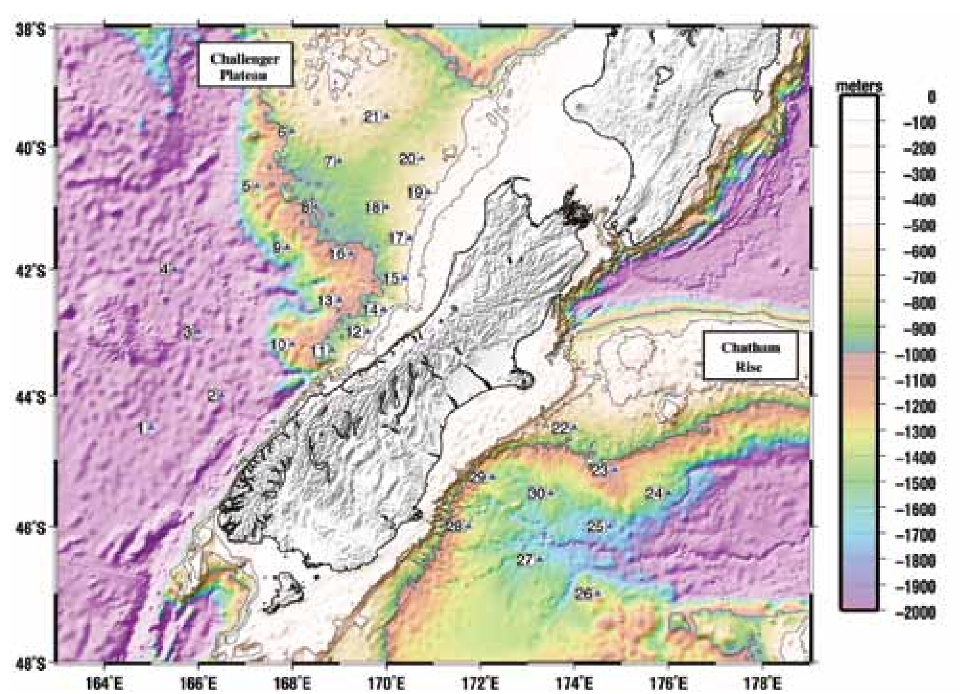
FUNDING: NSF CONTINENTAL DYNAMICS PROGRAM

In February 2009, CIRES Fellows Anne Sheehan and Peter Molnar joined a team from the Massachusetts Institute of Technology, Woods Hole Oceanographic Institution, and the Scripps Institution of Oceanography, to deploy 30 ocean-bottom seismometers off the east and west coasts of New Zealand. The goal of the project was to map out seismic structure, particularly anisotropy, of the crust and upper mantle on both sides of the Alpine Fault. The Alpine Fault is a major strike-slip fault and transform plate boundary in New Zealand. This study of the Alpine Fault will provide information for better understanding other plate boundary transform faults, such as the San Andreas Fault of California. Two end member models will be tested through this experiment. One model suggests that major faults, like the San Andreas, pass directly through the crust and through the mantle lithosphere as narrow shear zones, so that the adjacent lithosphere hardly deforms. In the other, the faults spread into wide shear zones in the lower crust, and the mantle lithosphere deforms over a broad zone hundreds of kilometers wide. The principal mineral of the upper mantle is olivine. As polycrystalline olivine deforms, individual crystals align so that the aggregate of crystals becomes anisotropic (different properties in different directions). Thus anisotropy can be used to map out patterns of deformation in the mantle, and test the models for plate boundary deformation described above.

The team was accompanied by Boulder, CO middle school science teacher Dan Tomlin, who blogged about his experience at sea for his class back in Boulder and other interested individuals. Tomlin teaches about plate tectonics, earthquakes, seismometers, and seismographs in his classroom, and on the cruise, he was able to see real seismometers and how they are used. He witnessed decisions being made by the scientists around instrument placement and data gathering, and appreciated the dynamic nature of science.

COURTESY OF ANNE SHEEHAN

Seismometers were deployed off the coast of New Zealand to map the seismic structure of the crust and upper mantle of the Alpine Fault.



Locations of ocean bottom seismometers (blue triangles) deployed in Jan-Feb 2009.

COURTESY OF JOHN COLLINS

Robert Sievers

CIRES Scientists Developing New Inhalable Aerosol Vaccines

FUNDING: AKTIV-DRY LLC

Colorado Governor Bill Ritter awarded the Global Health Group of CIRES (led by Robert Sievers and Stephen Cape with the participation of CIRES graduate students, David McAdams, Jessica Burger, and J'aime Manion) the 2009 Colorado Research Impact Award in Public Health for the group's research and development of inhalable aerosol vaccines.

Sievers was also chosen to receive an Astellas Foundation Prize from the American Chemical Society. An undergraduate student in the Sievers laboratory, Lowell Nicholson, wrote an honors thesis on inhalable capreomycin, a tuberculosis antibiotic, and won summa cum laude graduation.

The focus of our Gates Grand Challenges in Global Health project is to develop needle-free vaccine delivery systems. 1) Our team has reformulated the injectable Edmonston-Zagreb live attenuated measles virus vaccine, replacing sorbitol with myo-inositol. Our patented CAN-BD® process was used to produce micronized measles vaccine dry powder with residual moisture levels of 0.3-1.3 percent. The dry powder vaccine is stable for at least 1 year at 2-8°C and shows less than 1 log loss of virus infectivity at 37°C for seven days. 2) We have demonstrated that inhaled myo-inositol powders are non-toxic in a toxicology study in Sprague-Dawley rats. 3) Our team has developed two simple, low-cost active dry powder inhalers (DPIs) with performances virtually equivalent to an FDA-approved active inhaler. 4) In two established measles vaccine animal models, cotton rats and rhesus macaques, our active DPI's delivered aerosolized measles vaccine dry powder by at-liberty breathing.

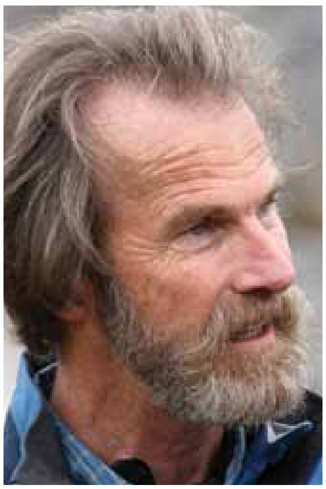
The microparticles rapidly dissolve and the virus replicates in the aqueous film in respiratory tracts, so no water for injection is needed. The dry powders are individually sealed in peelable blister packs or rupturable capsules to minimize bacterial contamination encountered in multi-dose vials. Delivery of the powder to the lungs, followed by viral replication, was confirmed by reverse transcription polymerase chain reaction. A measles-specific immune response was also demonstrated. In macaques, our vaccine formulation induced high avidity, neutralizing antibodies and T-cell responses equal to or better than that seen with injected liquid vaccine. Measles vaccine dry powders in unit dose packaging have the potential to effectively vaccinate infants, children, and adults by inhalation, avoiding many of the problems associated with liquid vaccines delivered by injection. This work is supported in part by the Foundation for the National Institutes of Health.

Konrad Steffen

with Eric Rignot (University of California, Irvine and NASA Jet Propulsion Laboratory), and Dan McGrath (CIRES)

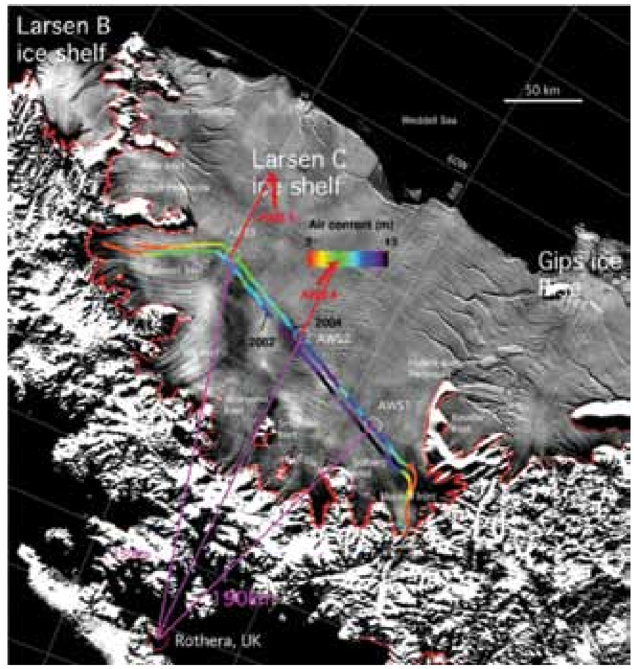
Stability of Larsen C Ice Shelf in a Warming Climate

FUNDING: NSF ANTARCTIC SERVICES,
LOGISTIC SUPPORT FROM BRITISH ANTARCTIC SURVEY



Significant glaciological and ecological changes are taking place in the Antarctic Peninsula in response to climate warming that is proceeding at six times the global average rate. Following the collapse of Larsen A ice shelf in 1995 and Larsen B in 2002, the outlet glaciers that nourished them with land ice accelerated massively, losing a disproportionate amount of ice to the ocean. Further south, the much larger Larsen C ice shelf is thinning, and measurements collected during more than a decade suggest that it is doomed to break up. We initiated a field experiment with partners from Chile, the Netherlands, and the United Kingdom to determine the state of health and stability of Larsen C ice shelf in response to climate change. We collected new measurements in the fall of 2008 to assess what physical processes are controlling the weakening of the ice shelf and whether a breakup is likely, using instrument towers to provide baseline data on climate and ice motion to quantify the consequences of a breakup.

Field activities included the collection of data from global positioning system, automatic weather stations, and ground-penetrating radar, as well as the extraction of shallow firn cores. These data are currently being analyzed to determine the dynamic response of the ice shelf to oceanic tides, iceberg calving, ice-front retreat, and ice-shelf rifting to weather conditions on the ice shelf. This effort complements an analysis of remote-sensing data (including from satellites InSAR, ICESat, and MODIS), ice-shelf numerical models and control methods as an umbrella research project during the International Polar Year (IPY).



MODS satellite mosaic of Larsen ice shelves (T. Scambos et al., NSIDC) with British research station Rothera and the 3 installed automatic weather stations AWS1-3, (190 to 230 km from Rothera), 2 AWS from our collaborators, along the NASA/CECS 2002 aircraft flight lines. The mosaic emphasizes the contributions of various inlets to the formation of Larsen C. Grounding lines (red) are from ERS-1/2 1996 InSAR at two different tides/epochs.

The overall objectives of this work are to better characterize the state of health and stability of Larsen C ice shelf in response to climate warming, assess its potential for breakup, and assess the consequences this breakup may have on sea level. In the context of IPY, an important objective is to educate the broader public about the nature of the changes taking place in this part of Antarctica, and why they matter to all of us.

This program supports graduate students from CU-Boulder, postdocs from the University of California, Irvine, and graduate students from the Centro de Estudios Científicos in Valdivia, Chile. Additional field seasons are planned for 2009 and 2010, and a follow-on project with the collaborators from Chile and the United Kingdom is in the works.

British research station Rothera.
KONRAD STEFFEN

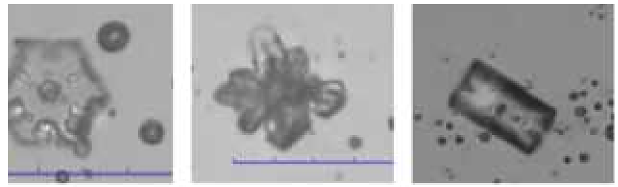
Margaret Tolbert

Laboratory Studies of Clouds and Aerosols

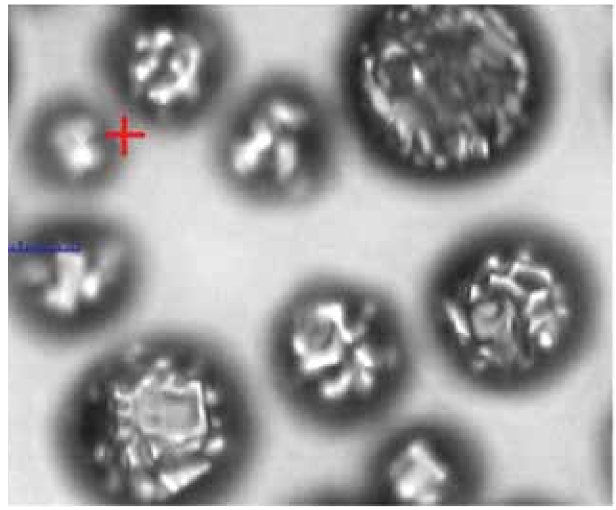
Cirrus clouds, composed of water ice, cover up to 30 percent of the Earth's surface at any time, and subvisible cirrus are almost always present in parts of the tropics. Depending on meteorological conditions, the appearance of cirrus clouds ranges from wide sheets 100-1000 km in length from the outflow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

Cirrus and subvisible cirrus clouds play an important role in the climate system as well as in 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 overall climatic impact. Microphysical properties, in turn, depend on the nucleation mechanism of ice in the atmosphere. Laboratory studies in the Tolbert research group are examining ice nucleation on a wide range of possible atmospheric aerosols including organics, minerals, sulfates, and combinations of these species.

To study ice nucleation, we use a combination of optical and Raman microscopy. Using an environmental cell, we expose aerosols to increasing relative humidity at low temperature and detect ice nucleation using optical microscopy. We then evaporate the ice and use Raman spectroscopy to identify the chemical nature of the particles that nucleated ice. In this way, we can identify the species most likely to nucleate ice, and also determine the atmospheric conditions necessary for ice nucleation. In our experiments, we can probe heterogeneous ice nucleation on solid substrates as well as homogeneous ice nucleation within a droplet. Sample ice habits formed in each case are shown above. It can be seen that heterogeneous ice nucleation is selective, with one special particle nucleating ice, while homogeneous nucleation results in all particles crystallizing at approximately the same time.



Ice habits for heterogeneous ice nucleation, above, and homogeneous ice nucleation, below, as observed using optical microscopy.



Research in the Tolbert group is also probing the hygroscopic growth of particles to sizes that can directly impact climate. This work is done using cavity ring-down aerosol extinction spectroscopy. Other researchers in the group are focused on understanding clouds and aerosols on Titan and early Earth. Titan, with its nitrogen and methane atmosphere, is thought to be a model for Earth early in its history. On Titan, an organic haze completely shrouds the moon and has a major anti-greenhouse effect. In the laboratory, we use aerosol mass spectrometry to compare simulated Titan and early Earth hazes, and probe the possible climate effect of such a haze on early Earth. Complementary research on Mars is also underway in the Tolbert group. Here we are investigating the mysterious observations of methane variability on Mars, and trying to understand if heterogeneous processes on the surface of the planet could be responsible for the observations.

Cirrus clouds over Boulder, CO.
Courtesy of Mark Zondlo

Greg Tucker

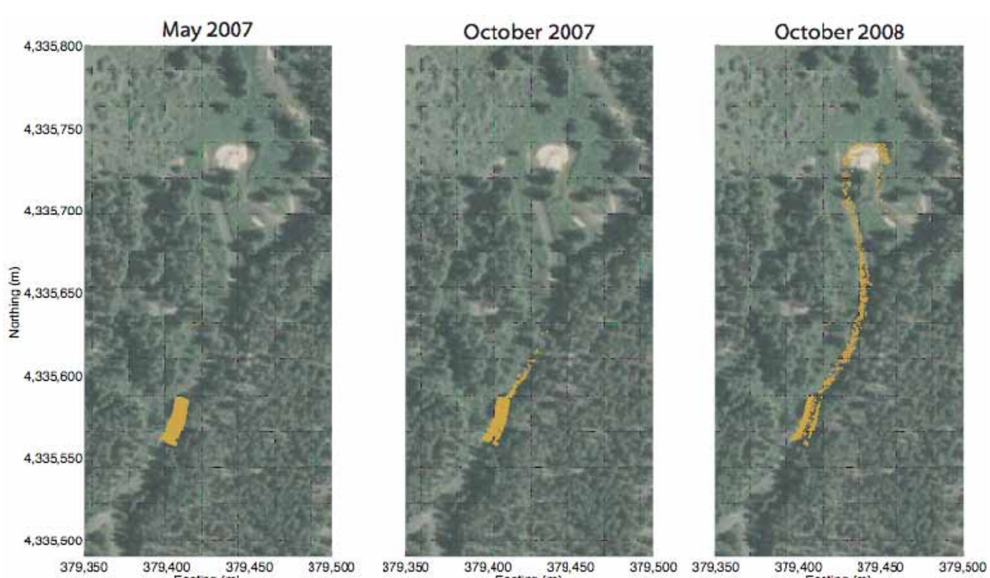
Quantifying Sediment Transport and Dispersion in River Networks

FUNDING: U.S. ARMY RESEARCH OFFICE,
CIRES INNOVATIVE RESEARCH PROGRAM

As mountains wear away, they generate vast quantities of sediment that are washed downstream through river networks. The economic impacts of erosion and sedimentation are enormous, and their impact on the rock cycle is no less important. Sediments sometimes carry with them undesirable contaminants, as in the case of plutonium-laden sands left over from mining. There are many good reasons why a quantitative, mechanistic theory of sediment transport and dispersion is essential. Yet traditional theories of sediment transport have been largely based on determining bulk mass fluxes, and are incapable of predicting the speed or dispersion characteristics of a sediment "plume."

To address this deficiency, we are studying random-walk models of sediment dynamics. Experiments with numerical particle-tracking models reveal that the expected dispersion characteristics depend critically on the statistics of grain motion. When the probability distributions of grain hop length and resting time are thin-tailed, the resulting dispersion behavior—the pattern of spread as a body of sediment moves downstream—is Fickian, and obeys all the standard and well-known rules of diffusion. However, when either the hop-length or resting-time distribution is heavy-tailed, the dispersion pattern does not follow the conventional diffusion law. Instead, the dynamics fall into a fascinating category of processes known as "anomalous dispersion," which has been observed in systems as disparate as charge transfer in semi-conductors and contaminant transport in groundwater.

To test random-walk models of sediment transport, we have turned to four sources of data. The first is a classical field experiment on radioactive sand dispersion conducted by the U.S. Geological Survey in the 1960s. Re-analysis of the experimental data reveals that the leading edge of the sand plume spreads farther and faster than predicted by standard diffusion theory. The pattern is, however, well matched by a heavy-tailed (Lévy) dispersion of grain velocities. Thus, the experimental data provide intriguing evidence for anomalous dispersion in a sand-bed river. The second data source is a new field experiment in gravel transport, made possible by a CIRES Innovative Research Program grant. By embedding passive integrated radio transponder tags in rocks, we have been able to follow the motion of a population of about 900 individual clasts in response to two (soon to be three) annual snowmelt floods along Halfmoon Creek, a tributary to the Arkansas River near Leadville, CO. The data reveal a surprisingly broad distribution of transport distances (see Figure). The third data source is a laboratory experiment on gravel dispersion, which was conducted in a research flume maintained by the U.S. Geological Survey's Geomorphology and Sediment Transport Laboratory in Golden, CO. The experiment used digital photography and image processing to track the motion of clusters of grains seeded at the head of the flume. The observed pattern of spread is strikingly similar to the pattern observed in Halfmoon Creek, despite the differences in scale. The fourth data source comes from a physically-based numerical model of river meandering and floodplain formation. The model is configured to track the resting time—the duration of rest between deposition in the floodplain and subsequent erosion by lateral channel migration—of a population of simulated tracer particles. The resulting distribution shows heavy-tailed behavior, with a relatively large fraction of particles having very long resting times relative to the median time. Such behavior implies that sediment passing through a meandering river system should be expected to exhibit anomalous, rather than Fickian, dispersion over time scales associated with floodplain recycling. Collectively, these findings have fascinating implications for how rivers "filter" the geologic record, as well as for the fate of sediment-borne contaminants.



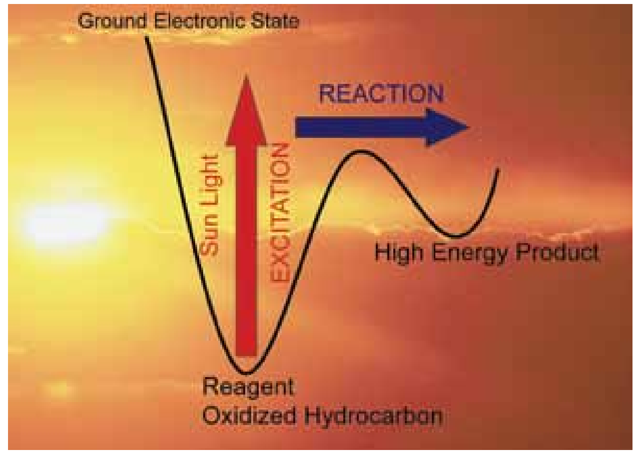
Positions of about 900 radio-tagged tracer clasts through time, Halfmoon Creek, CO. Image courtesy of Nathan Bradley, CU-Boulder.

Veronica Vaida

Light-initiated Chemistry of Organics in the Earth's Atmosphere

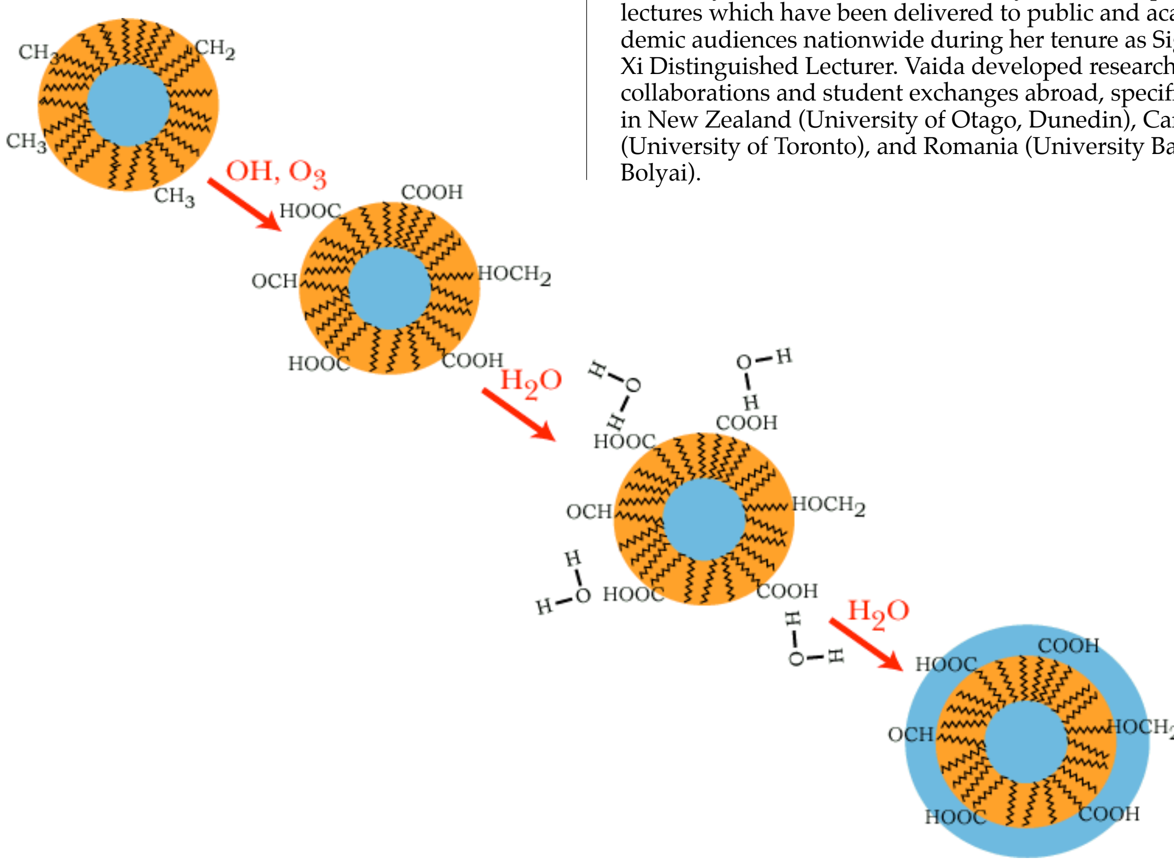
FUNDING: NSF

The Sun is the ubiquitous energy source for chemistry on Earth as well as for determining the planet's temperature and climate. Vaida's experimental program has unveiled and investigated new sunlight-initiated chemical reactions, which occur very fast and sequester the energy from solar radiation into chemical bonds. Especially challenging to understand are processes occurring in water environments, such as the surface of water and of aqueous atmospheric aerosols (particles in the air that become coated with water). Recent experimental and theoretical results from the Vaida and Skodje group at the CU-Boulder point to significant changes in atmospheric chemistry in the presence of water.



The reactions studied in the Vaida lab ultimately affect the environment and climate. Our research addresses the processing of organic and inorganic acids and alcohols, with consequences to atmospheric aerosols and secondary organic aerosol formation—which affect energy balance in the atmosphere. We have also considered the consequences of this chemistry in light of recently proposed geoengineering solutions to global warming.

To bring this research to a broader community, Vaida included environmental chemistry topics in teaching chemistry at all levels. Simultaneously, she developed lectures which have been delivered to public and academic audiences nationwide during her tenure as Sigma Xi Distinguished Lecturer. Vaida developed research collaborations and student exchanges abroad, specifically in New Zealand (University of Otago, Dunedin), Canada (University of Toronto), and Romania (University Babes-Bolyai).



Rainer Volkamer

Direct Observations of Reactive Trace Gases over the Tropical Pacific Ocean

FUNDING: NSF, EPRI

Oceans cover 70 percent of the Earth's surface, but the open ocean marine atmosphere is among the most poorly probed environments of our planet today. Glyoxal (CHOCHO) is a short-lived gas that indicates the rate of hydrocarbon oxidation, affects oxidative capacity, and forms climate-cooling secondary organic aerosol (SOA). Iodine oxide (IO) is a free radical, which forms by destroying toxic and heat-trapping tropospheric ozone, and can form climate-cooling inorganic aerosol. Yet measurements of glyoxal and iodine oxide are generally scarce. Most of our knowledge about the sources of glyoxal and iodine oxide is based on measurements over land or at coastal sites; measurements over the open ocean are non-existent at tropical latitudes and the Southern Hemisphere. Satellite instruments, for example, SCIAMACHY or OMI, now provide total column data on global scales. However, satellites have physical limitations. For example, the sensitivity varies over the height of the column and depends on environmental factors (albedo, aerosol abundance, and optical properties), and satellite data require careful evaluation prior to use in combination with numerical models to manage air quality and climate. Global models do not predict glyoxal or iodine oxide over the tropical oceans.

Dr. Volkamer's Atmospheric Trace Molecule Spectroscopy laboratory designed and assembled the one-of-a-kind instrument, the CU Ship MAX-DOAS (University of Colorado Ship Multi AXis Differential Optical Absorption Spectrometer) to measure directly the horizontal and vertical distribution of glyoxal, iodine oxide, and numerous other gases. The instrument was first deployed aboard the NOAA RV *Ronald H. Brown* as part of the VOCALS-REx and Tropical Atmosphere Ocean field campaigns in 2008 to directly probe atmospheric composition over the eastern Pacific Ocean.

Below, we show data (differential slant column density) collected from October to December of 2008, excluding data affected by ship exhaust. We accomplished unambiguous spectral proof for the existence of CHOCHO in concentrations exceeding 100 parts per trillion more than 3,000 km from the west coast of South America (Figure 1 inset). Our direct measurements locate CHOCHO and IO inside the marine boundary layer (Figure 2). The corresponding CHOCHO vertical column amounts exceed those inferred from space by a factor of 3-10. Correlations of CHOCHO and IO (Figure 3) point to a joint source mechanism for both gases. These results identify the ocean-atmosphere interface of biologically active upwelling regions, such as the tropical eastern Pacific Ocean, as a vigorously active chemical reactor that plays a previously unrecognized role in destroying heat-trapping ozone, and in cooling climate by forming aerosols.

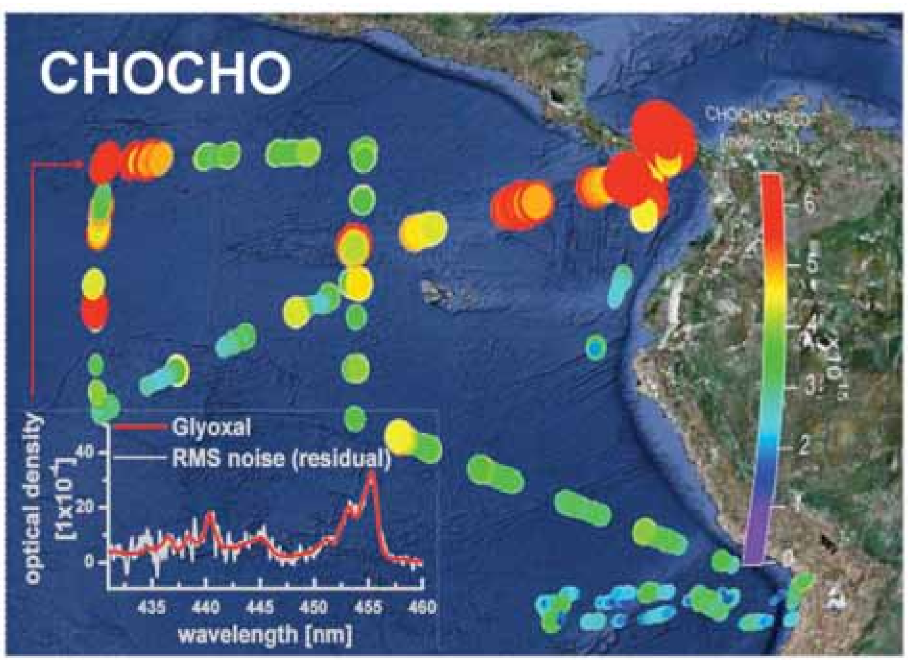


Figure 1

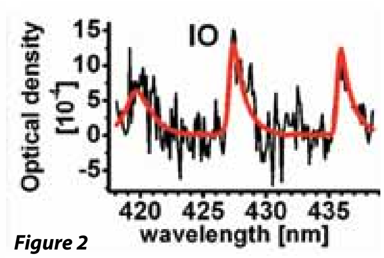


Figure 2

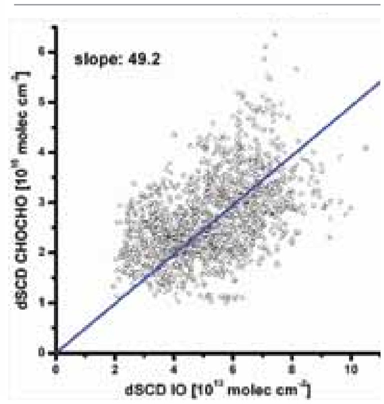


Figure 3

John Wahr

Applications of Time-Variable Gravity Measurements from GRACE

FUNDING: NASA, NSF, JET PROPULSION LABORATORY

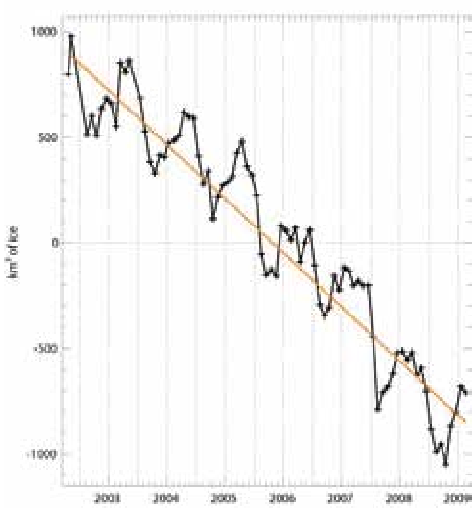
The Gravity Recovery and Climate Experiment (GRACE) satellite mission, launched by NASA and the German Space Agency in March 2002, is providing global maps of the Earth's gravity field to astonishing accuracy every month. Because the Earth's gravity field is caused by its mass distribution, time variations in gravity as determined from the GRACE maps can be used to estimate monthly changes in the Earth's mass distribution. GRACE can recover mass variability at scales down to about 250-300 km.

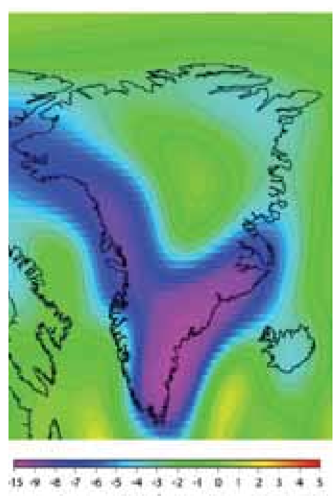
We have been using these data to look at a number of geophysical signals, particularly those that involve the storage of water—including snow and ice—on continents and in the polar ice sheets.

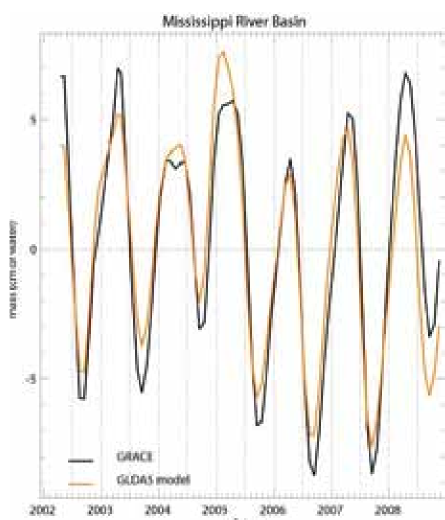
Because of its large effective footprint and its sensitivity to mass, GRACE offers the best available method for measuring the total mass balance of the polar ice sheets.

For example, the figure below on the left shows monthly GRACE results (black line) for the mass variability summed over the entire Greenland ice sheet, between April 2002 and February 2009. The trend of the best-fitting straight line (orange) is 256 km^3/yr of ice volume lost per year, which generates enough melt water annually to cover all of Colorado to a depth of 90 cm. There is a notable downward curvature to the black line, indicating that the mass loss rate has been increasing during this time period. The center figure shows how this mass loss rate is distributed across Greenland, as determined from the GRACE solutions. By far the largest rates occur in the southeast, where dramatic acceleration of outlet glaciers and accompanying ice thinning has been observed during the last few years. But mass loss has also been occurring up along the western ice sheet margin, particularly during the last two to three years. There appears to have been a modest mass gain in the northern interior, presumably associated with increased accumulation rates there.

For other land areas, GRACE mass results provide the sum of water on the surface, in the soil, and beneath the soil layers, and therefore can be used to assess land surface water storage models. Before GRACE, there was no practical way to measure total water storage at regional- to global-scales. As an example, the figure on the right shows monthly water storage variations for the Mississippi River Basin, and compares the results with output from the Global Land Data Assimilation System (GLDAS)/Noah land surface model (Rodell et al. 2004). The agreement between GRACE and GLDAS/Noah is excellent, showing that the model does a superb job of predicting water storage variations across this region.







Carol Wessman

with graduate student Kendra Morliengo-Bredlau and honors students Kerry Kemp and Julie Hayes

Impacts of Multiple Disturbances and Their Interactions in Subalpine Landscapes: Blowdown, Logging, Fire, and Beetle Kill

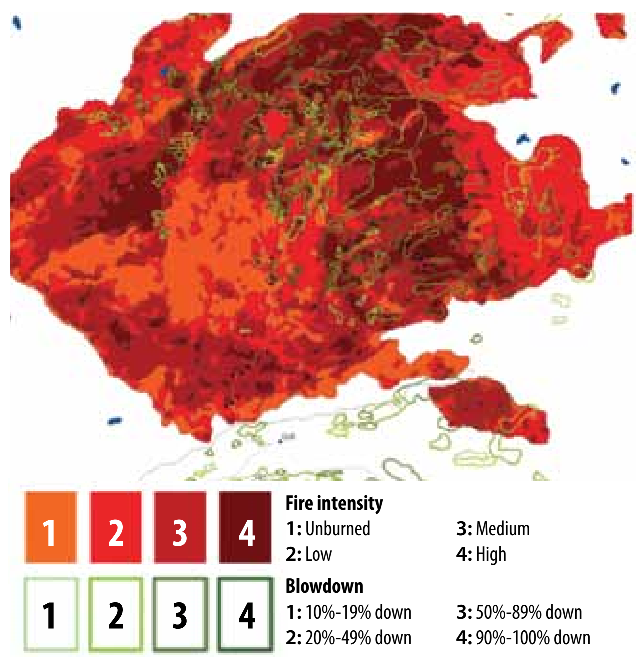
Ecological systems are dynamic, and change through disturbance is considered a natural process that maintains ecosystem biodiversity, productivity, and other important ecosystem services. However, ecosystems are increasingly exposed to multiple disturbances, from human land management practices to natural disturbance regimes and the system stresses of climate change. Interactions among disturbances are not well understood, but are likely to have a significant role in restructuring landscapes. We are studying the roles of large-scale disturbance interactions, historical contingencies and ecological resilience in ecosystem dynamics in a long-term study of subalpine ecosystem.

This study focuses on important drivers of forest regeneration at two scales: landscape (e.g., recent disturbance history, disturbance pattern) and local (e.g., biotic competition, microenvironment). Our study site in northern Colorado's Routt National Forest has experienced a series of catastrophic disturbances: a large blowdown in 1997, salvage-logging in 1999-2000, and a large fire in 2002. In recent years, spruce beetle and mountain pine beetle have impacted at least 99 km^2 in Routt County. We are examining subalpine forest regeneration, using a combination of field observations, remote sensing, and geospatial analysis to determine whether disturbance interactions create threshold conditions that significantly alter landscape heterogeneity and dynamics.

Initially, wildfire in 2002 appeared to erase the effects of previous disturbances on soil properties and processes. However two years after the fire, we observed seedling regeneration only in forests with no recent pre-fire disturbance, suggesting a role of disturbance history. Four to six years after the fire, succession was significantly less in burned blowdown sites (not logged), suggesting that fuels present in the blowdown contributed to increased fire severity. Pre-fire disturbance history significantly influenced post-fire diversity and proportional cover of the understory, and had a differential impact on lodgepole pine and Engelmann spruce regeneration. Soil nitrogen availability and total nitrogen were significantly decreased and total carbon increased in areas that were logged prior to the fire, indicating an influence of pre-fire surface soil conditions. Pre-fire disturbance history interacted with both burn severity and time, implying that patterns of disturbances on the landscape may be affected spatially by previous disturbances, and can have lasting temporal effects through seedling recruitment.

PHOTOS BY KERRY KEMP

Lodgepole pine seedling in salvage-logged area that burned in 2002.



Tingjun Zhang

Degrading Permafrost Across Eurasian Permafrost Regions

FUNDING: NSF OFFICE OF POLAR PROGRAMS, ARCTIC SYSTEM SCIENCE PROGRAM

Permafrost warming and thawing have dramatic impacts on regional ecosystems, carbon exchange, the hydrological cycle, and the infrastructure in cold regions. Documenting the past changes and monitoring the future evolution of permafrost warming and thawing in cold regions have become a prerequisite for environmental studies and engineering applications.

Based on Russian historical soil temperature measurements across Siberian Arctic and Subarctic, we document widespread permafrost degradation across Eurasia in the past several decades. By permafrost degradation, we refer to the increase in permafrost temperatures, thickening of the active layer, talik formation above the permafrost table, and any forms of thermokarst phenomena induced either by human activities or global warming.

During the past several decades, widespread permafrost degradation has occurred across the Eurasian permafrost regions, from the Tibetan Plateau in the south, through Mongolia, to Siberia in the north. Ground-based measurements indicate that permafrost temperature has increased by several degrees in Siberia to a few tenths of a degree on the Tibetan Plateau, while active layer thickness has, on average, increased from about 20 cm in Siberia since the early 1960s to about 1.0 m on the Tibetan Plateau.

Historical soil temperature measurements show that talik has formed in a large fraction of eastern and central Siberia (Figure 1), while decrease in permafrost areal extent has also been observed on the Tibetan Plateau. Widespread thermokarst development (Figure 2), drainage of thaw lakes in discontinuous permafrost regions, and development of new thaw lakes in continuous permafrost regions have all been observed and documented. These changes in permafrost conditions have significant influence on local and regional environments.

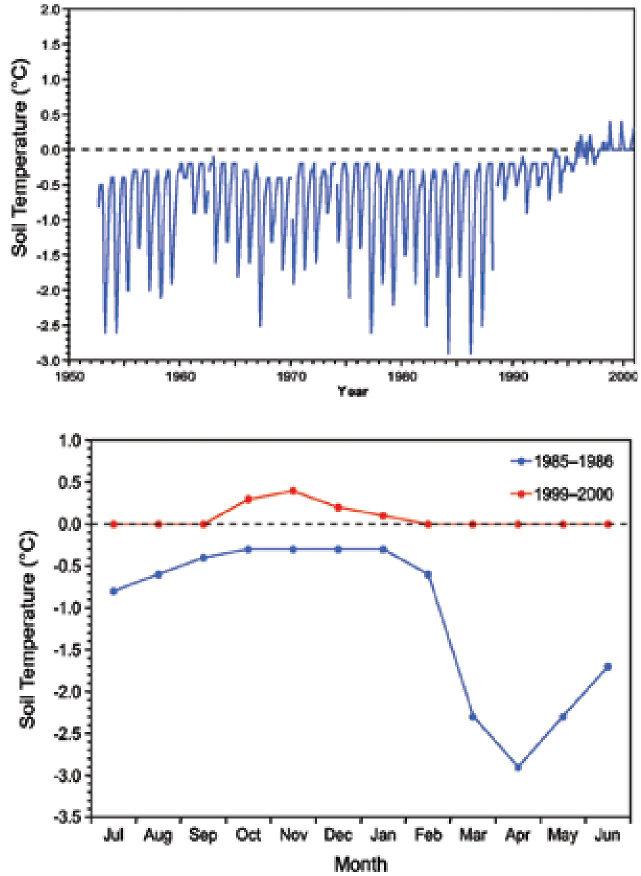


Figure 1: *Mean monthly soil temperatures at 3.2 m depth at a site in Siberia, Russia (top panel). A talik layer was potentially in formation since 1995. As an example, mean monthly soil temperatures at 3.2 m depth were below the freezing point from July, 1985 through June, 1986 (blue line), while it was at or above the freezing point (red line) from July, 1999 through June 2000, indicating permafrost was thawing and talik was in formation.*

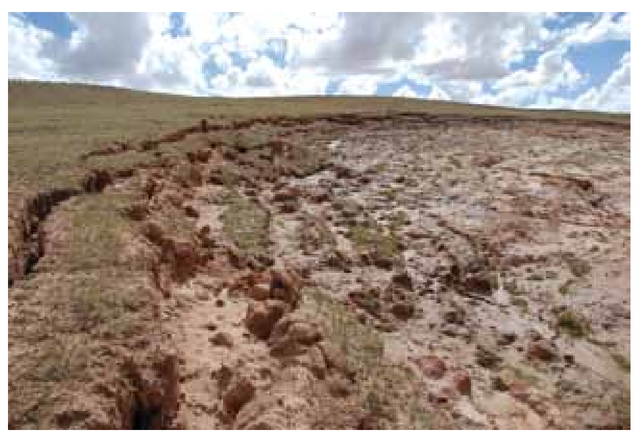


Figure 2: *Large-scale thermokarst development over permafrost on the Qinghai-Tibetan Plateau due to climate warming and surface disturbance.*

Alaskan wetlands.

SCIENTIFIC CENTERS

- Center for Limnology
- Center for Science and Technology Policy Research
- Climate Diagnostics Center
- Earth Science and Observation Center
- National Snow and Ice Data Center

Center for Limnology

The Center for Limnology supports research and graduate education related to biogeochemistry and metabolic functions of aquatic ecosystems. Examples of work in progress during 2008-2009 include assessment of the water quality of Rocky Mountain National Park (RMNP) and study of the effect of pine beetles on the chemistry of mountain streams and rivers. In addition, the Center continued its work on studies of the nitrogen cycle, with emphasis on factors controlling denitrification rates.

National Parks are managed for public accessibility, but attempt to maintain an environment that is relatively free of anthropogenic influence. The parks anticipate and successfully deal with management of foot traffic and vehicle traffic associated with public access. Some new and unanticipated problems have surfaced on the management agenda for RMNP, however. Oxides of nitrogen released into the atmosphere as a result of fossil fuel combustion along the Front Range become nitric acid through photochemical reactions that occur in the atmosphere. Nitric acid is then delivered to RMNP by atmospheric transport and removed from the atmosphere by rain. The nitric acid has two distinct and undesirable effects: acidification of weakly buffered water within the park, and enrichment of park waters with nitrate, a key plant nutrient. Park managers are frustrated by this unmanageable influence and are anxious to find out the extent to which it is changing the waters of the park.

The Center for Limnology, in collaboration with RMNP, conducted an initial water-quality mapping exercise across 185 sites during the summer of 2008. The collections, which were done in a single day, involved sampling by 70 individuals. The resulting maps are quite informative (Figure 1). Nitrate concentrations within the park are 50-100 percent higher than nitrate concentrations on the West Slope, indicating the effect of nitrate enrichment from the atmosphere and the passage of nitrate from terrestrial surfaces into water. In addition, gradients of pH and nitrate within the park probably reflect an uneven distribution of pollutant-derived nitric acid across the park. Further studies will be conducted during the summer of 2009.

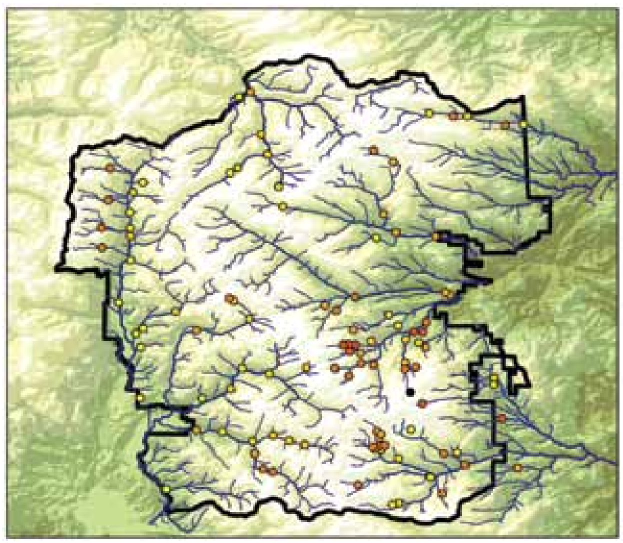
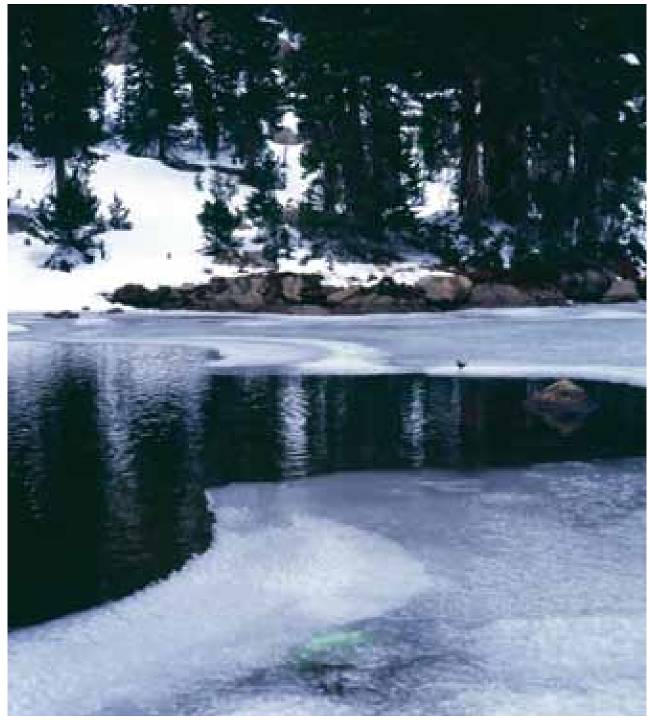


Figure 1: Nitrate levels in Rocky Mountain National Park, summer 2008.

Another frustrating management issue for the park has to do with fish. The park's native fish is cutthroat trout, which occupied some, but not all of the park's lakes and streams prior to human intervention. Where the streams have insurmountable barriers to fish, such as waterfalls, lakes above these barriers were barren of fish under natural circumstances. In the early history of the park, however, fish were introduced in many lakes where they did not formerly occur, and also in lakes where the cutthroat trout often ultimately were displaced by the non-native introduced trout. Present questions involve the desirability and feasibility of restoring the native cutthroat trout to many or all park lakes, and of maintaining or reestablishing the fishless status of some lakes. The Center for Limnology is collaborating with RMNP in the study of the latter question.

Fishless lakes have very different invertebrate communities than lakes with fish. Fish apply tremendous predation pressure on invertebrates, including crustaceans and aquatic insect larvae. As a result, the contrast between lakes with fish and lakes without fish is quite striking (Figure 2). For example, one may observe in lakes without fish large herds



WILLIAM LEWIS

***Figure 2:** Fishy (above) and fishless (right) lakes in Rocky Mountain National Park.*

of mayfly larvae roaming over the sediment surface, but no such free-ranging invertebrates are observed in lakes with fish. The effects of fish may be even more pervasive than they might appear, as selective elimination of larger invertebrates may affect algal populations as well.

During 2009, the Center for Limnology will collaborate with RMNP in quantitative comparisons of lakes with and without fish. The study will encompass the community structure for aquatic foodwebs as well as some biogeochemical work that may prove to be related to the presence or absence of fish. The results will help park managers decide how intensively to manage fish populations in the park, and whether to attempt to reverse changes made in the past.

The Limnology Center also continued its work on the nitrogen cycle during 2008-2009. The focus is and has been the effect of organic matter abundance and quality on the rate of denitrification in the South Platte River, where nitrate is abundant. The denitrification process involves the conversion of nitrate to N_2 gas by bacteria. This is a welcome process because it removes excess nitrate. Regulation of the process is not completely understood, but one potentially controlling factor is organic matter, which is needed by the microbes as food to support growth, even though they obtain much of their energy from the denitrification process.

In 2008-2009, the Center for Limnology used a new fluorescence method (Figure 3) for detecting specific kinds of organic matter. Studies of the South Platte River showed that a particular class of organic compounds, which could be described as labile (easily used by bacteria) is particularly abundant in the upper end of the study reach. The abundance of the labile carbon source stimulates denitrification, which explains why denitrification is higher in the upper part of the reach than the lower part of the reach. The fluorescence method shows the decay of the labile fraction of organic matter with distance downstream.

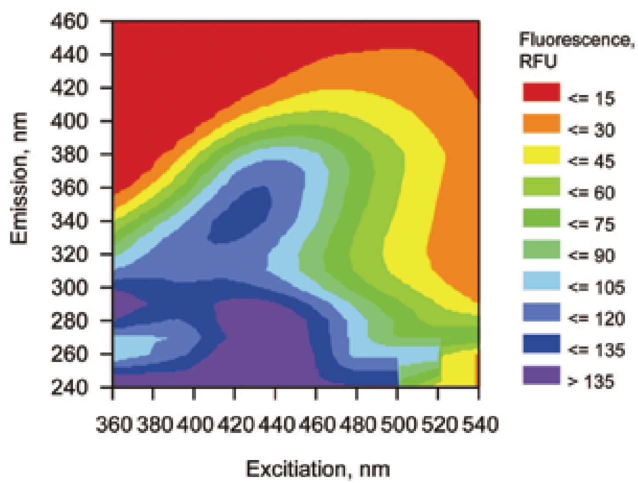


***Figure 3:** Fluorescence map of organic matter from the South Platte River.*

Center for Science and Technology Policy Research

Since 2001, the Center for Science and Technology Policy Research has contributed to both the CIRES goal of promoting science in service to society, and to the University of Colorado at Boulder's vision of conducting research and outreach across traditional academic boundaries.

The Center serves as a resource for science and technology decision makers and those educating future decision makers. Its mission is to improve how science and technology policies address societal needs, including research, education, and service.

Research Activities

The National Science Foundation-funded Science Policy Assessment and Research on Climate (SPARC) project conducts research and assessments, outreach, and education aimed at helping climate science policies better support climate-related decision-making in the face of fundamental and often irreducible uncertainties. SPARC research focuses on two themes. The Sensitivity Analysis theme attempts to disentangle the various factors that lead to policy impacts in areas such as climate impacts on ecosystems, natural disasters, and energy and emissions scenarios. The Reconciling Supply of and Demand for Climate Research theme focuses on developing science policies that are responsive to the needs of decision makers.

The NOAA-funded Scales of Decision-Making and the Carbon Cycle project is examining the drivers of land-use decision-making at different scales, and their intersection with new imperatives and opportunities coming from climate mitigation goals. This past year, researchers conducted a case study on land-use decision-making in Colorado, a Western state with a significant portion of land managed by federal agencies in addition to privately-owned agricultural, grazing, and forested lands. Our main goal was to put together a first-order look at the types of decision makers involved in managing land, what influences their decisions, and how the potential for storage of additional carbon on land might vary according to owner-

ship category and land vegetation type.

A Western Water Assessment-funded research project, The Impact of Earlier Spring Snowmelt on Water Rights and Administration, examined whether the growing mismatch between seasonal water rights and earlier runoff in the Mountain West has resulted in conflict between supply and demand. It found that no significant on-the-ground problems have yet emerged from the growing mismatch of rights and hydrographs. It remains unclear exactly where and how intensely these problems may be manifest, and whether they will present mostly as legal or water-management problems.

The Center collaborated with the University's Natural Hazards Center to inventory disaster loss data in the United States and globally. Disaster data are used to track trends and to fashion policy, but are notoriously inconsistent—our goal is to develop research-grade data subsets (such as those shown in the graphs at right of U.S. flood losses) that more reliably reflect trends in impacts and vulnerability.

Education Activities

The Graduate Certificate in Science and Technology Policy—a rigorous educational program to prepare graduate students for careers at the interface of science, technology, and decision-making—is completing its fifth year. Eighteen students are currently enrolled in the certificate program, and 18 others have completed the program. Program alumni have served on the staff of the House Science Committee, interned for the Office of Management and Budget, staffed a congressional office, and served in postdoctoral positions in science policy.

Outreach Activities

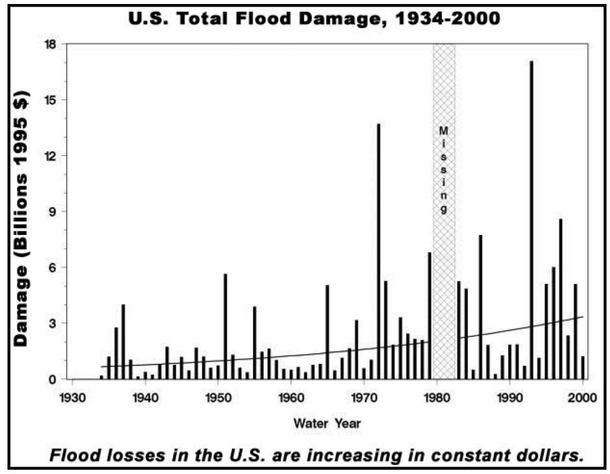
The Center, in partnership with the CU-Boulder Energy Initiative, sponsored a lecture and panel discussion series titled "The Energy and Climate Challenge," to examine the challenge of meeting rapidly rising global energy demand while simultaneously reducing planet-warming greenhouse gases. The series was intended to foster discussion and debate on these issues to coincide with the 2008 presidential campaign.

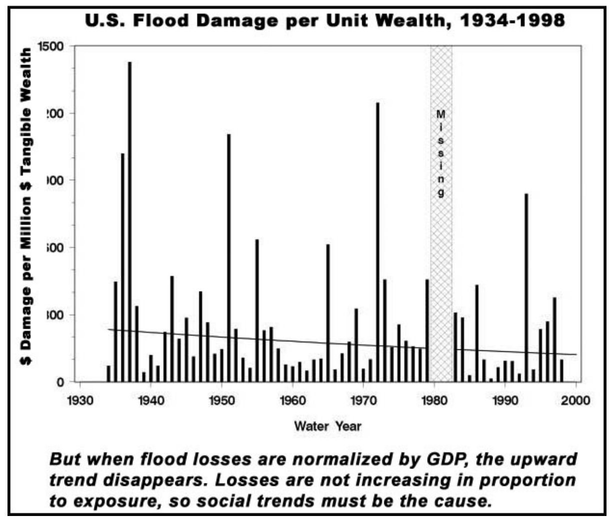
Other ongoing Center outreach efforts include a quarterly newsletter, an email briefing sent to more than 3,500 decision makers in Washington, D.C. and elsewhere, and an extensive web site. The Center continues to maintain its popular and well-regarded science policy blog, *Prometheus*, which underwent a significant revision in 2008 to improve its appearance and functionality.

Personnel

William Travis was appointed to succeed Roger Pielke, Jr. as director of the Center in 2008. Travis, an associate professor of geography who has taught for more than 20 years at CU-Boulder, is the former director of the university's Natural Hazards Center. He has researched and written extensively about humans and the environment, including in his latest book, *New Geographies of the American West: Land Use and Changing Patterns of Place*. His current work examines causes and patterns of regional land-use and cover change, and assesses the impacts of climate extremes.

Travis





Withough normalization by GDP, flood damages appear to be rising (top). A different trend emerges when data are normalized (bottom).

Panelists during the center-sponsored lecture and discussion, "The Energy and Climate Challenge." Pictured left to right are: Roger Pielke, Jr., CIRES; Frank Laird, University of Denver; Gwyn Prins, London School of Economics and Political Science; and Tom Wigley, National Center for Atmospheric Research.

Climate Diagnostics Center

The mission of the Climate Diagnostics Center (CDC) is to improve our understanding of global climate interactions, to improve regional climate predictions, and to train the next generation of climate scientists in advanced climate system diagnosis and prediction. CDC works to establish the causes of regional climate variations around the globe on time scales of weeks to millennia by 1) applying newly developed diagnostic techniques to global observations and model simulations; 2) developing new observational datasets and performing new climate model integrations as needed for this purpose; and 3) developing new techniques to diagnose and reduce model formulation errors.

Research disciplines include, but are not limited to, atmospheric sciences, oceanography, stochastic physics, remote sensing, numerical computational methods, computer sciences, data management, and complex dynamical systems analysis. An integration of these disciplines is required to transfer improvements in the understanding of climate processes to improvements in the models and methods used for climate predictions.

In 2008-2009, CDC published 27 peer-reviewed papers on topics that included:

■ Reconciling non-Gaussian climate statistics with linear climate system dynamics

■ A global view of non-Gaussian sea-surface temperature (SST) variability

■ The impact of rapid surface wind variability on thermal air-sea coupling

■ Oceanic influences on recent continental warming

■ Forcing of tropical ocean variability from the North Pacific through oceanic pathways

■ Representation of El Niño-Southern Oscillation (ENSO) in the United Nation's Intergovernmental Panel on Climate Change Fourth Assessment Report (IPCC AR4) climate models

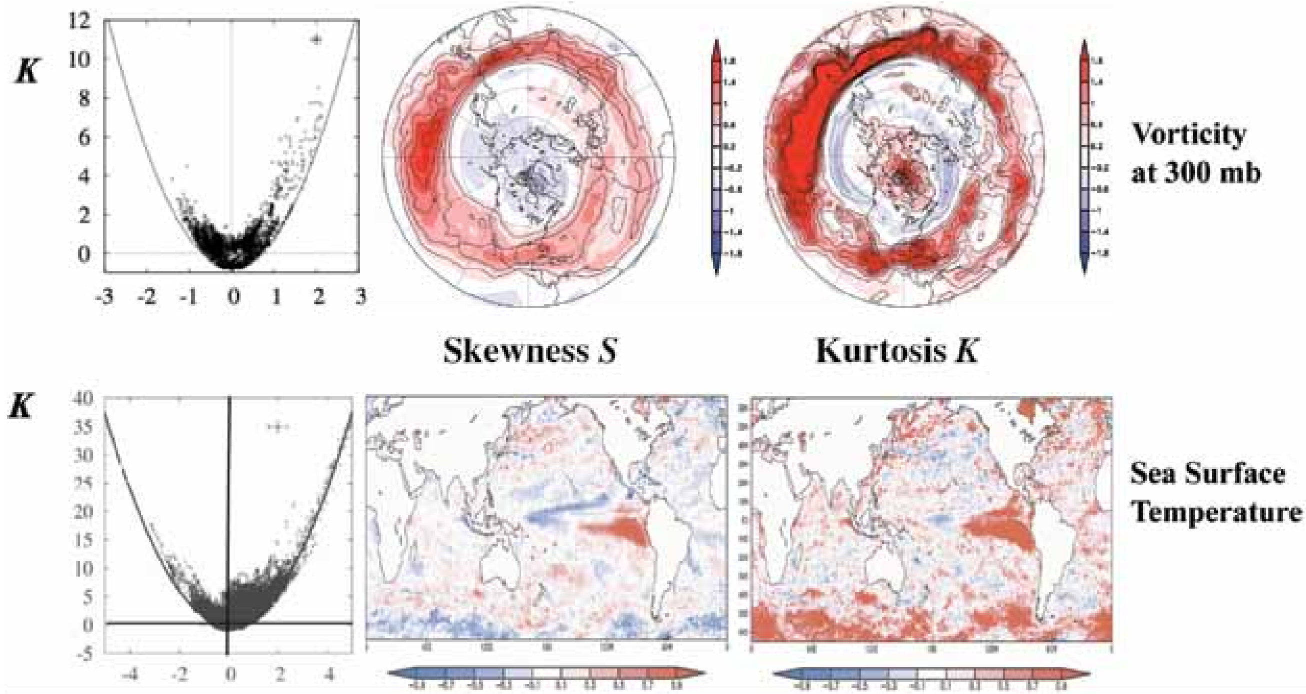
■ Evaluating the simulation of clouds, precipitation, and radiation in climate models

ISTOCK

■ Sensitivity of ENSO period in climate models to the mean pycnocline structure

■ Tropical vs. stratospheric influences on short-term extratropical climate variations

■ Characteristics of North American summertime rainfall with emphasis on the monsoon



Skewness S and Kurtosis K of the vorticity of daily upper tropospheric winds near the jet stream level (300 hpa), derived from the NCEP/NCAR atmospheric reanalysis dataset (upper panels), and the same statistics for daily sea-surface temperature (SST) variations, derived from a 20-yr high-resolution SST dataset (lower panels). Positive values of S and K are indicated in red and negative values in blue. For added clarity, the fields in the upper panels are also contoured at intervals of 0.4, starting at 0.2. The S and K values from the maps are displayed in the left panels in the form of scatterplots. Note the strong tendency for a parabolic K-S relationship. (Adapted from Sardeshmukh and Sura 2009 and Sura and Sardeshmukh 2008)

■ Origin of convectively coupled atmospheric Kelvin waves over South America

Additionally, CDC continued the development of several observational and atmospheric circulation datasets and forecast products, and provided scientific input to international programs, including:

■ Providing leadership in the international Global Climate Observing System Surface Pressure Working Group, to promote the development of long-term, high-quality surface pressure datasets

■ Completing production of version 1 of a global atmospheric circulation dataset for 1908-1958, using only daily surface pressure observations and an ensemble Kalman-filter based data assimilation system, and making the dataset widely available through a web interface.
More at http://www.cdc.noaa.gov/data/gridded/data.20thC_Rean.html.

■ Starting production of version 2 of the global atmospheric circulation dataset for 1891-2008, using a longer and improved surface pressure database, and an improved model for assimilating those data. The improved model includes better specifications of time-varying CO_2 and aerosol radiative forcings over the assimilation period. This effort will extend our ability to quantify 20th century climate variability, provide uncertainty estimates for climate change detection, and aid attribution efforts to inform climate policy decisions.

■ Developing and releasing a new experimental forecast product (jointly with NOAA ESRL's Physical Sciences Division) for subseasonal tropical forecasts based on a coupled linear inverse model of weekly tropical SSTs and outgoing longwave radiation variations.
More at http://www.cdc.noaa.gov/forecasts/clim/

CDC researchers have recently discovered some surprising aspects of atmospheric and oceanic variations, with important implications for climate modeling and prediction.

For instance, two recent studies provided evidence of striking deviations from "normality" in the observed statistics of daily SSTs and of the vorticity of daily wind variations at the 300 hpa jet stream level, as shown in the figure above for the Skewness (S) and Kurtosis (K), which are both identically zero for "normally" distributed quantities.

There are several remarkable features to note in the figure: 1) the patterns of S and K are highly geographically coherent in both the atmosphere and the ocean, 2) large magnitudes of S tend to be associated with large values of K, and 3) this K-S relationship is a remarkably simple parabolic inequality, K > 1.5 S2, as evident in the scatter plots of K versus S in the left panels. We have shown that this K-S relationship is a simple consequence of stochastically perturbed linear dynamics and physics. The precise values of S and K, however, depend sensitively on the extent to which the amplitude of the stochastic noise is independent of the system state or depends linearly on it. The magnitudes, geographical structures, and interrelationships of K and S evident in this figure have critical implications for climate models and their ability to represent the statistics of extreme and high-impact weather events. This is because accurate representations of K and S are necessary for accurately representing the tails of probability density functions, and therefore the likelihoods of extreme values.

The Earth Science and Observation Center

The Earth Science and Observation Center (ESOC), formerly the Center for the Study of Earth from Space (CSES), provides a focus for the development and application of modern remote-sensing techniques used in the research of all aspects of Earth sciences at the University of Colorado at Boulder. The aim is to work on all scales of problems, from technique development in small test sites to understanding pattern and process on regional and global scales. A long-term goal of ESOC research is to investigate problems in global geosciences—questions of global change, in particular—through remote-sensing observations. ESOC had six faculty associates during FY09, 17 graduate students, and three research associates. Below, ESOC accomplishments and activities are summarized by topic.

Cryospheric Change

Significant glaciological and ecological changes are taking place in the Antarctic Peninsula in response to climate warming that is proceeding at six times the global average rate. Following the collapse of Larsen A and B ice shelves in 1995 and 2002, the outlet glaciers that nourished them accelerated, losing massive amounts of ice to the ocean. We initiated a field experiment to determine the health and stability of Larsen C in response to climate change. Field instruments and activities complement analysis of satellite data, ice shelf numerical models, and control methods. This work is part the International Polar Year effort in Antarctica.

Land Surface Effects on Climate

Our work showed that East Asian monsoon precipitation prediction can be improved by including antecedent vegetation characteristics in the forecasting algorithm. By including the land surface, we effectively doubled the predictive power of our forecast models, demonstrating the important influence of land surface on climate. We also improved the land surface hydrology in the NCAR Community Climate System Model (CCSM), again highlighting the importance of land surface on climate.

KERRY KEMP

Ecology: *Mortality from spruce and mountain pine beetle infestations is increasingly evident in the Routt National forest. (Sept 2008)*

Ecology

We are studying the ecological effect of rapid sequencing of severe, large-scale disturbances in subalpine forest (wind throw, logging, and fire) with field work, remote sensing, and geospatial analysis. Initial work suggests that a sequence of disturbances creates extreme microenvironmental conditions, leading to spatially heterogeneous forest regrowth. In 2008, considerable spruce and mountain pine beetle kill in this region also stressed the subalpine landscape. Our work and observations suggest that recent disturbance interactions affect biogeochemical and succession processes, and widespread dieback from insect outbreaks will influence recovery trajectories.

Hydrology

A core hypothesis in large-scale hydrology is that floods exhibit spatial scaling (power laws). Our analysis of 28 medium sized river basins (about 3,000 km^2) confirmed the presence of power laws, supporting the hypothesis. This is the first time the theory has been put to test on such large basins (>10,000 km^2), giving a major boost to 20 years of flood research. The findings may improve methods for real-time flood forecasting and estimates of annual flood frequencies for the management of flood plains in a changing climate.

Cryosphere: *The shadow of an Antarctic Peninsula mountain range falls across the Larsen C ice shelf.*

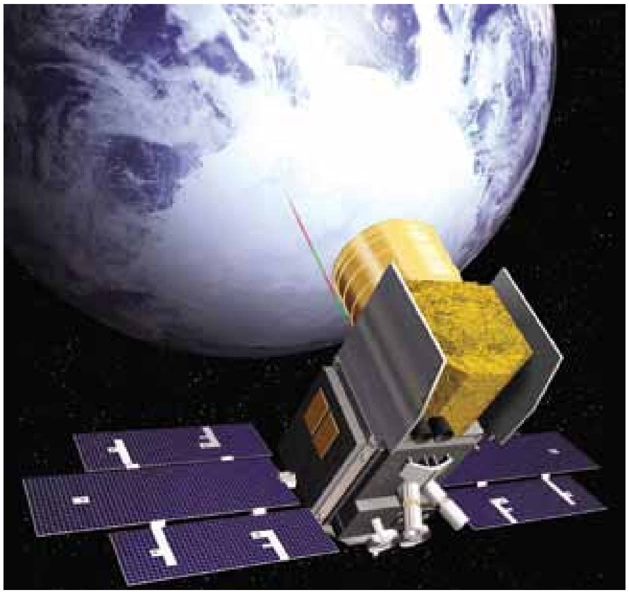
KONRAD STEFFEN

Satellite and Aircraft Missions

We assumed a scientific leadership role for NASA's Ice Cloud and land Elevation Satellite-2 (ICESat-2) laser altimetry mission, planned for launch by 2015. In this capacity, we lead the science team defining mission requirements that will drive ICESat-2's capabilities in measuring ice sheets, sea ice, and vegetation. We also consulted on NASA's IceBridge aircraft mission to survey the Arctic and Antarctic land and sea ice cover, providing scientific and technical guidance on measurement approaches and priorities. We expect to participate in other missions in the coming year, including the European Space Agency's Cryosat-2 mission to measure changes in ice sheet elevation and sea ice thickness, and NASA's Deformation Ecosystem Structure and Dynamics of Ice mission.

Laser Research and Development

With funding from NSF's Major Research Instrumentation Program, we partnered with Light Age Inc. to develop a unique pulsed alexandrite ring laser, which has the potential to revolutionize resonance Doppler. In collaboration with Colorado State University and Colorado Research Associates, we developed a sodium double-edge magneto-optic filter and incorporated it into the receiver of a 3-frequency sodium Doppler lidar, and successfully demonstrated its capability for simultaneous measurements of wind and temperature from 5-50 km. This moves us one step closer to achieving a lidar that can profile the entire atmosphere. We have also been participating in a European Space Agency study to develop a concept for putting a resonance-fluorescence Doppler lidar into space, hosted by the European Space Agency.



NASA

Satellite and Aircraft Missions: *NASA's ICESat laser altimetry satellite, which provides the foundation for the design of its successor, ICESat-2, planned for launch by 2015.*

National Snow and Ice Data Center

The National Snow and Ice Data Center (NSIDC) supports research into our world's frozen realms: the snow, ice, glaciers, ice sheets, and frozen ground that make up Earth's cryosphere. Scientific data, whether taken in the field or relayed from satellites orbiting Earth, form the foundation of the scientific research that informs the world about our planet and its climate system. NSIDC manages and distributes scientific data, creates tools for data access, supports data users, performs scientific research, and educates the public about the cryosphere. NSIDC has led the field of cryospheric data management since 1976. In 2008, the Center added new products to our online data offerings, which total more than 600 datasets. NSIDC also played a leading role in International Polar Year (IPY) data management through several ongoing projects:

- Discovery, Access, and Delivery of Data for IPY
- The IPY Data and Information Service
- The Exchange for Local Observations and Knowledge of the Arctic
- Cooperative Arctic Data and Information Service

Researchers using NSIDC data products are assessing and monitoring changes in the cryosphere that may have profound effects on society. NSIDC scientists and staff help explain the importance of studying the cryosphere through lectures, interviews with journalists, educational presentations, and by providing online content.

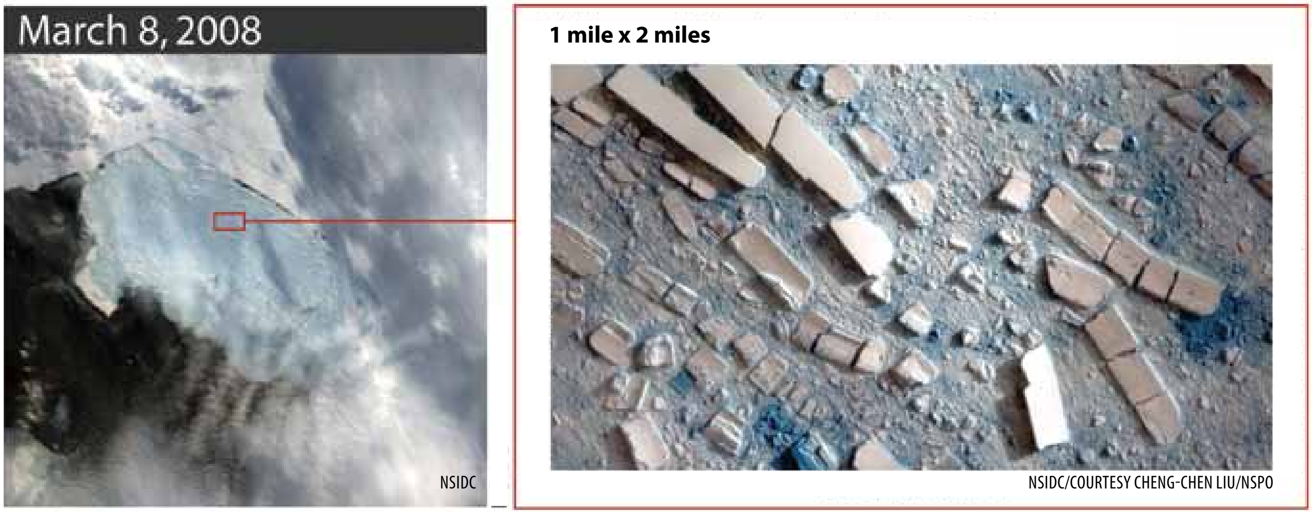
Like many organizations, NSIDC is evolving its data discovery interfaces, collaboration tools, and mapping services. During 2008, NSIDC began rebuilding its public-facing cyberinfrastructure to enable these capabilities across any number of datasets and specific requirements. The Searchlight project is building a general-purpose search and discovery tool that enables users to perform first-level analysis directly on our site; NSIDC demonstrated a proof-of-concept product at the 2008 Fall American Geophysical Union meeting. Using the same infrastructure, NSIDC's Services and Analysis for the Greenland Environment project addresses a specific science need: understanding Greenland's contribution to global sea-level rise through comparison and analysis of variables such as temperature, albedo, melt, ice velocity, and surface elevation.

Research at NSIDC Includes Activities Related to the Cryosphere

- **Ice Sheets and Glaciers:** Glacier and ice sheet mass balance are key variables in the monitoring of sea-level rise. NSIDC scientists continued to update a map of Antarctica and have been documenting glacier movement rates in critical parts of the Antarctic and Greenland ice sheets.
- **Sea Ice:** Sea ice is both a driver and indicator of climate change. The Sea Ice Index, developed by NSIDC to meet a need for tracking changes in real time, has followed declines in Arctic sea ice extent and area during recent years.
- **Permafrost and Frozen Ground:** Changes in the extent of permafrost and frozen ground are important climate change responses that impact communities, terrestrial ecology, and the infrastructure of northern lands. The carbon tied up in permafrost and frozen ground could affect the global carbon balance. Scientists at NSIDC are integrating in situ data with numerical models to refine predictions of frozen ground extent.
- **Snow Cover and Snow Hydrology:** The extent and variability of seasonal snow cover are important parameters in climate and hydrologic systems, due to effects on energy and moisture budgets. During the past several decades, visible-band and passive microwave satellite imagery of the Northern Hemisphere has allowed NSIDC scientists to perform trend analyses, and to determine the response of snow cover to a changing climate.
- **Climate Change in the Cryosphere:** Scientists working with near real-time monitoring of snow, sea ice, and vegetation under the Study of Environmental Arctic Change program are making progress toward documenting that change, using approaches such as the Sea Ice Index.
- **Impacts of Changes on Arctic Peoples:** The impacts of changes on Arctic peoples are being recognized and incorporated into research projects. An NSIDC scientist has been living in a community in northeast Canada, documenting the observations of, and impacts on, local people.

NSIDC Programs and Projects

NOAA@NSIDC: This NOAA project at NSIDC operates in cooperation with the NOAA National Geophysical Data Center and Arctic Research Office to extend the NOAA National Data Center catalog of cryospheric data and information products, with an emphasis on in situ data, data rescue, and datasets from operational communities. During 2008, NOAA@NSIDC added information for more than 35,000 glaciers to the World Glacier Inventory.

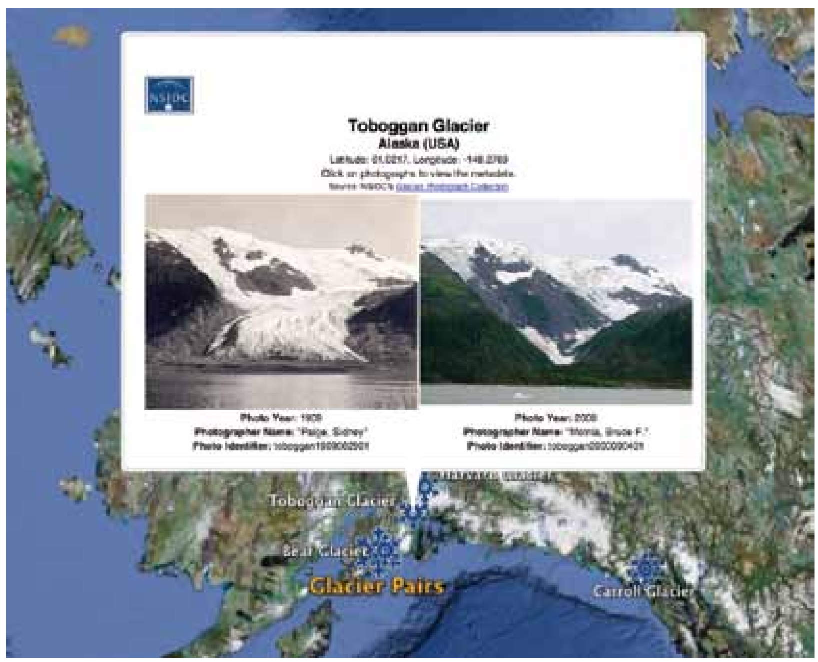


Satellite data managed and distributed by NSIDC provided insight into changes in the cryosphere. The image at left, from the Moderate Resolution Imaging Spectroradiometer sensor, captured the disintegration of the Wilkins Ice Shelf in Antarctica on March 8, 2008. The detail image at right shows a high-resolution, enhanced-color image of the narrow iceberg blocks (150 meters wide, or 492 feet) that crumbled into house-sized rubble. Taiwan's Formosat-2 satellite acquired this image.

The Glacier Photograph Collection nearly doubled in size, and now includes more than 10,000 high-resolution photographs of glaciers worldwide.

■ **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 multiagency-funded efforts at NSIDC to provide snow and ice data, information management services, and user support. In FY09, the NSIDC DAAC distributed 83.5 terabytes of data.

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



Several NSIDC datasets may be visualized using Google Earth. Here, a "then-and-now" pair of glacier photographs from the NOAA@NSIDC Glacier Photograph Collection is highlighted in Google Earth. NSIDC created this special Google Earth file featuring signals of climate change from the cryosphere.

■ **Global Land Ice Measurements from Space (GLIMS):** GLIMS, a cooperative project with more than 50 institutions worldwide, is designed to map and monitor the world's glaciers, primarily using satellite data from the NASA Advanced Spaceborne Thermal Emission and Reflection Radiometer instrument. More than 82,000 glaciers are now entered in the GLIMS database.

■ **Roger G. Barry Resource Office for Cryospheric Studies (ROCS):** ROCS offers unique collections related to the cryosphere. Its information center holds more than 44,000 monographs, serials, journal articles, reprints, videos, maps, atlases, and CD-ROMs. This archive specializes in analog science data and scientific materials, including thousands of maps, photographs, prints, expedition journals, and more items of interest to those researching the history of science or studying past climate.

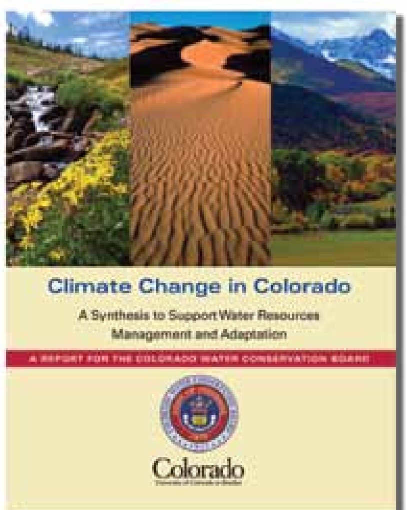
WESTERN WATER ASSESSMENT

- Climate Change in Colorado Report
- Intermountain West Climate Summary
- Reconciling Streamflow Projections for the Colorado River
- Ongoing Stakeholder Engagement and Collaborations

The Western Water Assessment (WWA) is CIRES' signature integrating activity, relying on multidisciplinary teams of experts in climate, water, law, and economics, to work with decision makers across the Intermountain West and produce useful information about natural climate variability and change. In the West, many of the impacts of climate change will be delivered through changes in the hydrologic cycle that have affected, and will continue to affect, water resources. WWA has focused on building relationships and networks of water-resource decision makers, and has used these relationships to develop practical research programs and useful informational products.

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

Some Highlights from 2008:



Climate Change in Colorado Report

In October 2008, WWA released the *Climate Change in Colorado* report at the Governor's Conference on Mitigating Risks of Drought and Climate Change. The report—commissioned by the Colorado Water Conservation Board in support of Governor Ritter's Colorado Climate Action Plan—is a synthesis intended to support water resources, management, and adaptation efforts throughout the state.

The report received considerable media attention and was a finalist for the Governor's Research Impact Award. It also provided a springboard for several climate initiatives within the state (e.g., the La Plata County Climate Action Plan), and the authors have given more than 30 public presentations about the report. As a follow-up, WWA is developing a Colorado Climate Roadshow, working with colleagues to adapt a NOAA Climate 101 training workshop for Colorado stakeholders.

Intermountain West Climate Summary

The *Intermountain West Climate Summary* (IWCS) continues to be WWA's most prominent outreach and education product. WWA distributes the IWCS to more than 400 decision makers, scientists, and climate information providers. The January 2009 IWCS was viewed by about 800 individual people. The IWCS provides the latest climate and forecast information in a simple, compact document aimed at managers, planners, and policy makers with water-related interests. During an extensive evaluation process in 2008, WWA learned that the IWCS is improving awareness and understanding about forecasts and climate phenomena; facilitating a dialog among potential users, researchers, and operational providers of climate information; and improving climate literacy.

Reconciling Streamflow Projections for the Colorado River

The goal of this project is to reconcile future Colorado River streamflow projections by evaluating the various methods and models being used in projections and to understand why different modeling approaches produce varying flow projections. Within the Upper Colorado River Basin, projected reductions in naturalized streamflow by the mid 21st century tied to climate change range significantly. Findings in

ANDY PERNICK/BUREAU OF RECLAMATION

The Western Water Assesment led a series of discussions on Colorado River streamflow projections in 2008, culminating in a "model bakeoff," with the intention of narrowing the range of projections so that decision makers can identify vulnerabilities and develop planning strategies.

recent scientific papers project reductions from about 6 percent to about 45 percent. This wide range makes it difficult for decision makers and water managers to prepare and plan for potential future reductions in streamflow resulting from climate change.

During 2008, WWA led a series of discussions culminating in a "model bakeoff," with the intention of narrowing the range of projections so that decision makers can identify vulnerabilities and develop planning strategies. Initial findings were presented in a November 2008 meeting involving water managers, non-governmental organizations, Tribes, and consultants. WWA is also trying to understand how this physical information feeds into the decision-making process. Initial findings from this work indicate that there is broad and deep confusion over the variety of available climate change scenarios and how differences affect Colorado River flow projections.

Ongoing Stakeholder Engagement and Collaborations

During 2008, WWA continued to be a trusted source of climate information for stakeholders and decision makers. Collectively, WWA researchers gave more than 60 public talks and seminars, were cited or quoted by the media more than 75 times, sponsored several streamflow and drought workshops in the Intermountain West, and served as members of many committees and organizations. Our partners are diverse, including non-governmental organizations, local water providers, state universities and governments, and federal agencies.

MARK LOSLEBEN, UNIVERSITY OF ARIZONA

Jeff Lukas holds a cross-section cut from a long-dead bristlecone pine in Colorado's South San Juan Mountains.

EDUCATION AND OUTREACH

- Climate Science Education
- Quake Cruise
- Sun-Earth Connections for Students and Teachers
- Mountain Mariner Challenge

The research conducted at CIRES provides knowledge that helps society build a sustainable future. The CIRES Education and Outreach (EO) group builds bridges between CIRES research and the rest of society. The work we do extends the expertise of the Institute into the community, to meet real needs. We help scientists increase their professional contributions through the development of science-literate citizens and students.

Our work emphasizes scientific inquiry, links to current research, and foundational concepts in geosciences education. Highlights of our work in FY09 are described below.

Climate Science Education

The "Making climate hot: Effectively communicating climate change" workshops provide research-based professional development in how to communicate climate change. Participants practice climate communication strategies, including ways to address controversy with the general public and in classrooms. EO worked with a variety of audiences, including groups at NOAA's Earth System Research Laboratory (ESRL), the American Geophysical Union Fall Meeting, the National Weather Service Western and Central regions, the Alliance for Climate Education, environmental educators, teachers, and undergraduate students.

A second workshop, "Climate 101," continued our support of the NOAA-led "Essential principles of climate sciences" (EPCS) framework. EO has been a part of this NOAA-led effort since inception, and the EPCS has recently been adopted as an official education and outreach document of the U.S. Climate Change Science Program. EO participated in several national conferences and workshops to promote the EPCS and climate literacy in pre-college education.

NOAA-supported research by an EO Visiting Fellow investigated the instructional practices of Colorado teachers around controversial topics such as evolution and climate change. The study is the first of its kind to examine U.S. teachers' views and teaching practices on climate change. Data indicate that nearly half of Earth and physical science teachers in the sample formally address climate change in their classes, but many hold a mixture of scientific and nonscientific perspectives on climate change.

Several new workshops for teachers were offered in FY09. A workshop for teachers on "Teaching climate change: Impacts in Colorado" was held at the University of Colorado Mountain Research Station. A new workshop series, "Oceans and climate," features NOAA researchers from ESRL. Teachers from Colorado and California participated in person or via videoconference.


CIRES

Teachers at a CIRES climate change workshop.

Quake Cruise: What's Shakin' Under the Sea?

Teacher-at-Sea Dan Tomlin and CIRES Fellow and geophysicist Anne Sheehan traveled to the Southern Ocean near New Zealand to install 30 earthquake-monitoring instruments on the ocean floor. Schoolchildren and members of the public submitted ideas for projects to be done while onboard, vied for prizes, and followed along on the Quake Cruise blog.

CIRES

CIRES' Klaus Wolter speaks with teachers at a "Teaching Climate Change" workshop.

Sun-Earth Connections for Students and Teachers

New offerings include an after-school unit on geomagnetism developed in partnership with the NOAA National Geophysical Data Center. Students participating in Colorado's Math Engineering and Science Achievement (MESA) program apply geomagnetism concepts through hands-on activities and outdoor orienteering activities. Space weather outreach included a workshop for teachers, tours of the NOAA Space Weather Prediction Center for teachers and students, and improvement of the MESA Space Weather modules for use after school. This work is funded through the NASA Solar Dynamics Observatory in partnership with LASP.

Mountain Mariner Challenge National Ocean Sciences Bowl (NOSB)

The 11th annual NOSB Mountain Mariner Challenge drew 11 high school teams from Wyoming, Colorado, Utah, and South Dakota for a fast-paced, quiz bowl event. The Mountain Mariner Challenge is NOSB's regional competition, sponsored by the Consortium for Ocean Leadership. Smoky Hill High School of Aurora won the challenge and traveled to Washington, D.C., to compete in national finals. More than 50 scientists and staff from CIRES, NOAA, and the community volunteered to make the event fun and challenging for some of the most accomplished students in the region.

Learn more

about CIRES educaton and outreach programs at cires.colorado.edu/education

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

Jonathan Bamber

Sabbatical
Ph.D., University of Cambridge, UK
Sponsor: Konrad Steffen
Theme: Climate System Variability
Project: Constraining the mass balance of the Greenland Ice Sheet

Jonathan Bamber is a professor of physical geography at the University of Bristol, UK. His main interests are in polar glaciology and meteorology and, in particular, how the ice sheets covering Antarctica and Greenland will, and have been, responding to climate change. While at CIRES, he is working with colleagues on a range of problems related to determining the present-day mass balance of the ice sheets and the relative roles of surface processes versus ice dynamics. Bamber's primary expertise lies in satellite and airborne microwave remote-sensing observations of surface and basal topography, ice motion, and surface processes. His interests, however, are pretty broad and he is also currently working on regional climate modeling of Greenland and Svalbard, fingerprinting the sea-level signature of ice sheet melt, and uncertainty analysis in climate modeling. He is enjoying a year of collaborations, discussions, and a few beers with colleagues at the University of Colorado at Boulder.

David De Haan

Sabbatical
Ph.D., University of Colorado
Sponsor: Maggie Tolbert
Theme: Atmospheric Chemistry
Project: Direct analysis of reactions between glyoxal, methylglyoxal, amino acids, and glycerol during cloud processing

David De Haan is feeling a little déjà vu, back at the University of Colorado at Boulder 15 years after earning his doctorate in John Birks' research group. Today, De Haan is working on the chemistry of aldehyde uptake by aerosol, and his lab experiments are set up in space formerly occupied by the Birks group.

"One day in 1990, John walked into the lab and proposed conducting some flow tube experiments on the chemistry of chlorine peroxide, a chemical involved in chlorine-catalyzed stratospheric ozone depletion, on ice surfaces," De Haan said. "I've been happily working on aerosol chemistry ever since."

A native of Los Angeles' smoggy inland valleys, De Haan soon became involved in the chemistry of smog haze. "Although ground-level ozone levels in L.A. are much better (lower) than they used to be when I was growing up, visibility hasn't improved at all," he says. "The fact that there are still so many aerosol particles blocking our view means that we don't fully understand how those particles form, and so regulations can't be effective."

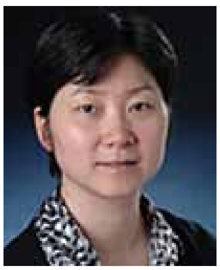
At CIRES, De Haan is unraveling the mechanisms of aerosol formation via cloud and fog droplets. Highly water-soluble gases like glyoxal and methylglyoxal dissolve into water droplets, but when those droplets evaporate, these compounds begin to polymerize rather than evaporate. In the presence of amine compounds, light-absorbing brown polymers form. "Scientists have found brown, nitrogen-containing polymers in atmospheric aerosol," De Haan explained. "This could be where they're coming from."

Until a few years ago, it was thought that glyoxal and methylglyoxal could not form aerosol. Now, they look like major sources. In urban areas, glyoxal and methylglyoxal are mainly produced by atmospheric oxidation of the aromatic components in gasoline. "It's possible that replacing these components with ethanol will finally clear the air," De Haan said.

De Haan is an associate professor of chemistry at the University of San Diego, USD, where he teaches technology-rich courses in analytical and environmental chemistry and leads a research group made up entirely of undergraduate students. During 2008-2009, four USD students will participate in summer research at CIRES. "Early research experiences are what draw people to careers in science,"De Haan said. "That's how I got pulled in."

Yue Deng

Postdoctoral
Ph.D., University of Michigan
Sponsor: Timothy Fuller-Rowell
Theme: Advanced Modeling and Observing Systems
Project: Assess the impact of non-hydrostatic processes on the response of the thermosphere/ionosphere system to magnetospheric forcing



The ionosphere and thermosphere are two overlapping regions of the upper atmosphere that are tightly coupled. The ionosphere represents the plasma and the thermosphere represents the neutral constituents in the upper atmosphere, and the coupling between them shows the strong plasma-neutrals interaction. Understanding of the ionosphere/thermosphere system under different magnetospheric conditions is important for a number of space research and space weather applications. For example, following a space weather disturbance, intense currents flowing from magnetosphere into the ionosphere/thermosphere dramatically increase the Joule heating and expansion of atmosphere, which strongly alters the orbit of satellites around the Earth. Meanwhile, ground induced currents can cause serious problems to pipelines, transoceanic cables, and power lines. It is vital to understand the variability within this critical region of our atmosphere so that scientists can predict its effects on satellite tracking and power grids.

During her doctoral dissertation research at the Atmospheric, Oceanic, and Space Sciences department at the University of Michigan, Deng co-developed a new three-dimensional Global Ionosphere-Thermosphere Model (GITM). As a critical part of the Space Weather Modeling Framework, GITM is the first global non-hydrostatic model in the upper atmosphere and is flexible to extend to other planets and their moons, such as Mars and Titan. She subsequently conducted scientific research on the magnetosphere and ionosphere/thermosphere coupling using GITM and instrumental measurements. Lately, Deng broadened her postdoctoral research at both the National Center for Atmospheric Research (NCAR) and CIRES by investigating the hydrostatic models, such as NCAR-TIEGCM and CTIP, which are well developed and highly recognized in the community. She is also working with the data-assimilating model, Assimilative Mapping of Ionospheric Electrodynamics, combined with measurements from ground-based instruments and satellite observations. Deng's "exciting" work in space physics and numerical simulation built up her strength, interests, and passion for the research of the magnetosphere and ionosphere/thermosphere coupling.

Jérôme Lavé

Sabbatical
Ph.D., University of Paris
Sponsor: Roger Bilham
Theme: Geodynamics
Project: Mountain evolution in response to tectonic and erosive processes

Jérôme Lavé is one of the most active researchers in erosion and active tectonics in France. After studying geophysics at the University of Paris, where he earned his Ph.D. in geophysics in 1997, Lavé worked as a postdoctoral scholar at Pennsylvania State University before getting a permanent position at the French National Center for Scientific Research (CNRS) in 1999. Until 2007 he was working at the Laboratoire des Chaînes Alpines (LGCA) in Grenoble, France, and recently joined the Centre de Recherches Pétrographiques et Géochimiques (CRPG) in Nancy.

Lavé is driven by an attempt to deepen our understanding of the building and erosion of terrestrial relief, and of the processes that drive mountain evolution in response to both tectonic and climatic forcing. For a decade, he has been tackling the problem of stream incision, in particular, with projects involving field work, experimental and numerical approaches, and the development of new sensors to monitor fluvial erosion during floods. He has been also working for 15 years in the Himalayas, identifying its seismotectonic behavior, measuring erosion rates and processes, and studying fluvial terraces and glaciers for paleoclimate reconstructions.

Because mountains are so fascinating, Lavé has mainly focused his research on active collision zones (Himalaya, Zagros, Longmen Shan), where large topographies are presently built. However he is curious about many natural phenomena, and has demonstrated broad interest in Earth sciences problems from seismic anisotropy to palaeoclimate, including crustal seismotectonic, landscape erosion, sediment tracking and abrasion, numerical modeling of geomorphic processes, and the use of cosmogenic nuclides for paleoaltimetric or morphoclimatic issues.

At CIRES, Lavé is working on the development of new erosion sensors, and on the seismotectonics of the Himalayas. He is also collaborating with CIRES Fellows Peter Molnar (to document the mechanical response of the crust and lithosphere to a localized zone of high erosion), and Gregory Tucker (to incorporate sediment evolution by abrasion into Tucker's landscape evolution model, CHILD).

Anita Rapp

Postdoctoral

Ph.D., Colorado State University
Sponsor: Chris Fairall
Theme: Climate System Variability
Project: Investigation of the precipitation process in marine stratocumulus clouds

Anita Rapp is interested in the remote sensing of clouds and precipitation and their application in studying the hydrologic cycle, energy budget, and climate change. Her focus at CIRES is on investigating the precipitation process in marine stratocumulus clouds in the tropical eastern Pacific Ocean.

Marine stratocumulus clouds play a critical role in our climate system, and recent studies have shown that drizzle from these clouds is much more prevalent than previously thought. However, the conditions under which precipitation forms and the feedback of the precipitation on cloud structure remain poorly understood.

Rapp is investigating these clouds through a multi-platform study combining measurements from multiple satellite, surface, ship, and aircraft platforms to perform a comprehensive analysis of drizzling marine stratocumulus clouds in the southeastern Pacific.

This work entails studying the influence of environmental variables, such as sea-surface temperature and water vapor, on the microphysical and radiative properties of these clouds, as well as how changes to warm rain clouds might in turn affect the recycling time scales for deep convective events in the tropics, such as tropical-depression type disturbances.

Melanie Roberts

Postdoctoral

Ph.D., University of Washington
Sponsor: Roger Pielke Jr.
Theme: Integrating Activities
Project: What organizational models best promote the utilization of university-generated knowledge by society?

Policy makers and the public trust that investments in university research will lead to economic growth and solutions to enormous societal needs, such as energy independence. There is no doubt that universities have made significant contributions to society, but is it possible to do even more?

This question motivated Roberts to return to academia—after two years in the federal government—to study how to better utilize university-generated knowledge for societal needs. As a visiting fellow at CIRES' Center for Science and Technology Policy Research, she is exploring several different research questions related to this topic. Whether and how do scientists and engineers communicate their research results to potential users? What is the effectiveness of different knowledge transfer mechanisms—such as extension offices, engaged research, and open innovation—to harness university-generated knowledge for societal needs? Roberts is also co-designing a participatory ethics course to help scientists and engineers better connect expert knowledge with local and global sustainability projects.

Prior to her CIRES fellowship, Roberts was an AAAS Science and Technology Policy Fellow in the office of Senator Jeff Bingaman (2006-07) and in the Division of Social and Economic Sciences at the National Science Foundation (2007-08). In these positions, she took a lead role in several initiatives related to policy for innovation and competitiveness, science and technology advice for Congress, regulatory policy, interdisciplinary and transformative research, and ethics education policy.

Roberts completed her Ph.D. in neurobiology and behavior from the University of Washington in 2005. While at UW, she founded both the Biocareers Seminar Series and the Forum on Science Ethics and Policy, an interdisciplinary organization that promotes dialogue about the role of science in society among scholars, the public, and policy makers.

INNOVATIVE RESEARCH PROGRAM

The CIRES Innovative Research Program (IRP) encourages novel, unconventional, or fundamental research that might otherwise be difficult to fund. Funded projects are inventive, sometimes opportunistic, and do not necessarily have an immediate practical application or guarantee of success. This program supports pilot or exploratory studies, which may include instrument development, lab testing, field observations, or model advancement. Below are IRP winners from two years, 2008 and 2009.

2008 awards

2009 awards

A micro blue/green laser for unmanned aerial systems (UAS) geoscience research

John Adler (CIRES), Steve Mitchell (CU Aerospace Engineering), and Xinzhao Chu (CIRES)

Adler and colleagues are working to develop a micro blue/green laser profiler for use in multiple scientific arenas. The small size of this water-penetrating laser system will pave the way for new and innovative scientific measurements from an unmanned aerial system (UAS) such as:

- obtaining profiles of supraglacial lakes that form on portions of the Greenland ice sheet
- determining actual snow depth measurements on the surface of sea ice, used in conjunction with a micro snow-penetrating radar
- determining coral reef depths in areas such as the Hawaiian National Marine Sanctuary

The laser system's small size (<5 kg) will allow it to be integrated into UAS along with other existing micro sensors to obtain unique datasets. Some small UAS have extended mission durations (>20 hours), and can operate from areas without airfields.

This project is truly multi-disciplinary: CIRES is the catalyst, members of the CU-Boulder engineering department will build the device, and CU-Boulder geography students will evaluate initial results.

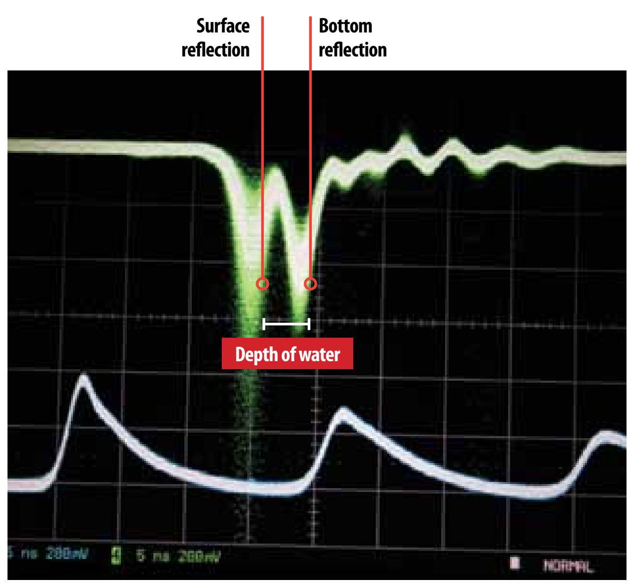
The newly developed blue/green laser profiler will be tested with an existing small near-infrared (IR) laser system developed by James Maslanik, of the CU-Boulder Aerospace Department. This combination of laser altimeters will allow for direct determination of depth. The blue/green laser, operating at approximately 500 nm, will be able to "see" furthest into the water, reflecting off the bottom. The near-IR laser will record its reflection off the surface of the lake, so differencing the two will enable determination of lake depth. After flying multiple profiles, total lake volume can be calculated.

Light detection and ranging (lidar) has been used since the 1970s to measure distances between the laser and the item of interest. The distances can be determined between an aircraft and many surfaces, such as ice, land, or snow. The blue/green laser systems currently in existence are large and heavy, unsuitable for use on a UAS. Although there are a few small near-IR laser systems, such as Maslanik's, they are constructed with existing off-the-shelf components. Contacts with industry representatives revealed that there is no market for a small, blue/green laser range finder, so it must be custom built. Rough estimates higher than $80,000 were given to develop this commercially. This project should reduce costs and risk by building a nadir-viewing blue/green laser profiler to obtain the range distances.

CIRES

John Adler explains how the blue/green laser he is developing with Steve Mitchell will be able to measure the depth of supraglacial lakes. The instrument, inset, is small enough to mount on an unmanned aerial system, and will be significantly less expensive than traditional laser systems.

Calculating the difference between the initial pulse of the green laser and its reflection off a surface provides researchers previously elusive accuracy in measurments from remote locations.



Small-scale atmospheric turbulence, with implications for modeling and prediction

Ben Balsley (CIRES), Lakshmi Kantha (CU Aerospace Engineering), and Allen White (NOAA ESRL)

Turbulent diffusion and transport in the atmosphere are vital to the prediction of the state of the atmosphere and are at present poorly parameterized in global climate and weather forecast models. A major reason for this lies with the paucity of turbulence measurements in the troposphere and the lower stratosphere (0-30 km). This project should remedy the shortcoming.

Recent work by the Balsley group has shown that small-scale turbulence in the lowest few kilometers of the nighttime atmosphere is surprisingly ubiquitous, strongly structured, and extremely variable. This challenges the conventional wisdom that the atmosphere is, by and large, in laminar flow, with only occasional regions of turbulence.

Informal discussions with members of the modeling community agree that, 1) turbulence transport and diffusion are poorly parameterized in general circulation and weather models; and 2) the inclusion of an average value of an enhanced turbulence diffusivity/viscosity term in these models would be important and could significantly improve predictability.

Members of the Balsley research group have begun to extrapolate some lower-atmospheric techniques to include the entire troposphere and stratosphere. Unfortunately, the best available untethered balloon data have relatively poor vertical resolution. While useful, these data are incapable of resolving the smaller scales where the Richardson number (Ri) could be ≤0.25.

For this project, Balsley's team is producing a small series of similar profiles using significantly better resolution. To better connect with the community involved in small-scale processes, the group is cooperating with Lakshmi Kantha (Aerospace Engineering). Kantha, who has an extensive background in small-scale dynamics in both the ocean and atmosphere, has been in contact with the Väisälä Corporation near Boulder, which provided balloons and sensors for the original measurements. Discussions with Väisälä representatives suggest that the earlier measurements could be improved by a factor of three or four by reducing the current ascent rate of about 5 m/s and sampling faster than the current rate of 0.5 Hz. The telemetry receiver required for data acquisition costs about $65,000. However, Allen White of NOAA's Earth Systems Research Lab, who has the requisite receiver, joined in this effort. White is a meteorologist and a leader in the innovative use of new technology and has experience in the use of Väisälä systems.

The research team expected to launch 20 radiosondes during a period of a week or two to a height of roughly 25 km, with the intention of sampling the atmospheric column at a vertical resolution of about 2.5 m. The sonde is expected to take nearly three hours to sample the atmospheric column. The resulting profiles will be analyzed to demonstrate the ubiquity of dynamical instability at small scales and hopefully change the paradigm when it comes to modeling turbulence in the atmospheric column. The team expects to submit a journal paper within a year after the data is collected, and to develop an NSF proposal based on successful results.

Acidic trace gases emitted by forest fires

Joost de Gouw and Carsten Warneke (CIRES), and Jim Roberts (NOAA)

This group is using a newly developed chemical ionization mass spectrometer (CIMS) to measure acidic trace gases from burning vegetation at the Fire Sciences Laboratory operated by the U.S. Forest Service in Missoula, MT. The goal is to quantify the atmospheric source of organic and inorganic trace gases from forest fires, which are suspected to be a large fraction of the total emissions, and to assess their potential to contribute to aerosol formation.

Forest fires are one of the important issues at the nexus of air quality and climate change. The frequency and intensity of wildfires is widely expected to increase due to global change with far reaching consequences for air quality, the global carbon cycle and climate change. Emissions from wildfires in the western United States have the potential to impact air quality at large distances from the sources. Also, a significant fraction of atmospheric aerosol has been shown to originate from biomass burning, with important ramifications to the direct and indirect effects of aerosol on climate.

There are still many unknowns about the emissions of trace gases and aerosol from forest fires. Part of this is caused by the unpredictability of fires, which hinders systematic field studies. Much has been learned from experimental burning, for example at the Fire Sciences Laboratory. From these studies it is clear that a large fraction of the gaseous emissions consists of oxygenated organic species, acids in particular—an observation that has been confirmed by field measurements. Acidic trace gases are among the hardest trace gases to measure, however, and as a result good data exist only for the two simplest organic acids (formic and acetic acid). We have recently developed a novel CIMS method to measure acidic trace gases based on the use of acetate ions, $CH_3C(O)O^-$, which readily react with most organic and many inorganic acids by proton transfer. De Gouw, Warneke and Roberts took the CIMS instrument to the Fire Sciences Laboratory and to measure the acidic trace gases emitted from burning vegetation collected in different areas of the country (California, Arizona, North Carolina, and Florida).

Existing methods for organic acids are time-consuming, prone to measurement artifacts, and only provide long-term averages, making them unsuitable for following the rapidly changing concentrations in a transient fire experiment. The new method has 1) a fast time response (1 sec) to evaluate the acid/CO and acid/CO_2 ratios in real time,

CIRES/NOAA

An experimental burn at the Fire Sciences Laboratory in Missoula, MT.

2) a high sensitivity (20 pptv) to measure even the smallest emissions, and 3) can be used for a much wider range of species than previously observed.

This work will potentially provide the first emission factors for a wide range of organic and inorganic acids from forest fires. These emission factors are important inputs to analyses and models that assess the regional to global effects of biomass burning. In addition, the emission ratios from this work will be very useful for the interpretation of field data, including, for example, data as we hope to obtain from NOAA's CalNex study in California, planned to start in 2010.

How much do Langmuir circulations matter for climate?

Baylor Fox-Kemper (CIRES), Keith Julien (CU Applied Mathematics), Gregory Chini (University of New Hampshire), and Edgar Knobloch (University of California at Berkeley)

Fox-Kemper and colleagues are estimating the effects of the Langmuir cells—small wind- and wave-driven overturning cells in the near-surface ocean—in the context of global climate models. The goals of the research are implementation of a rough parameterization of Langmuir cells into the ocean component of the National Center for Atmospheric Research's Community Climate System Model (NCAR's CCSM) and documentation of the climate impact versus a control run. Including this effect will quantify a novel climate sensitivity, foster interdisciplinary cooperation, and provide a framework for bringing new mathematics into practical use in climate models.

Langmuir cells are one of the most recognizable near-surface mixing processes in the ocean. The long, parallel "windrows" of surfactants and bubbles that form along the direction of the wind at the convergences of the Langmuir cells are well-known to beachgoers. Since the early description of this phenomenon and its mathematical underpinnings, much progress in modeling and theory has been made. It is obvious from the windrows themselves that the transport of tracers and water due to Langmuir cells can dominate other near-surface processes at times, and this transport has been documented to overturn the entire mixed layer in a matter of hours.

Langmuir cells are an intriguing phenomenon in themselves, but it is their impact on climate that is the issue here, because it remains a largely unexplored topic. Recently, other small-scale, near-surface phenomena have been shown to have substantial climate impact (e.g., submesoscale eddies). The climate impact derives from

COURTESY OF CREATIVE COMMONS

Langmuir circulation windrows in Rodeo Lagoon, CA.

the important role of the near-surface ocean—often called the mixed layer—acting as a alter for the air-sea exchange of heat, momentum, and gases. Furthermore, these near-surface phenomena should have a large effect on biology and the carbon cycle, as the euphotic zone of the ocean—where there is enough light for photosynthesis—exists mostly within the mixed layer.

Langmuir cells are sensitive to both wind stress and wave strength. Boundary layer turbulence parameterizations do depend on wind stress, but in a different way than Langmuir cells, and the effects of surface wave magnitude are neglected altogether in climate models. Regions with both significcant wave activity and strong winds are often where air-sea contact is important (e.g., Mode/Deep water formation sites, the Southern Ocean, and tropical upwelling regions).

If this research finds sensitivity of global climate models to the effects of Langmuir circulation in regions of climatic importance, it will support continued interdisciplinary collaboration and bring cutting-edge applied mathematics into practical use in global climate modeling.

Testing the accuracy of channel erosion rates with cosmogenic radionuclides

Scott McCoy and Gregory Tucker (CIRES)

McCoy and Tucker are testing a novel method for measuring rates of channel incision during thousand-year time scales. The method uses the gradual accumulation of cosmogenically produced radionuclides (CRNs) in near-surface rock as a measure of the speed of surface lowering. The assumptions required in applying this method to active bedrock channels have never been tested, and this work takes advantage of a one-of-a kind dataset of channel incision rates near active earthquake faults in the Italian Apennines.

A central focus of geomorphology has been the explanation of diverse observed landforms in terms of the physical processes that have created them. Much of the recent progress has come from the development of "geomorphic transport laws." These physically based rules express mathematically how a particular process moves mass downslope and changes the elevation of the surface of interest. By explicitly representing the dependence of mass transport on the parameters controlling the process (e.g., channel gradient or water discharge), it is possible to explore how changes in external variables such as land use, climate, or tectonics would be manifested in the landscape.

Studies have shown that the sculpting of dramatic ridge-valley topography in mountain ranges mainly derives not from rivers, but rather by the occasional, violent surges of rock and mud known as debris flows. Yet there is not an agreed upon geomorphic transport law for what controls the rate of channel incision by debris flows. This makes it difficult to predict how steep portions of a landscape will respond to changes in climate and tectonic variables or what the consequence of changing land use would be. Recent publications describe speculative geomorphic transport laws for debris flows, but they remain untested due to the lack of data.

PHOTOS BY SCOTT MCCOY

Debris flow channel in the Italian Apennines.

Finding radiofrequency identification tracer rocks at Chalk Cliffs, CO.

Field-measured erosion rates are essential to validate and further develop debris-flow geomorphic transport laws. Unfortunately, in these steep debris flow channels, the common methods of using dated remnants of the previous channel location are not possible due to lack of preservation. The only other viable method to obtain the erosion rate at a point is to use rates determined from the concentration of CRNs in the bedrock of the active channel. This method has not been favored due to the difficulty in constraining how the accumulation of CRNs in the bedrock has been affected by shielding due to an unknown history of sediment cover. We are aware of only two studies that have used this method on bedrock channels, and both studies simply assume that the sediment cover has been negligible during the past 10^2-10^3 years, due to the current channel being devoid of sediment. We are testing this assumption. If it can be shown that this assumption is valid in steep, actively incising channels, we would have grounds to move forward in using this method in similarly steep and active settings where the erosion rate is not known.

This validation is possible due to two features of the proposed field site in the Italian Apennines. First, the debris flow channels are in local equilibrium with the rate of base-level lowering due to throw on the normal faults that they cross. Equilibrium is implied by the smooth channel profile over the fault and lack of preserved scarp in the channel. This indicates that the local rate of channel incision is equal to the throw rate on the fault. Second, researchers have precisely documented the slip history during the last 12 ka using ^{36}Cl on the Magnola fault. In addition, our colleagues are currently in the process of collecting similar data for five additional faults. This fault displacement data provides unprecedented documentation of slip history over precisely the time scale that it is possible to measure erosion rates using in situ CRN (10^2-10^3 years). This unique match of timescales makes it possible to test the accuracy and precision of our proposed CRN determined erosion rates.

If we can demonstrate that through appropriate site selection CRN-derived active channel erosion rates are accurate and reproducible, we and others will have grounds for using this unconventional technique in a full-scale study of channel erosion rates across similarly steep and active channel networks. A subsequent full-scale study of debris flow channel erosion rates would provide data necessary to better understanding how steepland evolves.

Is absence of sea ice a causal factor in recent Antarctic ice shelf breakups?

Ted Scambos (CIRES) and Robert Massom (Australian Antarctic Division and Antarctic Climate and Ecosystems Cooperative Research Centre, Australia)

Satellite images from February and March of 2008 indicated the southwestern part of the Wilkins Ice Shelf was undergoing an abrupt Larsen B-style breakup event. The event marked the latest in a series of similar ice shelf disintegrations, which have become iconic indicators of rapid climate change in the world's ice.

Ice shelves are sensitive climatic indicators, and it is important to fully understand the processes responsible for their recent rapid and abrupt demise. The shelf breakup events around the Antarctic Peninsula during the past two decades have removed features that appear to have been stable during previous several centuries to millennia, and have major physical and ecological ramifications

To date, the breakups have been linked to intense summer surface melt in the years prior to breakup, associated with a regional air temperature warming trend of 0.5 ºC per decade. A hydro-fracture model for the breakups has been proposed, and additional factors may come from 'toppling block' forces within the fractured ice shelf, and natural weakening by rift formation. An additional common factor, hitherto unstudied, is a complete absence of sea ice cover at the ice shelf fronts, preceding the events for several weeks.

This IRP work addresses the following questions:

■ Is the removal of sea ice a necessary precursor to the ice shelf breakup events?

■ What role might incoming wave energy (un-damped by sea ice) play?

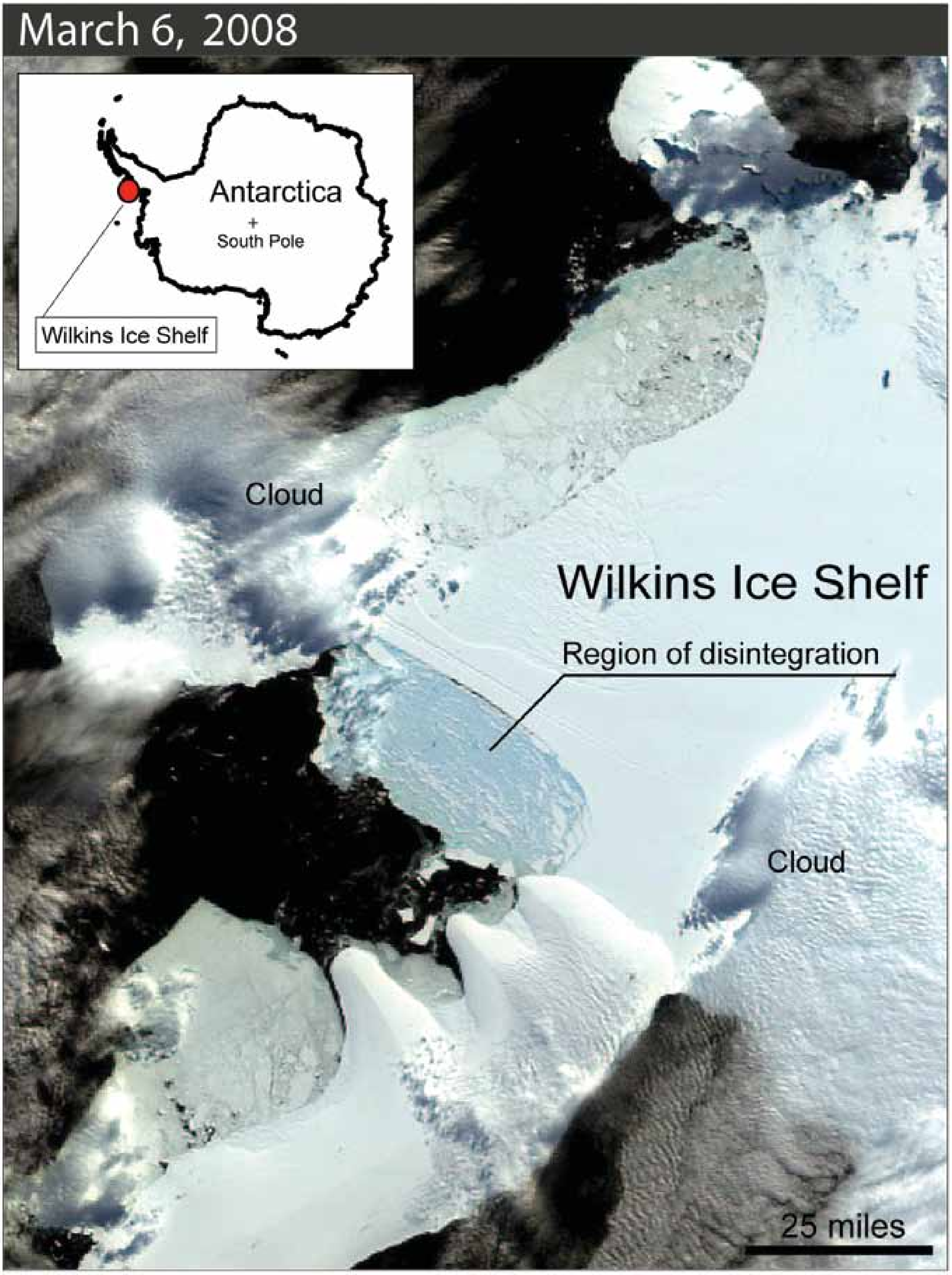
■ What role might solar warming of (ice-free) ocean surface water play?

■ How do these potential factors intermix with the current known contributing factors (ice shelf melting, melt ponds, thinning, rift weakening) to cause a catastrophic breakup?

■ Can we gain further insight into the specific mechanisms behind the 'crumbling' process of the runaway calving (e.g., toppling blocks, other factors)?

We are addressing these questions by analysis of satellite imagery and data, meteorological data (station and reanalysis), in situ observations, ocean wave model data, and a state-of-the-art model including wave-ice shelf-sea ice interactions. The latter simulates how ice-coupled waves traveling beneath a uniform, floating sea-ice sheet propagate into a second sheet of different thickness (i.e., an ice shelf 200-300 m thick) by way of an arbitrarily defined transition region (e.g., fast ice). The model is being fine-tuned and output compared with observations in the period leading up to breakup events. The impact of the presence or absence of the protective pack/fast ice "buffer" on wave energy entering an ice sheet will be investigated by turning it on and off in the model. This will provide insight into the possible effect of anomalous exposure of the ice shelf to enhanced destructive ocean wave/swell energy associated with a negative sea ice extent anomaly. In the case of the current Wilkins breakup, wave energy may have reached the ice front from a severe storm to the northwest in late February. We are further testing the hypothesis that long-period ocean swell from far-remote storms—energy propagating vast distances in the ocean—may have contributed to or even triggered the abrupt ice shelf calving. The analysis will also consider the timing, extent, and severity of melt on the Wilkins ice shelf surface, and melt day trends during the past 20 years.

The work will compare the present Wilkins breakup with similar past breakup events, and also those of the Larsen A and B ice shelves in 1995 and 2002, respectively. Further south, Larsen C has thinned and continued warming


March 6, 2008
Antarctica
South Pole
Wilkins Ice Shelf
Cloud
Wilkins Ice Shelf
Region of disintegration
Cloud
25 miles

NSIDC

could lead to its breakup within the next decade. Can we forecast breakups based on sea ice and climate anomalies?

Ice shelf distintegration events underline the complexity of an Antarctic system undergoing rapid change, and highlight the need to understand the links between different components of the cryosphere. The Antarctic Peninsula may well be a model for a future, warmer Antarctica—with future changes occurring at a greater scale, and speed, than was previously considered possible.

Measuring low water vapor mixing ratios using mass spectrometry

Troy Thornberry (CIRES and NOAA ESRL), Ru-Shan Gao (NOAA ESRL), and David Fahey (CIRES and NOAA ESRL)

Thornberry, Gao, and Fahey are designing and building a prototype instrument, using mass spectrometry, capable of fast response (<1 s) measurements of water vapor at the low (1-10 parts per million, ppm) mixing ratios typical of the upper troposphere and lower stratosphere (UT/LS).

Water vapor is the most important greenhouse gas in the atmosphere and represents a major feedback to warming and other changes in the climate system. Understanding the distribution of water vapor and how it is changing due to climate change is especially important in the UT/LS, where water vapor plays a critical role in determining atmospheric radiative balance, cirrus cloud formation, and photochemistry. Dehydration processes reduce water vapor amounts to ppm values in the UT/LS. The microphysics related to dehydration and cirrus cloud nucleation are poorly understood, limiting our ability to accurately model the dehydration process and, hence, our ability to estimate the influence of climate change on the UT/LS water vapor distribution.

Part of this limitation derives from the large uncertainty in available water measurements in the 1-10 ppm range typical of this region of the atmosphere. For example, in situ instruments operated on airborne platforms in the UT/LS consistently show significant disagreement (about 25-50 percent) at low water values. The consequence of these differences is that there is a wide range of supersaturation over ice observed in the UT/LS, with the largest values being higher than 200 percent (which is inconsistent with our understanding of the fundamental microphysics of ice formation). A technique that combines an in-flight internal reference measurement with high sensitivity and fast time response, and that could be developed into a small payload instrument (<50 kg) for deployment aboard a high-altitude aircraft or unmanned aircraft system would do much to advance the state-of-the-science regarding water vapor in the UT/LS.

The new instrument now in development uses a fundamentally different analytical technique than the extant instruments, which have produced divergent results at the lower mixing ratios. Thornberry et al.'s approach includes several potential advantages, including 1) an internal reference measurement for determining water vapor mixing ratio, 2) insensitivity to ambient condition changes, and 3) low detection limit. This instrument has the potential to contribute to the ongoing community effort to understand the processes controlling water vapor in the UT/LS. While confidence in the absolute mixing ratio and stability of calibration are the priority objectives with this new technique, the intrinsic fast response time of the instrument (< 1 s) will also provide an unprecedented view of the variability of water vapor in regions where microphysical processes, such as ice formation and sedimentation, are active. The fast response derives from the low inlet volume and the high sensitivity. Furthermore, the instrument will have high sensitivity for detecting water isotopes, which are an emerging diagnostic for the transport of water vapor into the UT/LS.

Exploring the role of bacteria in Atmospheric ice formation

Margaret Tolbert, Noah Fierer, and Ray Fall (CIRES)

Bacteria are abundant throughout the atmosphere and many bacteria are potent ice nucleators, capable of catalyzing ice formation at temperatures far warmer than those required for spontaneous ice formation. This may have important implications for local and regional climate patterns, as ice nucleation plays a key role in regulating precipitation events. This topic is remarkably understudied despite anecdotal evidence suggesting that bacteria may be important nucleators in the troposphere. Tolbert, Fierer, and Fall are addressing the following questions:

- How does the abundance and composition of airborne bacterial communities shift in response to changes in the atmospheric environment?

- What is the contribution of bacteria to tropospheric ice formation?

Addressing these research questions requires the adoption of a novel set of approaches and an interdisciplinary team (a microbiologist, an atmospheric chemist, and a biochemist) that can effectively bridge the disciplines of microbiology and atmospheric science.

Ice nucleators are often essential for the freezing processes that induce cloud formation and precipitation events in the troposphere, where temperatures may not be low enough to cause spontaneous freezing of supercooled liquid water. Although a wide range of organic and inorganic materials can function as ice nucleators, bacteria appear to be particularly effective ice nucleators as they are capable of initiating ice formation at very warm temperatures. Such ice-nucleating bacteria are commonly found in the troposphere and a large downward flux of ice-nucleating bacteria has been observed during precipitation events, leading to some speculation that ice-nucleating bacteria can modify weather by enhancing precipitation and cloud formation under certain conditions.

Not suprisingly, much of the evidence in support of this proposed "bioprecipitation" cycle is anecdotal. We do

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Christopher Williams works on the prototype of his less expensive vertical-profiling radar. The system uses a Sony PlayStation to process inputs from a set of three $200 radar dishes.

not know how ice-nucleating bacteria compare to other ice-nucleating agents present in the atmosphere with respect to their weather-altering capabilities, nor do we know how the abundances of ice-nucleating bacteria in the atmosphere vary across time and space, or if this variability has any influence on weather dynamics. Although the bioprecipitation cycle remains to be verified, it is an intriguing avenue of research and a potentially important type of biosphere-atmosphere interaction.

This work represents the first comprehensive study examining bacteria in the troposphere and their role as ice nucleators. This work will demonstrate how bacterial communities respond to atmospheric conditions, and it will also allow us to determine how bacteria may be able to directly alter atmospheric conditions by functioning as ice nucleators. If bacteria do indeed have the capacity to alter precipitation patterns, it would be an astounding finding as it would represent a novel mechanism by which micron-sized organisms can influence atmospheric conditions evident at kilometer-scales. Our results are likely to be of interest to researchers in a range of scientific disciplines, as we are linking the fields of atmospheric science and microbiology, usually considered to be non-overlapping entities. This project will not provide all the answers, but it will substantially improve our understanding of a unique biosphere-atmosphere interaction, and should yield a solid set of results that can be leveraged to obtain additional funding.

Sony PlayStation for science: Developing a dual-frequency radar to study precipitation

Christopher Williams (CIRES and NOAA ESRL)

Christopher Williams is developing an inexpensive dual-frequency vertically pointing precipitation profiling radar, using technologies developed for the mobile phone, the police radar, and video games.

Better observations of precipitating cloud systems are needed to improve our understanding of microphysical and dynamical precipitation processes. Better understanding will lead to improved model parameterizations of precipitation in high-resolution cloud-resolving models and global climate models. But with commercial profiling radars costing more than $200,000, it is cost-prohibitive for academics to purchase commercial radars for precipitation studies. This project involves a relatively small investment in time to understand technology developed for other industries, and use it in building low-cost precipitation profiling radars for research and educational applications.

A bistatic Frequency-Modulated Continuous-Wave (FMCW) radar uses two antennas to continuously trans-

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Don David begins mounting a radiosonde to a DataBird glider, for testing.

mit and receive frequency-modulated radio signals. The difference in the transmitted and received signal represents the distance and the motion of the targets within the radar's field of view. The proposed radar will generate two FMCW signals in the S- and X-frequency bands (near 2.8 and 10 GHz) with both signals being transmitted and received on the same set of antennas. The frequency modulation will use a linear ramp-up and ramp-down sawtooth pattern. The processing unit will need to be fast enough to sample the S-band signal during the ramp-up and sample the X-band signal during the ramp-down.

Two elements of this project are especially innovative. First, the transmitted signal is generated directly from voltage-controlled oscillators. The frequency modulation (FM) is produced by changing the input voltage from 0-4 volts. This simple and inexpensive device is the result of the mobile phone and police radar industries requiring low-cost components.

Second, this project uses a Sony PlayStation 3 (PS3) for the signal processing unit. The PS3 contains a Cell Broadband Engine (Cell BE) developed in collaboration with Sony, Toshiba, and IBM. The Cell BE has nine processing elements with the main processing element acting as a general-purpose dual-thread processor that distributes tasks in parallel to the eight other vector processors. The Cell BE is the fastest computational processor commercially available, and it costs less than $500!

The developed FMCW radar will be deployed at the NOAA Boulder Atmospheric Observatory next to a NOAA-owned commercial profiler, to evaluate performance. The two operating frequencies will have different attenuation properties through rain and will constrain the inverse modeling estimates of rain rate versus altitude. The radar hardware is expected to cost less than $12,000. With a proof-of-concept, funds can be requested from NSF or NASA to develop multiple (at least nine) profiling radars, to investigate the spatial and temporal structure of precipitating cloud systems over a 10-km^2 satellite footprint.

2009 PROJECTS

Developing an autonomous mini-glider to study small-scale atmospheric structure

Ben Balsley, Don David, and Ken Smith (CIRES)

Balsley, David, and Smith are developing a simple, effective, and inexpensive method for obtaining very high-vertical-resolution atmospheric measurements from the ground up to 10 km. The proposed platform—a small GPS-controlled glider—already exists and the research team has also already developed much of the necessary electronics for other projects. The team is combining existing sub-modules and rigorously flight-testing the device. If successful, the device can be used by the entire atmospheric science community.

Improved understanding of atmospheric dynamics requires a clear knowledge of local, small-scale, non-linear processes such as the breakdown of atmospheric gravity waves and other turbulence-generating mechanisms, as well as recently-discovered atmospheric "overturning" events. Typical vertical scales of these studies range from a few tens of meters on the largest scales down to 1-2 m, and probably even smaller. Current methods of profiling atmospheric quantities (e.g., winds, temperatures, humidity, and pressure) involve balloon-launched radiosondes with data normally archived every few hundred meters. In view of the emerging needs for high-resolution, vertically-measured profiles, conventional data are inadequate in at least two major ways: 1) the vertical resolution of the archived data is insufficient, and 2) since the data are obtained using wind-driven balloons, the resulting profiles are not vertically-oriented, and can be inclined from the vertical by as much as 70˚. It follows that high-resolution vertical profiles of atmospheric quantities throughout the troposphere and lower stratosphere do not exist.

Important emerging studies that require high-resolution, vertically-measured profiles include:

■ Breaking AGWs: With a vertical scale of a few tens of meters, breaking AGWs appear to supply the lion's share of energy for the generation of atmospheric turbulence. This turbulence underlies critically-important processes, such as turbulent transport and diffusion.

■ Turbulence, vertical wind shears, and temperature gradients: Small-scale atmospheric turbulence is truly ubiquitous, and its generation depends primarily on the vertical shear of the horizontal wind coupled with the vertical gradient of the potential temperature. The pertinent parameter is the gradient Richardson number, R_i, and atmospheric R_i values are strongly scale-dependent.

■ Atmospheric overturnings: Recent work at CIRES shows that, surprisingly, both the troposphere and lower stratosphere exhibit 'overturnings' on vertical scales of about 10-100 m. Fine-scale overturning in the atmosphere is a relatively unstudied phenomenon that needs to be better documented and understood, including understanding the processes responsible for the overturnings themselves.

■ Turbulence studies using clear air radars: If they have sufficient vertical resolution, wind-profiling radars are useful tools for studying AGWs and vertical turbulence structure. Unfortunately, although wind profilers measure both turbulence intensities and vertical wind gradients, they cannot measure the concomitant temperature gradients needed to compute local R_i values. This information requires separate relative high-resolution temperature profiles measured in close proximity to the vertically-directed radar antenna beam. R_i profiles would enable the first in situ comparison between measured and computed turbulent values, and their relation to overturnings.

The data needs described above can be met with a small, reusable, automated, GPS-controlled, glider system equipped with radiosonde sensors and a data logging module. This system will archive accurate temperature and reasonably accurate wind profiles between about 0-10 km with a vertical resolution of 2-4 m. In a typical operation, the glider (Databird) is launched beneath a conventional radiosonde balloon and carried to a pre-determined altitude (about 10 km). The Databird is then released and glides to a preset waypoint (e.g., over a radar antenna beam), where it begins a slow spiraling descent to a second waypoint near the surface. The glider then automatically glides to a prescribed landing site. Archived data are downloaded onto a conventional laptop computer.

Databird technology could potentially revolutionize studies of high-resolution dynamic processes in the free atmosphere. One can envision a series of Databirds making a sequence of such profiles every 20 minutes or so, to document the evolution of the observed processes. It is equally feasible to make simultaneous profiles separated horizontally by a few hundred meters (or more) to determine the horizontal extent of the processes (e.g., overturnings and AGWs) under study. Finally, CIRES Databird studies could also be expanded to fly lightweight chemistry sensors that would provide high-resolution profiles of chemical species (e.g., ozone, CO_2, H_2O) under varying conditions.

Quantifying 19th-21st century ice-volume loss in the Karakoram and Himalaya

Roger Bilham (CIRES)

Bilham is quantifying glacier deflation recorded by photographic scenes captured between 1880 and the present. Himalayan glaciers are shrinking rapidly but few have been studied quantitatively due to their inaccesibility. The glaciers currently provide a perennial water supply for agriculture in communities in the Himalaya, which, if current trends continue, may dry up in the next century. In Europe, London, and India, Bilham has discovered glass-plate collections of glaciers that record oblique views of glaciers north of Everest, in the Kanchenjunga region, in Kumaun, and in the glaciers of the Karakoram. It is the intention of David Breasheares, the mountain cinephotographer, to re-photograph these scenes from identical view angles and vantage points to provide the basis for a quantitative measure of glacier deflation. He has no tools or experience for quantifying the scenes, and recently approached CU-Boulder to ask whether we can provide this vital component of the research project.

The photographic archive is unique, and few have access to the raw oblique views of the glaciers. Corona images and subsequent space photography show glacial retreat but do not well-document the vertical ablation of glaciers. Bilham has access to the raw data in Kolkata, India and in the British Library. Breaseaers has access to collections in Zurich, Vienna, and the Royal Geographical Society. The availability of scenes during at least three times in the past century permits us to estimate an acceleration rate in glacial ablation.

Vittorio Sella served as "recording photographer" for the Duke of Abruzzi, who organized an expedition to the Karakoram in 1909. Sella also accompanied Douglas

The Himalayas.

Freshfield on his seven-week trek around Kangchenjunga, and the photographer acted as a photographic adviser to Gottfried Merzbacher, whose expedition was to the Tian Shan in 1902. N.A. Tombazi, "A Photographic Expedition to the Southern Glaciers of Kangchenjunga," includes photographs of Kangchenjunga's glacier in 1925, which will serve as data reference points 26 years after the Sella photographs in 1899. Tombazi printed only 125 copies of the book, one of which resides in CU-Boulder's Norlin library. The Kolkata archives include the original photos taken during an expedition from the Geologic Society of India, planned by T.D. LaTouche in 1909. It also includes Hayden's photos of glaciers in Sikkim, Oldham photos from Ladakh, and Heron's photos of the north side of Everest.

This pilot project is quantifying mass loss in individual scenes. From point measurements along certain valleys, we would estimate mass loss in individual glaciers (Bilham is working with CU-Boulder's Tad Pfeffer on the details of photogrammetric scaling), and extrapolate this to mass loss in glacial catchments depending on available data. We would then characterize the westward trend in glacial loss from Sikkim to Pakistan, using remote sensing (Bilham is discussing this issue with CIRES' Waleed Abdalati who is interested in the extrapolation problem). The ultimate product will be a complete ice-wastage estimate for the Himalaya (with velocity and acceleration terms), with ice-mass extinction estimates for a half dozen glacial drainages. The estimates will provide a measure ofthe contribution from Himalayan glaciers to decadal global sea-level rise (probably <5 percent).

Secondary organic aerosol from glyoxal: Linking laboratory, field, and model studies

Barbara Ervens (CIRES and NOAA ESRL)
and Rainer Volkamer (CIRES)

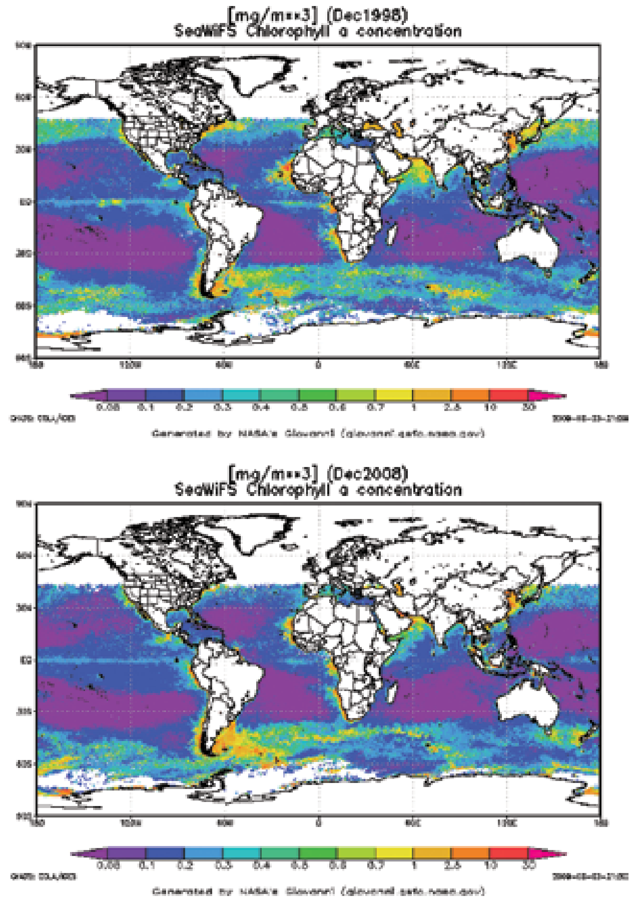
Ervens and Volkamer are using recent laboratory data to develop a module that represents the aqueous-phase chemistry of glyoxal to form low-volatility oligomers, sulfate, and/or ammonium adducts. They are implementing this module into an existing parcel model to evaluate, for the first time for atmospheric conditions, the relative importance of these formation routes for secondary organic aerosol (SOA) in haze particles (SOAhaze). The model will be applied to a case study in Mexico City to test the ability to reproduce field observations of SOA formation and assess the relative importance of different pathways in haze particles and cloud droplets. A computationally efficient approach will be developed for modeling studies at a larger scales—regional or global.

Uncertainties arise when estimating the effects of aerosols on global radiative forcing because of the complexity of aerosol properties and the diversity in source and sink processes. A significant fraction of fine aerosol mass is organic, and most organic aerosol forms in the atmosphere by chemical transformations of precursor gases (SOA). Current models describe SOA formation by condensation of low-volatility oxidation products from precursors into an organic aerosol phase, ignore chemistry in the aqueous phase, and underestimate SOA mass by factors of 5-100. During a 2003 case study in Mexico City, Ervens and Volkamer demonstrated for the first time that SOA formation from volatile glyoxal is an atmospherically relevant SOA source also in the absence of clouds, and helps bring measured and predicted SOA in better agreement.

Due to lack of a detailed chemical model representing glyoxal chemistry in aerosol water, previous interpretation of field data could not distinguish which reaction pathway was most responsible for the SOA mass inferred to form from glyoxal. Recent laboratory studies now provide means to parameterize the formation of oligomers and sulfate and/or ammonium adducts. The high organic and inorganic solute concentrations in haze particles accelerate reaction rates, and appear to lead to different products. To date, no systematic attempts have been made to understand the relative importance of these various possible reaction pathways of glyoxal to form SOA in haze particles, and clouds.

This study represents a new link between recent laboratory studies and observations of the atmosphere towards a quantification of SOA formation in haze particles and clouds by creating a modeling tool on a process basis.

The work is the first assessment of the drivers for SOA formation from glyoxal in haze. The results will help guide further laboratory studies by revealing weakness in the current process description and understanding. In addition, the model will show under what conditions significant SOA haze production can be expected and help guide future field experiments. A new (parameterized) 'SOAhaze module' will be developed and made available to the modeling community to be implemented in larger scale models that describe aerosol formation on regional or global scales. Thus, the proposed project will lead to a reduction in the gap between observed and modeled SOA mass, by providing better model tools, and will contribute to a better representation of aerosol formation and properties in the climate system.



Two examples of monthly averaged chlorophyll a *concentration for the month of December from SeaWiFS. Chlorophyll a concentration will be used as a measure for primary production. Note the apparent differences in surface area of oligotrophic habitat shown by the change in the surface area of depleted chlorophyll A concentrations between December 1998 and December 2008.*

Global climate changes and tropical ocean productivity

Brandi McCarty (CIRES and NOAA ESRL)

Climate models predict that the region of low productivity in the tropics will increase by 4 percent between the beginning of the Industrial Revolution and 2050. It is estimated that the low surface chlorophyll areas in several oceans combined (North and South Pacific, North and South Atlantic, and outside the equatorial zone) have expanded by 6.6 million km^2 or by about 15 percent from 1998-2006. While the biological productivity of these oligotrophic ecosystems is low, their large size allows for a substantial global contribution. Several factors work together to limit productivity—and thus the uptake of carbon dioxide by phytoplankton—in these waters. These factors include temperature, light, iron, and the availability of nutrients. McCarty is studying the relative effects of aerosol and temperature on observed ocean productivity.

In the tropics and mid-latitudes, there is limited vertical mixing of ocean waters, because the water column is stabilized by thermal stratification (i.e., light, warm waters overlie dense, cold waters). In these areas, the typically low levels of surface nutrients limit phytoplankton growth. Climate warming further inhibits mixing, reducing the upward nutrient supply and lowering productivity. There are several hypotheses, none with conclusive evidence yet, about subsequent feedback loops.

The CLAW hypothesis proposes a feedback loop between the ocean ecosystems and Earth's climate (the acronym is from the last names of proposers Robert Charlson, James Lovelock, Meinrat Andreae, and Stephen Warren). The hypothesis is that an increase in global temperature would increase phytoplankton productivity, and therefore the number of cloud condensing nuclei (CCN). In theory, the feedback loop begins with an increase in the available energy from the Sun, acting to increase the growth rates of phytoplankton due to either elevated temperature or increased irradiance. Certain phytoplankton synthesize dimethylsulfoniopropionate, and their enhanced growth increases the production of this osmolyte. In turn, this leads to an increase in the concentration of its breakdown product, dimethyl sulfide (DMS), first in seawater, and then the atmosphere. DMS is oxidized in the atmosphere to form sulfur dioxide, and this leads to the production of sulfate aerosols. These aerosols act as CCN and increase cloud droplet number, which in turn elevates the liquid water content of clouds and cloud area. This acts to increase cloud albedo, leading to greater reflection of incident sunlight, and a decrease in the forcing that initiated this chain of events.

A counter-hypothesis—still speculative—is advanced in *The Revenge of Gaia*, the book by James Lovelock. Warming oceans are likely to become stratified, with most ocean nutrients trapped in the cold bottom layers, while most of the light needed for photosynthesis is in the warm top layer. Under this scenario, deprived of nutrients, marine phytoplankton would decline, as would sulfate cloud condensation nuclei, and the high albedo associated with low clouds.

Climate investigations using satellite data generally average over monthly or seasonal time scales and spatial scales of degrees or more. By using the sea-surface chlorophyll concentration, aerosol optical depth, and sea-surface temperature data from the same platform, McCarty is investigating interactions at a variety of temporal and spatial scales, to identify those scales of potential importance. This project will improve our understanding of a unique ocean/atmosphere interaction, and offers the opportunity to further investigate the specific mechanisms in which aerosols contribute.

NASA

Old (top) and reprocessed (bottom) images of the Earth.

Extending the Arctic sea ice record by reprocessing data from the 1960s

Walter Meier and Mary Brodzik (CIRES NSIDC), and Dennis Wingo (NASA Ames Research Center)

Old satellite data can now be reprocessed using modern algorithms and processing capacity not available in the 1960s. This has been demonstrated by the Lunar Orbiter Image Recovery Project (LOIRP) at the NASA Ames Research Center, which has reprocessed images taken by Lunar Orbiter 1 in 1966, including an image of the Earth (figure).

Nimbus I, II, and III data are of a similar vintage as the LOIRP data. The Nimbus satellites carried a high-resolution infrared radiometer (HRIR), with a resolution of 8 km. They also carried a medium resolution infrared radiometer (MRIR) and an Advanced Vidcon Camera System (AVCS). By fortunate coincidence, these early Nimbus satellites likely captured the annual Arctic sea ice minimum (occurring each September) even though they collected data for relatively short durations. Nimbus I collected data from 28 August–22 September 1964; Nimbus II collected data from 15 May 1966–18 January 1969; Nimbus III from 14 April 1969–22 January 1972. Data coverage was global with twice daily acquisitions (day and night). In related work, researchers have produced an image mosaic of the Antarctic coastlines using Argon satellite photography from 1963 (this project did not involve reprocessing of original data; it used scanning versions of original Argon photographs).

Meier, Brodzik, and Wingo are addressing the following questions:

- Can the Nimbus data be reprocessed to enable new science?
- Do the level-0 data still exist or do we use later versions from NASA archives?
- From the limited bands available, can we determine average sea ice edges?
- Can we differentiate clouds from sea ice by using a time series?

Due to limitations of historical program funds and processing systems, there is a wealth of early Earth-observing satellite data that were never fully explored. However, the window of opportunity to recover these data is closing—only one tape drive remains in the world that can read the Ampex 2-inch media. Additionally, the original researchers are now mostly in their late 70s and 80s, and contact with them is critical to answering some of the necessary instrumentation questions. Since the HRIR data coverage is global, the reprocessing techniques could make new 1960s-era data available to the entire Earth science community. The techniques Meier's team is using will recover valuable data in danger of being lost, and should elevate the quality of historic data from Earth-observing satellites (not limited to Nimbus instruments) to contemporary standards, reinvigorating the datasets for current applications.

The research team is applying 21st-century processing and data handling capacity to answer questions of critical importance to modern climate change research. In particular, Meier, Wingo, and Brodzik are hoping to extend the sea ice record several years to a decade back before the current standard satellite record, beginning in 1978. The images the team is recovering will be significantly better resolution than anyone has ever seen from these sensors.

Finally, this project is truly collaborative: CIRES' NSIDC is the catalyst, NASA Ames Research Center developed the algorithms, and CU-Boulder students will be involved in time-series analysis to determine sea ice extent.

CIRES

Russ Monson, left, and Joost de Gouw, second from left, talk with graduate student Chris Gray, far right, and a visiting postdoctoral researcher at one of the sites where trees have been girdled to simulate a pine beetle attack.

Pine beetles and forest soil emissions

Russ Monson, Joost deGouw, and Noah Fierer (CIRES)

Monson, deGouw, and Fierer are studying the types and origins of volatile organic compound (VOC) emissions from a subalpine forest in Colorado that is in the incipient stages of a pine beetle attack. They hypothesize that the death of lodgepole pine trees and deposition of their needles to the soil will shift the source of VOC emissions from live to decomposing foliage, with concomitant production of novel VOCs. The team is conducting a three-month measurement campaign at the Niwot Ridge AmeriFlux, focused on characterizing VOC emissions from the soil on plots with pine trees that have been girdled (simulating a pine beetle attack) at different times in the past seven years. The researchers are also collecting data on the VOC composition of air collected at different heights from the Niwot Ridge flux tower at weekly intervals, to provide a high-resolution picture of VOC production in a forest not yet subject to intense pine beetle attack. From these observations, Monson, deGouw, and Fierer will evaluate the potential for the current beetle epidemic, which has devastated many forests in the western United States and Canada, to alter local-to-regional atmospheric chemistry and air quality.

The pine beetle epidemic has destroyed 9 million hectares of forest in Canada and 600,000 hectares of forest in Colorado. Recently, all lodgepole pine forests in Colorado have been rated as among the most susceptible to catastrophic beetle damage in the western United States, and Colorado state foresters have estimated that all lodgepole pine stands in the Colorado Rockies will be dead within five years. Past studies of atmospheric chemistry dynamics above the montane forests near Niwot Ridge, CO, have shown that air from the Denver metropolitan corridor is progressively processed as it moves upslope, almost daily, during summer mountain-valley flow episodes. This processing often results in near-surface ozone (O_3) concentrations at the Niwot Ridge site (3,050 m elevation) that are higher than in Boulder. During its upslope ascent, air containing nitrogen oxides (NO_x) has the opportunity to mix with air containing forest-emitted VOCs, causing the photochemical production of O_3 and aerosol. Thus, forest VOC emissions may contribute to this unique air quality problem, and the recent trend toward increased beetle attacks may change the types and amounts of VOCs emitted from the forest. The decomposition of needles and trees following a beetle attack is likely to be slow, occurring during several years. Monson, deGouw, and Fierer are taking advantage of forest plots treated with simulated beetle kill to gain information on how beetle attacks are likely to affect soil VOC emissions. Their key question: Does the beetle-induced death of lodgepole pine trees cause the soil beneath them to emit different types of VOCs and in different amounts during a seven-year response period?

Most past studies of VOC emissions from landscapes have focused on the role of vegetation; few have focused on soils. Preliminary laboratory studies at CIRES suggest that VOC emissions from soils could be significant in their quantity and atmospheric reactivity, particularly when those soils receive needle and root litter inputs. Furthermore, the pine beetle devastation of western U.S. forests caught most people off guard. The extent of the devastation was not anticipated and researchers generally did not have time to establish observation sites and platforms that could effectively track the environmental impacts caused by the epidemic.

We expect the decomposition of needles and roots to accelerate the production of unique VOC compounds emitted from the soil. We expect the soil emissions to not be reflected in the VOC types and quantities present in natural canopy air at this site. In other words, if the cause of these unique soil emissions is from beetle-killed trees, then they should be rare in the air sampled from this forest, which is only in the initial stages of beetle attack.

Predicting short-term climate change: How much to trust regional decadal projections?

David Noone (CIRES) and Gilbert Compo and Matthew Newman (CIRES and NOAA ESRL)

Noone, Compo, and Newman are using two new CIRES-developed datasets to evaluate the ability to predict decadal climate variability at regional scales by assessing the temporal characteristics of organized patterns of variability. The group aims to establish the degree to which dominant patterns of variability are subject to change during the 20th century, and to use this information to gauge the reliability with which they can be predicted in the 21st century. The researchers are conducting their analysis based on an algorithm developed at CIRES-NOAA and already applied to an ice core database and a recently completed atmospheric reanalysis.

With the emergence of consensus on global mean temperature change, both the scientific community and non-scientific stakeholders have turned their attention to decadal and regional prediction of climate—the scales critical for decision-making. To develop adaptation strategies and make choices in the face of uncertainty and risk, policy makers need to understand the degree of confidence in regional climate predictions.

While some aspects of climate change are clearly predictable, such as warming associated with increasing greenhouse gases, the ability to predict in greater detail remains unclear. In particular, regional changes in atmospheric circulation that often control local precipitation patterns and year-to-year temperature variations appear less predictable. This issue first emerged in weather forecasting in the 1960s. Ed Lorenz pointed out that fundamental issues linked to error growth in non-linear systems meant that weather is unpredictable beyond about 10 days. A similar result emerged for seasonal prediction of ENSO, with the limits on the order of months.

This CIRES project widens the scope, asking to what degree is regional climate, associated with organized patterns of variability, unpredictable? While patterns of variability have both forced and unforced contributions, the researchers suspect that there are aspects of the unforced behavior that limit the ability to predict forced response. To this end one might ask, what is the time scale within which regional-scale climate projections (which depend on knowing how these patterns change) can be treated as reliable by decision makers?

To date, measuring the ability to predict regional climate has been limited by the lack of sufficiently long and comprehensive observations to characterize decadal-scale variations in atmospheric circulation anomalies. Attempts have been made to assess the quality of decadal projections by noting where ensembles of climate model projections agree and taking model consensus as a measure of predictability. This approach lacks the satisfying rigor of an observationally based estimate. As such there is a need to use both better decadal-scale datasets and more appropriate statistical methods.

Eigenmode analysis of an empirically derived linearization of climate system dynamics is based on techniques pioneered at CIRES and NOAA ESRL. This approach has begun to show utility in seasonal prediction, but as yet, has not been applied to the task of decadal prediction of climate. This new research offers a critical test of the ability of such an approach to be used for decadal prediction. If successful, the findings will have immediate relevance for understanding predicted regional climate change from 2010-2050, and will offer insight into the reliability of regional climate projection.

Because the ice core network captures a significant part of the true variability in atmospheric circulation, the team can consider direct assimilation of paleo-proxy data. This moves beyond more traditional uses of proxy climate data, focused on simple statistics and known to be limited because of the lack of the dynamical and thermodynamic constraints. While there has been discussion of the need to perform an assimilation of proxy data, there has been no significant demonstration of the capability. This study will provide a critical test of the utility of proxies by establishing if the dynamics of circulation are captured reliably by the proxy records.

The recently completed historical reanalysis by Compo and others in NOAA ESRL is set to facilitate analysis of climate variability on decadal scales. While some data in the Southern Ocean were included in the assimilation and offer valuable constraint, the lack of comprehensive constraints raises questions as to the reliability. This study should offer an independent check on not only variations in the mean state, but the degree to which the new dataset reliably captures the variations that are linked to organized variability. The researchers expect to determine those regions where the gridded data are the most reliable, building the confidence of the scientific community in the dataset's use.

The acoustic tomography array at the Boulder Atmosheric Observatory.

Scanning heat flux with sound waves

Vladimir Ostashev (CIRES), Jesse Leach (NOAA ESRL), and Sergey Vecherin (New Mexico State University)

Ostashev, Leach, and Vecherin are studying the feasibility of measuring area-averaged vertical sensible heat flux with the array for acoustic tomography of the atmosphere at the Boulder Atmospheric Observatory (BAO). Vertical sensible heat flux (Qs) is one of the most important parameters in boundary layer meteorology. It is needed in weather forecasts, studies of climate change, etc.

Today, conventional meteorological devices are used for point measurements of this flux. However, such point measurements may not be representative, due to horizontal variations in the flux. At present, there is no remote-sensing technique for measurements of the area-averaged values of Qs. The main goal of this new work is to study the feasibility of such measurements with acoustic tomography of the atmosphere, a relatively new technique.

The idea of acoustic tomography of the atmosphere is similar to that in medicine, where electromagnetic or ultrasound waves probe a particular organ of a human body resulting in an image of that organ. In the case of acoustic tomography of the atmospheric surface layer (ASL), sound waves are used as a probe and, then, the temperature, T, and wind velocity, v, fields within a tomographic volume or area are reconstructed using different inverse algorithms. This CIRES research team started theoretical and experimental studies of acoustic tomography of the ASL in 2004, and has built an array for acoustic tomography of the atmosphere at the BAO. The array comprises three speaker and five microphone towers, arrayed to allow measurement of the travel times of sound propagation between pairs of speakers and microphones. T and v fields are then reconstructed using the time-dependent stochastic inversion (TDSI) algorithm. The tomography array became operational in March of 2008 and is the only acoustic tomography array in the United States. Speakers and microphones at the upper level of the array have been used so far in transmission and reception of acoustic signals, enabling two-dimensional, horizontal slice tomography. Transducers at the other two levels of the BAO array are proposed to be employed later. Then, three-dimensional tomography of the ASL will be feasible.

In theoretical studies, CIRES developed the TDSI algorithm for reconstruction of T and v fields. Results clearly showed that TDSI yields the best reconstruction of T and v fields among known inverse algorithms. The TDSI algorithm was used in reconstruction of T and v fields in experiments with the BAO array and also with a portable tomography array used by scientists from the University of Leipzig, Germany. Also the TDSI was used extensively in two-dimensional and three-dimensional numerical simulations of the BAO tomography array. The results obtained showed that the temperature and horizontal components of the wind velocity can be reconstructed reliably (with accuracy of about 0.2 K and 0.2 m/s). However, in numerical simulations so far, researchers have not been able to reliably reconstruct the vertical component of the wind velocity, which is needed in measurements of Qs. The reason is that the BAO tomography array is highly anisotropic, with the vertical dimension being much smaller than the horizontal. Therefore, Ostashev, Leach, and Vecherin are taking a different approach for measurements of Qs.

First, the team will develop computer programs for calculating the point and area-averaged values of Qs. Then, already-existing acoustic tomography data will be used to test the programs and make sure that the values of Qs make sense. Second, the scientists will carry out new experiments with the two-dimensional BAO tomography array and simultaneously will make point measurements of the heat flux with sonic anemometers/thermometers inside the array. These point measurements will be compared with point measurements of Qs with the acoustic tomography. Finally, point measurements of Qs will be compared with area-averaged values of Qs to study a difference between the two.

Measurements of the area-averaged heat flux are of primary importance to NOAA and the National Weather Service. This research project will demonstrate the feasibility of such measurements with acoustic tomography. The relatively inexpensive technique might become a component of a very wide net of U.S. sensors for measurements of atmospheric parameters—to improve the weather forecasts and studies of climate change. Furthermore, acoustic tomography would allow measurements of the area-averaged heat flux over complex terrain (e.g., over a river, lake, or polynya), where point measurements of the heat flux are difficult or infeasible.

Passive radio imaging for studying water resources, glaciology, and space weather

Nick Zabotin and Oleg Godin (CIRES)

Zabotin and Godin are developing a new, passive method of measuring water table depth, the ice thickness, and the altitudes of ionospheric layers, by observing autocorrelation of polarization components of the ambient radio noise with modern, digital high-frequency (HF) receiving systems.

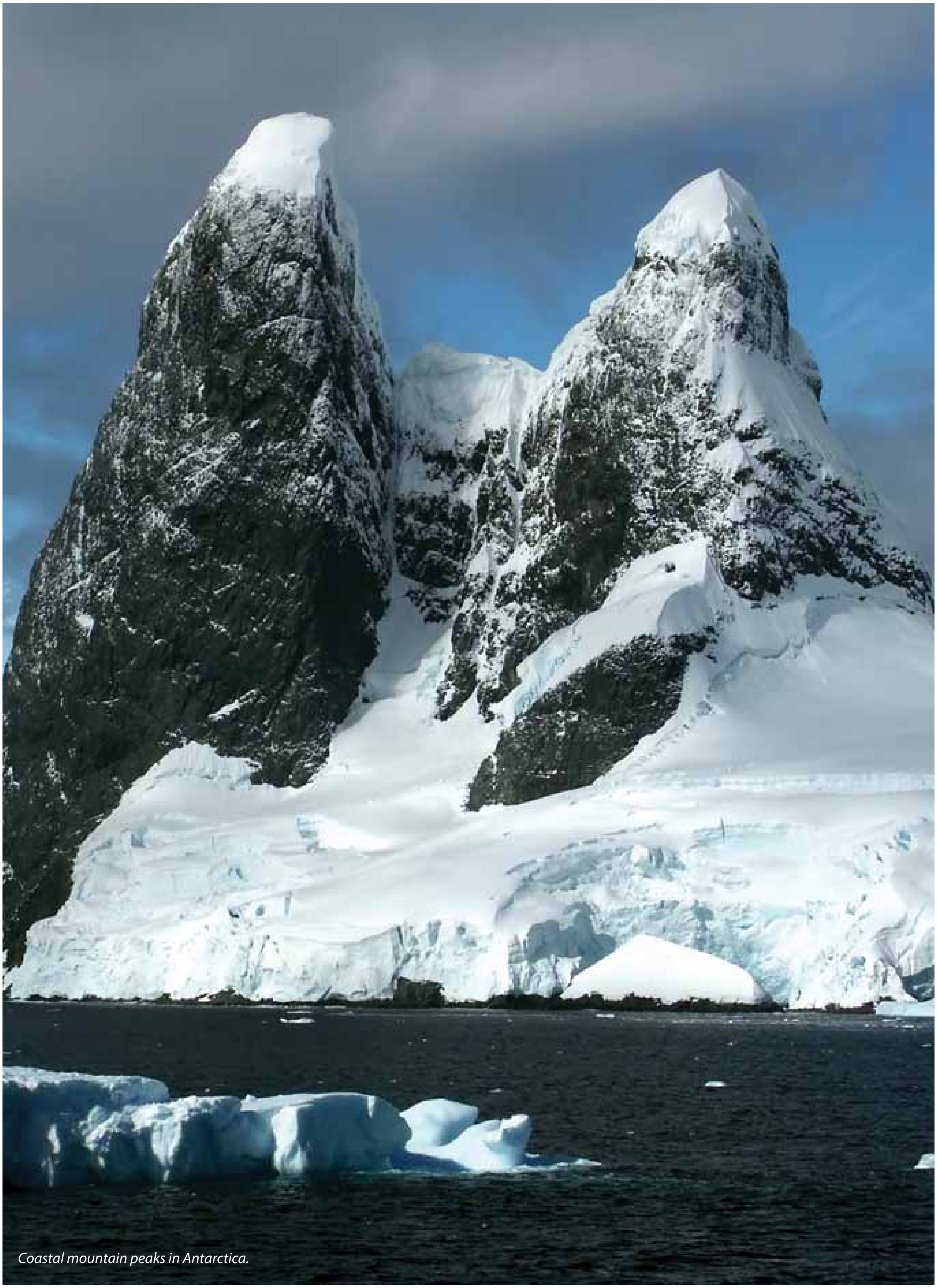
Passive imaging, or noise interferometry, has become increasingly popular as an approach to environmental remote sensing, after its success was demonstrated experimentally a few years ago in helioseismology and in ultrasonics. Its applications have become very popular in regional seismology, geological prospecting, and ocean acoustics. The basic idea is very simple: instead of a dedicated probing signal, use correlation reception of ambient noise for interrogating the environment. It is not unlike the way the eyes use daylight. The approach differs from conventional radiometry by coherent processing of diffuse wave fields. It has been shown theoretically and verified experimentally that the twopoint correlation function of a diffuse noise reproduces the shape of the Green's function, which describes propagation of a deterministic probing signal between the two points. Moreover, there exist applications that require no controlled source of waves and only one receiver (the passive fathometer technique, for example).

This research project is exploring the possibility of expanding the passive imaging technique to the area of HF radio wave propagation, where it is feasible to imagine applications including monitoring the water table level, measuring ice thickness, and determining ionospheric layer altitude.

Implementing passive techniques in this field would have positive environmental and societal impact: the radio spectrum is densely occupied by various vital applications, and using new active sources of radio signals is often prohibited. Passive techniques allow using frequencies that may be unavailable for active methods. Low power consumption of passive sensors increases the time of their autonomous operation, while their low cost allows for a large number of networked sensors and an improved spatial resolution of tomographic inversions. Of course, frequencies and necessary data acquisition rates are many orders of magnitude higher for radio than for seismic waves. Passive imaging with HF radio waves is made possible by digital receivers that became available only recently.

Radio noise in the HF band is constant, caused by multiple and globally-distributed sources of natural (lightning) and technogenic (industrial noise and distant radio stations) origin. On the other hand, now we have numerous instruments incorporating modern, fully digital HF receivers highly appropriate for measuring and studying the noise properties. Among them are four Vertical Incidence Pulsed Ionospheric Radar (VIPIR) systems just installed at Jicamarca Radio Observatory, Peru; NASA's Wallops Flight Facility in Virginia; Tomsk State University in Russia; and in Boulder, CO. The primary purpose of the VIPIR systems is active radio sounding of the ionosphere; this project puts them to novel use.

Measurements of this kind have never been undertaken in the HF band. This method is energy efficient, representing real "green science." It implies no interference for existing communication and other industrial radio systems, and measurements would not be subject to any frequency use restrictions. Furthermore, only initial development requires cumbersome sensor systems like VIPIR. In case of success, compact and/or mobile systems implementing this principle can be developed, and the principle itself may be patented.


Coastal mountain peaks in Antarctica.

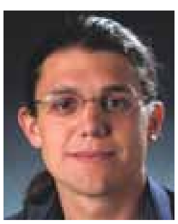
GRADUATE RESEARCH FELLOWSHIPS

CIRES supports two prestigious student fellowship programs, the ESRL-CIRES Fellowship—begun in 2008 with the support of NOAA's Earth System Research Laboratory—and the long-established CIRES Graduate Student Research Fellowships. For the 2009-2010 competition, the selection committee awarded ESRL-CIRES Fellowships to three students, and CIRES Graduate Student Research Fellowships to another seven. In this report, we also list fellowship recipients from the 2008-2009 academic year. Recipients of the two fellowships are exploring topics ranging from the effects of pine beetle infestation on watershed dynamics in Colorado to surface-atmosphere interactions on Mars.

ESRL-CIRES Fellowship

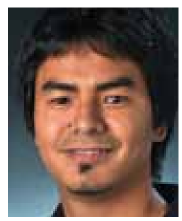
The ESRL-CIRES Graduate Student Fellowship allows students to pursue a master's or doctoral degree in a CIRES-affiliated department or program at CU-Boulder, while working with the world-class research team at NOAA's Earth System Research Laboratory (ESRL). Students will work with both a CIRES faculty advisor and an ESRL science advisor. Awards include tuition, partial health insurance, half-time stipend during the academic year, full-time stipend during the summer, and support to participate in one professional meeting per year. Students may be funded for a two-year master's degree or four-year Ph.D.

2008 ESRL-CIRES FELLOWSHIP RECIPIENT
Doctoral Awards Program

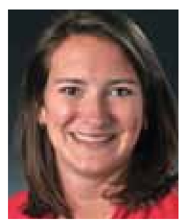


Ryan Neely
■ B.A., Physics, North Carolina State University
■ M.S., Atmospheric and Oceanic Sciences
■ Ph.D. student in Atmospheric and Oceanic Sciences

2009 ESRL-CIRES FELLOWSHIP RECIPIENTS
Doctoral Awards Program

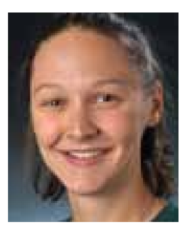


Sunil Baidar
■ B.S., 2009, Chemistry and Math, Dickinson College
■ Ph.D. student in Chemistry and Biochemistry



Katherine McCaffrey
■ B.A., 2009, Applied Math, University of St. Thomas
■ Ph.D. student in Atmospheric and Oceanic Sciences

Masters Awards Program

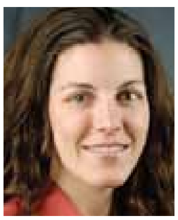


Alice Duvivier
■ B.S., 2008, Physics, Colorado College
■ M.S. student in Atmospheric and Oceanic Sciences

CIRES Graduate Student Research Fellowships

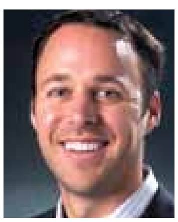
CIRES' Graduate Student Research Fellowships attract outstanding students at the outset of their graduate careers, and let current students emphasize the completion and publication of their research results. Support ranges from a summer stipend to tuition, stipend, and partial health insurance for 12 months. Fellowships are restricted to graduate students advised by a CIRES Fellow, or any prospective or current graduate student who might be advised by a CIRES fellow. Evaluation by a committee of CIRES Fellows is based on the candidate's university application, accomplishments, and the likelihood of their contribution to environmental science. Independence, passion for science, and ability to communicate are considered.

2008-2009 CIRES GRADUATE STUDENT RESEARCH FELLOWSHIP RECIPIENTS



Kelly Baustian

■ B.S., 2006, Chemistry and Russian and Central European Area Studies, St. Olaf College
■ Ph.D. student in Atmospheric and Oceanic Sciences
■ Academic Advisor: Margaret Tolbert
■ Research Area: Using optical microscopy and Raman spectroscopy to investigate cirrus cloud formation



David N. Cherney

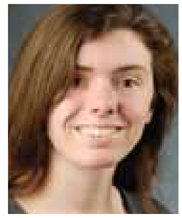
■ B.A., 2002, Environment, Economics, and Politics, Claremont McKenna College
■ M.A., 2005, Environmental Management, Yale University
■ Ph.D. student in Environmental Studies
■ Academic Advisor: Roger Pielke, Jr.
■ Research Area: Reforming conservation: Moving beyond persistent policy conflict in Greater Yellowstone

Leigh Ayn Cooper

■ B.A., 2005, Biology, St. Olaf College
■ Ph.D. student in Ecology and Evolutionary Biology
■ Academic Advisor: William Lewis
■ Research Area: Effects of watershed disturbance by mountain pine beetle on Rocky Mountain stream ecosystems

Christopher Harig

■ B.S., 2004, Geological Sciences, Cornell University
■ Ph.D. student in Geological Sciences
■ Academic Advisor: Peter Molnar
■ Research Area: Mantle lithosphere dynamics



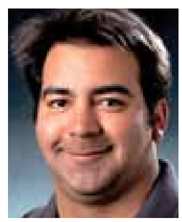
Samantha Stevenson

■ B.A., 2000, Mathematics, Western Connecticut State University
■ M.A., 2003, Astronomy, Wesleyan University
■ Ph.D. student in Atmospheric and Oceanic Sciences
■ Academic Advisor: Baylor Fox-Kemper
■ Research Area: Climate change sensitivity of an accurately modeled El Niño: Using improved ENSO physics for El Niño prediction

Nicole Trahan

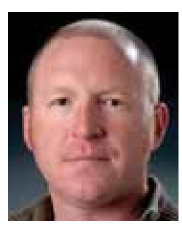
■ B.A., 1999, Biology, Colorado College
■ M.S., 2005, Biological Sciences, University of Northern Colorado
■ Ph.D. student in Ecology and Evolutionary Biology
■ Academic Advisor: Russell Monson
■ Research Area: The response of a subalpine forest ecosystem to earlier spring warm-up

2009-2010 CIRES GRADUATE STUDENT RESEARCH FELLOWSHIP RECIPIENTS



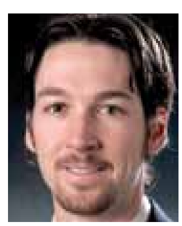
Robert Bowers

■ B.S., 2003, Biology, California State University, San Marcos
■ M.S., 2006, Biology, California State University, San Marcos
■ Ph.D. student in Microbial Biology
■ Academic Advisor: Noah Fierer
■ Research Area: A survey of airborne microbial communities across different land-use types of the Colorado Front Range



Nathan Bradley

■ Ph.D. student in Geological Sciences
■ Academic Advisor: Greg Tucker
■ Research Area: Stochastic and dispersive models of fluvial sediment transport

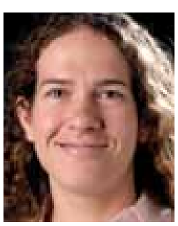


William Colgan

■ B.Sc.H., 2004, Biology and Geography, Queen's University, Kingston, Ontario, Canada
■ M.S., 2007, Earth and Atmospheric Sciences, University of Alberta, Edmonton, Alberta, Canada
■ Ph.D. student in Geography
■ Academic Advisor: Waleed Abdalati
■ Research Area: Modeling the influenece of meltwater on the ice dynamics of the Greenland Ice Sheet

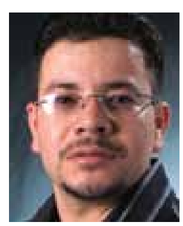
CIRES

Leigh Cooper has been investigating the effect of pine beetle kill in streams in Rocky Mountain National Park, CO.

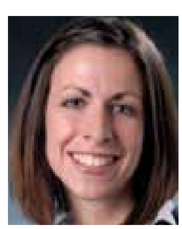


Raina Gough
■ B.S., 2004, Chemistry, Montana State University
■ Ph.D. student in Analytic and Atmospheric Chemistry
■ Academic Advisor: Margaret Tolbert
■ Research Area: Laboratory studies of heterogeneous reactions relevant to understanding surface-atmosphere interactions on Mars

Adina Racoviteanu
■ B.S., B.A., 2000, Environmental Studies-Geography, Middlebury College
■ M.S., 2004, Geography, CU-Boulder
■ Ph.D. student in Geography
■ Academic Advisor: Richard Armstrong
■ Research Area: Integrating remote sensing and field techniques to assess decadal glacier changes across the Himalayas using a multi-scale approach



Jose Solis
■ B.S., 2005, Civil Engineering, New Mexico State University,
■ M.S., 2008, Civil Engineering, New Mexico State University
■ Ph.D. student in Civil Engineering
■ Academic Advisor: Vijay Gupta
■ Research Area: Identify the interaction between hillslope-scale and riparian water balances and develop a model for interactions between hillslope and riparian systems across different stream orders



Amy Watson
■ B.S., 2005, Integrative Biology and Philosophy, University of Illinois, Champaign-Urbana
■ Ph.D. student in Ecology and Evolutionary Biology
■ Academic Advisor: Russell Monson
■ Research Area: Investigating the potential for climate to affect ecological signaling processes: Monitoring controls over plant defense and pinon forest health

DIVERSITY AND UNDERGRADUATE RESEARCH

CIRES is involved in many important efforts to educate undergraduate students and involve them in hands-on research. The two highlighted below are Significant Opportunities in Atmospheric Research and Science Program (SOARS) and the Undergraduate Research Opportunities Program (UROP).

SOARS

Significant Opportunities in Atmospheric Research and Science Program (SOARS) is a learning community and mentoring program for promoting ethnic and gender equity in the atmospheric and related sciences. The National Center for Atmospheric Research (NCAR) created and administers the highly regarded program, and CIRES partners with NCAR to provide a wider range of research options for students, called protégés. SOARS provides four years of mentorship—and summer research experience—for undergraduate and graduate protégés majoring in an atmospheric science or related fields.

■ More: http://www.ucar.edu/soars/

2008 SOARS PROTÉGÉS

Ramiro Mata
■ Project: Modeling Antarctica
■ CIRES Mentors: Adriana Bailey, John Cassano, and Mark Seefeldt

Sandra Diaz
■ Project: Analysis of daily monsoonal wind circulations in the lower troposphere over Estación Obispo, Mexico using wind profilers and the Gulf Surge Index
■ CIRES Mentor: Leslie Hartten

Eowyn Connolly-Brown
■ Project: Investigating the ability of CLM-CN 3.5 to accurately simulate vegetation density
■ CIRES Mentor: Tina Arthur

Christopher Williams
■ Project: Assessing tropical cyclone contribution to annual global rainfall
■ CIRES Mentor: Lesley Smith

McArthur Jones
■ Project: A statistical comparison of vertical Total Electron Content from three ionospheric models
■ CIRES Mentor: Jennifer Gannon

UROP

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

■ More: http://www.colorado.edu/Research/UROP/

2008 UROP PROGRAM RECIPIENT

Justin Ball
■ Project: Seismic investigation of the Cheyenne Belt Continental Collision Zone
■ Faculty or CIRES sponsor: Vera Schulte-Pelkum

Theme Reports

AMOS-01 Instrumentation Design, Prototyping, and Analysis

- ■ CSD-01 Instumentation for Atmospheric Observations and Analysis
- ■ PSD-08 Sensor and Technique Development
- ■ CET-01 Remote Hydrology Sensing

CSD-01 Instrumentation for Atmospheric Observation and Analysis

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

Milestone 1. Develop a scanning aerosol lidar system to measure plume dispersion, rise, and particle mass emission rates of aircraft jet engines.

Design, fabrication and initial testing have been completed. The system can scan a full hemisphere and collect aerosol data at a rate of 20 beams per second over a measurement range of 300 mm-12,000 meters. Spatial resolution is 1.5 m in short-range mode (300-3000 m) and 6 m with four-gated average at full range.

Milestone 2. Develop, test, and deploy an aircraft-based Doppler lidar to measure wind and turbulence profiles.

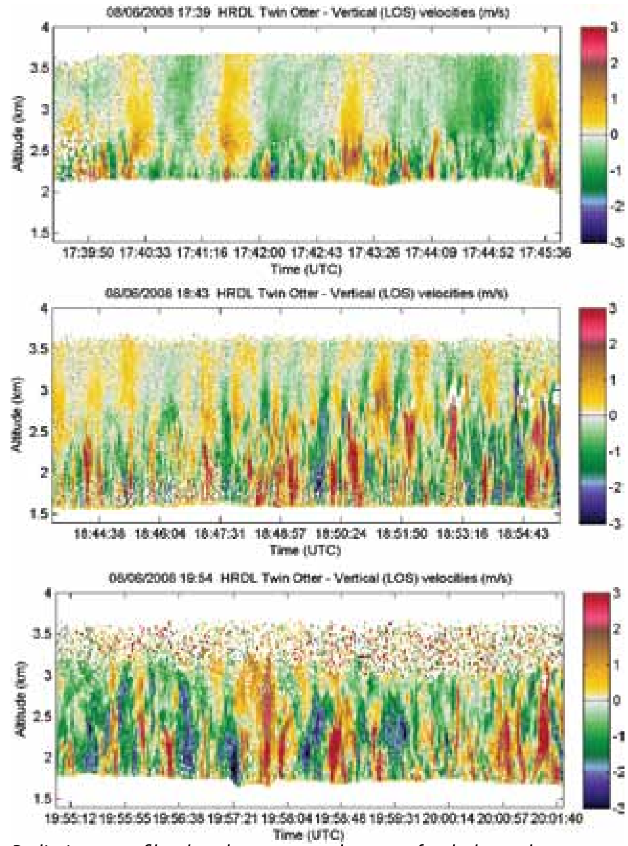
The NOAA / ESRL High Resolution Doppler Lidar (HRDL), modified for aircraft installation during July 2007-June 2008, was installed on the NOAA Twin Otter aircraft in early August 2008 for test flights and acquisition of preliminary data for aircraft-based wind and turbulence profiles. Main accomplishments include:

1) Installation: The instrument was installed on the Twin Otter in August 2008. Initial on-ground testing, performed using a turning mirror underneath the aircraft, indicated that the instrument performance was adequate to carry out the test flights.

2) Test Flights: Two test flights were performed with the instrument (weather and aircraft schedules did not permit a third planned test). NOAA Twin Otter pilots were extremely helpful in adjusting the flight plans and aircraft operation to optimize the limited number of flight hours.

3) Data Analysis: Data from the second flight were analyzed to produce profiles of vertical wind speed and velocity variance.

The initial test flight demonstrated two main issues: Intolerance of certain components of the system to high cabin temperatures while still on the runway, and high sensitivity of the instrument to aircraft sound / vibration, measured using vibration sensors and a stereo microphone recording setup. Data were acquired at different aircraft speed and thrust settings, to enable future study of the instrument's response to similar conditions.



Preliminary profiles that demonstrate the type of turbulence data acquired using HRDL in a near-nadir staring configuration on the NOAA Twin Otter. Warm vs. cool colors in the images indicate updrafts vs. downdrafts, with speeds as indicated. The top panel demonstrates the low-level turbulence observed before noon over the plains along the Colorado Front Range, when boundary layer mixing heights were at about 500 m above the ground. Larger scale updrafts, downdrafts, and aerosol return extended up to the aircraft altitude. The middle panel shows the growth of the boundary layer height in the middle of the day (around 12:30 p.m. local time) to about 1.5 km above ground. The bottom panel shows the fully developed convective boundary layer reaching up to the top of the aerosol layer, with turbulent cells reaching +/- 3 m/s.

Overall, the system was able to perform fairly well under slower speeds, with less vibration and noise, but would need significant engineering to make it robust enough to operate at full potential under normal operations (e.g., normal flight speeds) alongside other lidar instruments.

Milestone 3. Develop an improved version of the single-particle albedo instrument.

A significant accomplishment of the past year was the preparation and submission of a manuscript describing the general characteristics and measurement capabilities of the Aerosol Scattering To Extinction Ratio (ASTER) instrument. Most of the data in the paper were from laboratory tests on particles with known size and optical properties. These studies were critical in determining the feasibility of making high-quality measurements on atmospheric particles with ASTER. One dataset of measurements on samples of ambient particles highlighted the importance of this instrument—by making measurements on single aerosol particles to obtain information about the optical properties of the aerosol population that otherwise would have been masked in a bulk measurement. For this paper, Mie scattering calculations were also carried out for the instrument geometry. These calculations revealed that the method for measuring particle diameter is largely insensitive to particle index of refraction, a dependence that plagues the accuracy of traditional optical particle sizers. The data in the manuscript were used to make improvements to the basic ASTER design. The cavity mirrors were bonded directly to a silica plate to help minimize mirror misalignment. Automated flow controllers were installed to allow better control and characterization of the various flows present in the instrument. Sensors to measure housekeeping data, such as temperature and pressure, were also installed to provide instrument diagnostic information. Near the end of the calendar year, work was begun on testing alternative light sources for the instrument. These light sources do not require frequency locking the source to the ASTER cavity. Avoiding locking would greatly simplify the operation of the instrument and reduce the complexity of a field instrument.

Product: Sanford et al. 2008.

Milestone 4. Evaluate fast response, state-of-the-art instrumentation suitable for airborne measurements of nitrate (NO_3)/dinitrogen pentoxide (N_2O_5).

During the summer of 2007, CIRES researchers participated in an intercomparison campaign at the SAPHIR (Simulation of Atmospheric PHotochemistry In a large Reaction chamber) in Jülich, Germany, to assess the performance and accuracy of instruments for measurements of the nocturnal nitrogen oxides, NO_3 and N_2O_5. These compounds are relevant to air quality and climate through their roles in chemical transformations of oxides of nitrogen (NO_x), volatile organic compounds (VOCs), ozone (O_3), and aerosol, yet the factors governing their atmospheric abundance are poorly understood for lack of observational data. The 2007 campaign included about 10 research groups from the United States, Europe, and Japan. Results showed that the NOAA instrument based on pulsed cavity ring-down spectroscopy agreed well (within 10 percent) with a standard based on differential optical absorption spectroscopy for NO_3. Comparisons with other N_2O_5 instruments based on various techniques also showed excellent agreement. No artifacts due to environmental variables, such as water vapor, reactive VOCs, or aerosol loading, were apparent in the NOAA data. A paper describing the calibration methodology for this instrument was published in 2008, and papers describing the intercomparisons are currently in preparation. Additional papers describing the scientific studies of organic aerosol production from NO_3 reaction with biogenic VOCs as part of this study have also been recently published.

Product: Fry et al. 2008, Fuchs et al. 2008, Rollins et al. 2008.

PSD-08 Sensor and Technique Development

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

Milestone 1. Deploy roving calibration standard on two ships.

Two calibration deployments were planned for FY09: the research vessel *Kilo Moana* for the Woods Hole Oceanographic Institute Hawaii Ocean Time-series Station (WHOTS) cruise (July 9-17, 2009) and the research vessel *Ronald H. Brown* for the Northwest Tropical Atlantic Station (NTAS) cruise (June 17-July 4, 2009). CIRES staff met with University of Hawaii ship personnel and scientists in February 2009. The marine center director was briefed on the purpose of the work and the Flux Measurement Handbook was distributed. The portable system has been packaged and will be shipped for deployment on the *Kilo Moana* on July 1. The system for the *Ronald H. Brown* has been re-engineered and a new system for routine fast carbon dioxide measurements was added and will be housed inside the ship. This system was shipped June 1, 2009.

Milestone 2. Complete construction of PSD W-band radar for ship and airborne deployment.

The W-band radar system was completed and shipped for deployment on the *Ronald H. Brown* for the VOCALS cruise. Data and images are available at ftp://ftp.etl.noaa.gov/et6/cruises/VOCALS_2008/RHB/radar/wband/.

The system failed early on the first leg when the preamp burned out. This was determined to be a fault in the radar processor card. A programming change was made and the radar was repaired when the ship made port in Arica, Chile in November. The radar operated at full capability the rest of the cruise and provided amazing data. Work is currently underway to build a structure to house the radar on the NOAA WP-3 aircraft. In the meantime, the radar will be deployed on the *Kilo Moana* on the WHOTS cruise.

Milestone 3. Complete installation and develop operations plan for the flux tower at the Canadian Arctic station in Nunavut (Eureka).

Upgrades and maintenance on the micrometerological flux tower in Eureka, Canada were completed in July 2009. Starting from the top, the flux tower houses a PIR pyrgeometer (measures downwelling longwave radiation from the atmosphere), CM22 pyranometer (measures solar radiation received from the entire sky), wind vane and cups, four ASPTC Thermocouples located at different heights and orientations, 7.5m ATI sonic anemometer (measures wind speed), Licor gas analyzer, two Vaisala RH/Ts (relative humidity and temperature) installed at different heights, infrared surface temperature sensor (measures emitted longwave radiation from the surface), 3-m sonic anemometer, ultrasonic snow depth sensor, and soil heat flux plates installed at the surface. Preliminary covariance analysis has established that data are good during seasons when icing and riming are not a problem. It is an ongoing problem to determine how to properly operate these instruments in the Arctic winter. Heating and ventilation solutions and operator protocols are being investigated. Preliminary results of the atmospheric boundary layer behavior and CO_2 fluxes at Eureka have been reported at

AGU and EGU meetings.

Product: Grachev et al. 2008, and:

Grachev, AA et al. (2009), Turbulent fluxes and transfer of carbon dioxide in Arctic at the SEARCH station Eureka, Canada, EGU General Assembly.

CET-01 Remote Hydrologic Sensing

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

Milestone 1. Develop a ground-based microwave profiling system for long-term Arctic cloud and water vapor measurements.

A new radiometric scanhead for the ground-based Polar Climate Profiler instrument containing the key radiometers receivers operating at 18-24, 31, 55, 90, and 183 GHz was constructed and tested. The scanhead was built for ruggedness, precision calibration, and high sensitivity to the extremely low amounts of moisture in the Arctic and Antarctic environments. Improvements in the retrieval algorithm were demonstrated by using field data from 2007 in conjunction with a numerical weather prediction model, the combination of which provided a more accurate background for the retrieval than the current climatological first-guess method.

Milestone 2. Develop submillimeter microwave radiometers for ground-based and airborne cloud sensing.

Progress was made on the development of a 425-GHz radiometer for temperature profiling and cloud detection using the strong oxygen resonance line at this frequency. The radiometer detection hardware was designed, and the components are currently being assembled. Outdoor tests of this unit are expected during the fall of 2009.

Milestone 3. Develop all-weather radiance assimilation of satellite passive microwave observations.

A new fast Mie scattering algorithm was developed, based on a wavelet-compressed look-up table of scattering and absorption coefficients and scattering asymmetry values. The fast algorithm is necessary as a component in an all-weather radiance assimilation scheme to provide rapid scattering and absorption calculations needed for real-time assimilation. The algorithm is being incorporated into an upgraded radiative transfer package with Jacobian that will be used in ongoing clear and cloudy radiance assimilation experiments.

AMOS-02 Data Management, Products and Infrastructure Systems

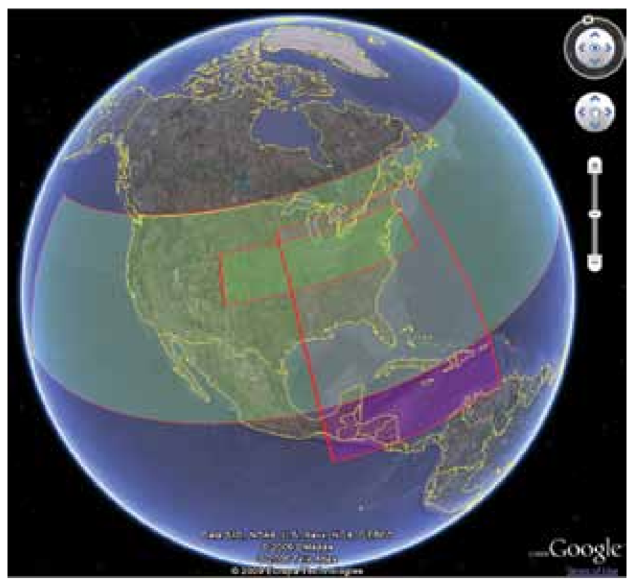
- NGDC-01 Geospatial Technology for Global Integrated Observing and Data Management Systems
- NGDC-02 Marine Geophysics Data Stewardship
- NGDC-08 Improve Integration of Coastal Data to Support Community Resiliency
- SWPC-03 Information Technology and Data Systems
- SWPC-04 Space Environment Data Algorithm and Product Development
- GSD-07 High Performance Computing Systems

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

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

Milestone 1. Design, develop, and demonstrate systems that provide integrated access to data quality information using international standards.

Systems were developed to visualize the bounding geographic areas of NOAA in situ and remote observing system datasets. This information is extracted dynamically from international metadata and presented on Google Earth.



Google Earth displays the bounding geographical areas of NOAA observing system datasets.

Product: http://www.ngdc.noaa.gov/metadata/published/19115/NOSA/kmlList.html.

Milestone 2. Design, develop, and demonstrate systems that provide integrated access to in situ environmental observations using Open Geospatial Consortium standards as well as emerging international approaches.

Multibeam bathymetry data from a ship cruise is detected via an Open Archives Initiative (OAI) metadata server. Each new metadata record is parsed to determine the URL for downloading the entire dataset, which is stored into a spatial database using an automated data pipeline tool.

The trackline of the bathymetry cruise is overlaid with all other cruise tracklines in the NGDC database using a standard WMS map server.

Multibeam bathymetric data displayed on the NGDC web site.

Product: http://www.ngdc.noaa.gov/mgg/bathymetry/multibeam.html.

NGDC-02 Marine Geophysics Data Stewardship

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

Milestone 1. Search, target, acquire, and provide access to new marine geophysical data from the worldwide oceanographic community.

Easy, reliable searching and retrieval of marine geophysical data is a primary requirement of scientists studying a wide range of environmental issues. The value of NGDC's databases is enhanced by inclusion of all available global data, long-term archiving for future use, data-quality assurance and documentation, and continued improvements in data access.

NGDC provides long-term archiving, stewardship, and delivery of data to scientists and the public by using standard metadata, spatially-enabled databases, robotic tape archive, and standards-based web services. In the past two years, marine geophysical data archived at NGDC has more than doubled to 70 terabytes. Since July 2008, 366 multibeam swath sonar surveys (956,930 nautical miles) and 109 trackline surveys (bathymetry, magnetics, gravity, and seismic reflection; 218,000 nautical miles) throughout all the world's oceans have been added to the archive by NGDC and CIRES staff. National and international multi-organizations contribute to and retrieve marine geophysical data from the interactive databases.

Marine geophysical data archived at and delivered by NGDC are currently supporting two specific, ongoing U.S. mapping efforts: the Extended Continental Shelf (ECS) project, and the Integrated Ocean and Coastal Mapping (IOCM) program. Data collected for the ECS will be used to define the maximum extent of the U.S. continental shelf (Figure 1). NGDC and CIRES staff collaborate with the IOCM as a data integration center for scientists to search and download data in their area of interest, and coordinate data collection efforts to maximize survey value and reduce duplication of effort.

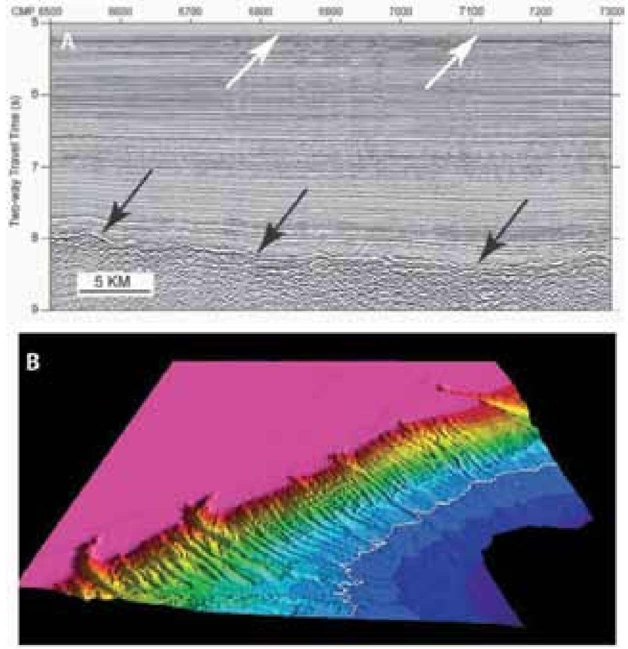


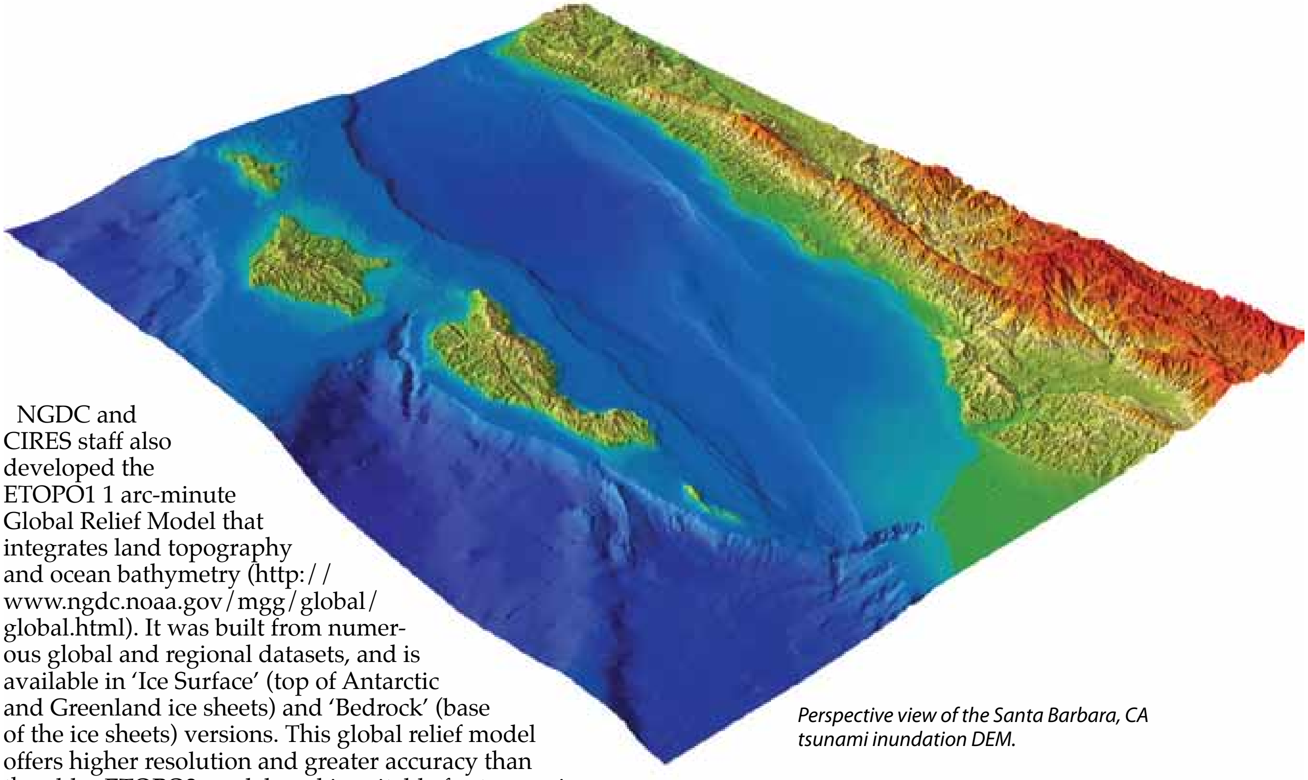
Figure 1: *Examples of marine geophysical data archived and disseminated by NGDC for use in determining the extent of the U.S. ECS. a) A seismic-reflection profile across a U.S. continental margin reveals approximately 2,200 meters of visible sediment overlying oceanic basement (black arrows; seafloor indicated by white arrows). Sediment thickness is a key component in determining the extent of the U.S. ECS. b) Color, shaded-relief image of multibeam swath sonar data collected along the continental margin off New Jersey. The white line represents the 2,500-m depth contour, an important formula line used in ECS analysis. Note the morphologic detail revealed by the modern multibeam sonar survey.*

NGDC-08 Improve Integration of Coastal Data to Support Community Resiliency

Goal: Improve integration of coastal data and develop new products that enable improved assessment of hazards, coastal vulnerability, and risk for improved community resiliency. Research goals include the development of seamless, accurate, high-resolution digital elevation models (DEMs), which will improve the accuracy of coastal inundation modeling, and the development and expansion of historic events databases, tsunami deposits databases, and hazard assessments.

Milestone 1. Produce six to nine seamless, integrated bathymetric–topographic DEMs of select U.S. coastal communities sufficient for tsunami forecast and warning and coastal inundation mapping.

During FY09, NGDC and CIRES staff developed 22 DEMs covering 12 U.S. coastal communities (e.g., opposite page). These DEMs are used by NOAA's Tsunami Warning Centers to support NOAA's tsunami forecasting and warning efforts, and by NOAA's State partners in the National Tsunami Hazard Mitigation Program for use in coastal tsunami inundation mapping. Ten nested DEMs were specifically built to support the State of Alaska's tsunami modeling and coastal inundation mapping efforts aimed at improving the resiliency of four Alaska communities.



Perspective view of the Santa Barbara, CA tsunami inundation DEM.

NGDC and CIRES staff also developed the ETOPO1 1 arc-minute Global Relief Model that integrates land topography and ocean bathymetry (http://www.ngdc.noaa.gov/mgg/global/global.html). It was built from numerous global and regional datasets, and is available in 'Ice Surface' (top of Antarctic and Greenland ice sheets) and 'Bedrock' (base of the ice sheets) versions. This global relief model offers higher resolution and greater accuracy than the older ETOPO2 model, and is suitable for tsunami propagation and ocean circulation modeling. This global relief model is a frequent download from the NGDC web site, indicating the utility and usefulness of the model to researchers, private companies, and the general public. It is available in multiple file formats, as well as a georeferenced, color, shaded-relief image.

NGDC and CIRES staff also completed the development of a 24 arc-second coastal relief model (CRM) of Southern Alaska (http://www.ngdc.noaa.gov/mgg/coastal/s_alaska.html). This CRM spans the Alaska Peninsula, Gulf of Alaska, Aleutian Islands and the Bering Sea, and is available in multiple file formats. This CRM also supports tsunami propagation and regional ocean circulation modeling.

Product: Amante and Eakins 2008, Carignan et al. 2008, Lim et al. 2008, Medley et al. 2008, Taylor et al. 2008a, Taylor et al. 2008b, Taylor et al. 2008c, Taylor et al. 2008d, and:

Caldwell, RJ et al. (2009), Digital elevation models of Prince William Sound, AK: Procedures, data sources and analysis, NGDC technical report, Boulder, CO.

Caldwell, RJ et al. (2009), Digital elevation models of Yakutat, AK: Procedures, data sources and analysis, NGDC technical report, Boulder, CO.

Carignan, KS et al. (2009), Digital elevation models of Adak, AK: Procedures, data sources and analysis, NGDC technical report, Boulder, CO.

Lim, ED et al. (2009), Digital elevation models of Akutan, AK: Procedures, data sources and analysis, NGDC technical report, Boulder, CO.

Lim, ED et al. (2009), Southern Alaska Coastal Relief Model: Procedures, data sources and analysis, NGDC technical report, Boulder, CO.

Medley P et al. (2009), Digital elevation models of Wake Island: Procedures, data sources and analysis, NGDC technical report, Boulder, CO.

Milestone 2. Produce an online database of global tsunami deposits that will support improved assessment of tsunami hazards for at-risk coastal communities.

The online database of citations to articles on tsunami deposits provides additional data on historical events and extends the record of tsunamis backward in time, in some cases to prehistoric or paleotsunami deposits preserved in the geologic record. For example, coseismic deformation along the U.S. Pacific Northwest coast produced the 1700 Cascadia tsunami, which was observed by residents of Japan. In North America, it was observed by native peoples, as evidenced by oral histories, and was also recorded geologically as distinct sand sheets beside bays and river mouths and alternating layers of sand and mud beside muddy bays. These data support improved tsunami hazard assessments, and tsunami modelers use the presence of deposits and their thickness and coarseness to verify inundation estimates.

The initial online database includes more than 500 citations that describe deposits from all over the world (e.g., Figure 1 next page). The time period ranges from Precambrian to Quaternary (present day). Users can search the database by author; article date; event description (e.g., 1700 Cascadia Earthquake and Tsunami); deposit date; and deposit location name, country, and/or coordinates. The tsunami deposits are also linked to the historical tsunami event database where applicable. For example, there were many post-tsunami surveys conducted after the 2004 Indian Ocean tsunami. Articles resulting from these surveys and describing these tsunami deposits are linked to the related historical tsunami event record for the 2004 tsunami. As additional citations are retrieved and quality-controlled, they will be added to the database and made available online.

NGDC and CIRES staff also developed a standalone (off-line) GIS application, distributed on CD-ROM, to interact with a local copy of NGDC's historical hazards databases. The standalone GIS application was developed to meet the needs of local authorities and tsunami warning centers from countries around the world without reliable Internet access. The software is based on uDig (User-friendly Desktop Internet GIS), an open-source GIS framework written in Java which is built upon the well-established Eclipse Rich Client Platform. The behavior of uDig was customized by developing plug-ins that allow the user to query the database using many different search parameters and display information about events on the map and in a table format. An additional plug-in was developed to calculate and display tsunami-travel-times on the map. NGDC's historical hazards databases (http://wwwdev.ngdc.noaa.gov/hazard/hazards.shtml) contain information about historical hazards, such as tsunamis, significant earthquakes, and volcanic eruptions from ancient times (2000 B.C.) to the present.

Figure 1: *Cross-section of the 2004 Sumatra tsunami deposit at Lampuuk, Banda Aceh, Indonesia. Photograph courtesy of Guy Gelfenbaum, U.S. Geological Survey.*

Product: Dunbar et al. 2008, and:

Dominey-Howes, D et al. (2009), Estimating probable maximum loss from a Cascadia tsunami, *Natural Hazards*, DOI 10.1007/s11069-009-9409-9.

SWPC-03 Information Technology and Data Systems

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

Milestone 1. Support ongoing development of the Geostationary Operational Environmental Satellite (GOES) N, O, P series ground data system (GDS). Enhance the current GOES-N GDS and deploy it to operations. Provide project management for GDS deployment to operations. Begin transitioning this system to support GOES-O telemetry streams and product development. Continue to provide analysis and technical support to algorithm development, instrument checkout and data verification.

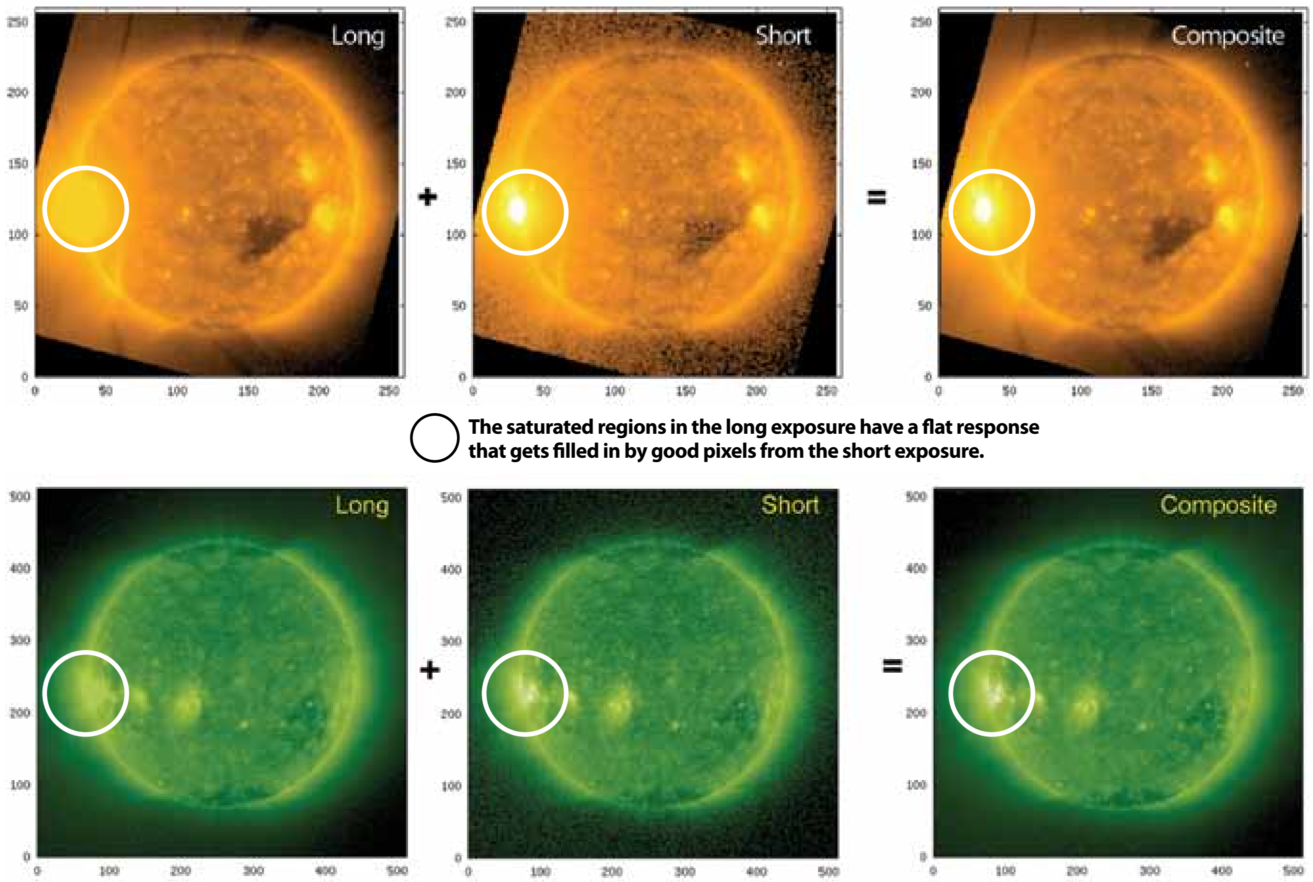
The SWPC's GOES-N GDS preprocessor was improved and expanded, with important upgrades to magnetometer, particle, extreme ultraviolet, and X-ray sensor processing algorithms to support scientific model development. Further modifications were made to increase reliability, optimize system operations, improve logging, expand configurability, and create more detailed documentation. Further, the preprocessor was expanded to include the processing of GOES-O telemetry data and products, in preparation for the launch of this newer satellite in the GOES series. Lastly, a more advanced prototype Solar X-ray Imager data processing system was developed to begin fleshing out the image processing functionality of the ground data system.

Milestone 2. Assist SWPC efforts to modernize data processing and distribution systems that are currently hosted on legacy systems. Provide development, transition, and mentoring support for contracts to outsource modernization efforts. Implement specific portions of the modernization that will not be outsourced. Develop and deploy the next generation decoder/processor for weather station observation messages received from the Air Force Weather Agency network.

CIRES affiliates provided detailed specifications and sizing information in support of outsourcing modernization efforts, and participated in the source selection process. As a result of these efforts, the selection process is nearing completion for all operational systems currently implemented in the legacy QNX-based operating system. The next generation decoder/processor for weather station observation messages received from the Air Force Weather Agency network was successfully developed and deployed. This next generation system replaces a very large, complex, and hard-to-maintain system that was consuming an inordinate amount of resources to support operationally.

Milestone 3. Aid in new model development and transition to operational products. Develop ionospheric analysis products to improve Global Positioning System (GPS) location determination. Implement extensions to the D-RAP product to improve its utility in forecasting high frequency communication availability. Continue to support the identification of new models and products, as well as assisting in refining the organizational work flow processes by which those new models and products are developed and deployed.

CIRES provided technical leadership and developed requirements, scope, and vision documentation for the GPS Ionoshpheric Prediction Correction project, and built several prototypes to implement pieces of the required software infrastructure. This project is scheduled for test product completion next year. CIRES staff also helped successfully complete and deploy a NWS "test product" version of the D-RAP software for use by the forecast center and airlines industry. The new D-RAP system will allow the forecast center to issue weather products covering the high-latitude, high-frequency communications. The airlines industry will save millions of dollars in fuel by making more accurate decisions to reroute flights over the high-latitude polar regions. A new product for the forecast center was implemented in the Real Time Ground Magnetometer software, in collaboration with the U.S. Geological Survey. The new product was made available in forecast center displays that present a more complete picture of the Earth's magnetosphere, particularly localized to the United States.



CIRES research scientists have developed an algorithm to better utilize the Solar Ultraviolet Images (SUVI) that will be available from GOES in the 2015 time frame. The algorithm combines a long exposure image and a short exposure image to make features such as solar flares on the Sun more visible and easier to analyze. These images show the algorithm applied to currently available images from operational satellites and demonstrate the improved resolution.

Milestone 4. Provide support for SWPC endeavors to improve data storage systems. Help optimize the operational data store, for example by implementing views and stored procedures. Deploy externally the available product data store to operations. Improve data archiving processes that move product data to the National Geophysical Data Center, and deploy these processes to operations. Develop documentation that better describes SWPC's data storage system and its operation.

SWPC's data storage systems were improved with new views and the development of new archival processes. CIRES aided in the transformation of logical data models for new projects into physical database table and view implementations. CIRES specifically assisted the Real Time Ground Magnetometer project by authenticating data through automated byte-by-byte comparisons with mirror datasets to help validate early prototypes.

Milestone 5. Continue to maintain the reliable operation of existing operational product generation infrastructure, generation, and display systems that are used by SWPC to specify and forecast the space environment. Perform ongoing data quality validation, as well as provide timely problem analysis and resolution services as requested.

Researchers at CIRES 1) provided on-call enhancements and support for utilities that verify data quality, 2) automated data discrepancy detection and notification for several ongoing projects, and 3) regularly provided timely problem analysis and resolution, ensuring continuity of SWPC operations.

Milestone 6. Investigate current Graphics Processor Unit (GPU) technologies and Global Systems Division applications suitable for acceleration with GPU co-processors.

The research team began researching opportunities to use current GPU technologies useful for implementing the linear algebra common throughout SWPC's forecasting models. Some hardware has already been acquired, but no prototypes have been developed yet.

SWPC-04 Space Environment Data Algorithm and Product Development

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

Milestone 1. Develop, validate, document and implement new algorithms and products to be generated with the GOES-13 and the GOES-R series satellites.

CIRES team members completed the Critical Design Review for the six Delivery 1 GOES-R algorithms, which meet 22 product requirements. These algorithms included Time Series Data Averages, Magnetometer Comparison to Quiet Fields, Magnetometer Conversion to Alternate

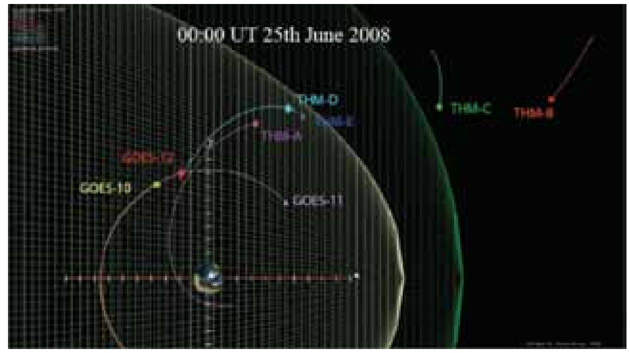
Coordinate Systems, Energetic Particles Conversion of Differential Flux to Integral Flux, Solar Ultra-Violet Imager (SUVI) Composite Images, and SUVI Fixed/Running Difference Images. Development and documentation of these algorithms is nearly complete. Test proxy data and test cases have been developed to prove the functionality of the algorithms as well as the software processing reliability. In cases where algorithms already exist for previous GOES satellites, results are being compared with existing algorithms and improvements are being made whenever possible. An Algorithm Theoretical Basis Document for each algorithm has been drafted and will be delivered with working software as the end product.

Milestone 2. Research and develop new models and analysis techniques to improve the accuracy and to expand the scope of operational products derived from the GOES data.

Work on developing automated image segmentation algorithms for SUVI multiwavelength extreme ultraviolet (EUV) images is underway. A statistical analysis technique known as principal component analysis is showing great promise. Using Solar and Heliospheric Observatory Homepage images as a proxy for four of the six EUV bands planned for SUVI, it has been determined there is enough redundant information across all images that at least one band may be dropped, simplifying the subsequent process of image segmentation.

Magnetometer efforts are taking advantage of recently developed tools to represent the magnetic field in different coordinate systems and to make comparisons with several different magnetic field models and proxy datasets. These tools will lead to improved capabilities for GOES-R validation and product development. One highlight has resulted from the use of magnetic field data from three current GOES spacecraft and five spacecraft from the NASA THEMIS mission, and solar wind measurements from ACE and models recently implemented for use in the GOES-R era. The figure shows the locations of the spacecraft from a vantage point looking down on Earth's North Pole and shows the locations of the satellites and Earth's magnetopause and bow shock. Results are still under investigation and will contribute to future products developed for GOES-R. Current GOES magnetic field observations are also being compared with empirical magnetic field models and work done on coordinate transformations.

Risk reduction work for Space Environment In Situ Suite includes the specification of the energetic electron environment in geosynchronous orbit based on GOES observations. Prediction efficiencies and correlation coefficients for phase space density predictions at one GOES satellite location, based on measurements of electron flux at another GOES satellite, were calculated for specific times. Work was also accomplished in the augmented solar proton observational capability present in the GOES-N and GOES-R series. Starting with GOES-13, the solar proton detectors have a second, east-looking field-of-view (FOV) in addition to the baseline, west-looking FOV. The west-looking FOV is of importance because it observes protons whose spiral motions are centered closer to the solar wind and therefore are more representative of what is ejected by the Sun. The east-looking FOV observes protons whose spiral motions are centered further inside the magnetosphere than geosynchronous orbit, and and can be used for alerts in the event of failure of the west-looking FOV.



The locations of three NOAA GOES satellites and five NASA THEMIS satellites on June 25, 2008. Also shown are the locations of Earth's magneto-pause (white boundary) and bow shock (green boundary). The events on this day are supporting our understanding and development of tools to predict the radiation environment at geosynchronous orbit.

GSD-07 High Performance Computing Systems

Goal: Provide systems research support for high-performance computing (HPC) efforts and assistance to the user community; provide HPC systems (HPCS) communications equipment and software research; and provide research support for high-performance file systems.

Milestone 1. Complete feasibility study of implementing Cluster Resource's Moab on Boulder HPCS and estimates of improved system efficiency through use of advanced scheduling features, such as advanced reservations and user-definable node sets.

Moab has been implemented on the production Boulder HPCS systems and proved beneficial for several reasons. First, it has improved scheduling efficiency by 15-20 percent. Second, through the use of advance reservations, ongoing, real-time computational experiments are better supported. Third, improved logging and simulation capability provide a method to better understand user workloads.

Milestone 2. Continue development of HPC Workflow Manager, further extending its use outside of NOAA-Boulder and publish system as open source.

Several new features have been added to the Workflow Manager that have improved its functionality and reliability. These features include improvements in language parsing that allow users to specify complex workloads more succinctly. This change simplifies the creation of workflows and reduces the chance for user errors. Several features have been added which increase its performance and scalability. The use of Domain Specific Languages is under research, to further simplify and enhance the definition of workflows.

Milestone 3. Implement single open source image and tools across multiple generations of HPC hardware platforms.

After the installation of hJet in the fall of 2008, the development of a single system image that ran across three different generations of hardware was completed. This provided several benefits to the administration and user community, including simplification of system usage and maintenance. This image was then used on the followup system which is currently being installed, thereby providing a seamless way to transition from one system to another. Little to no changes are required by the users.

Milestone 4. Begin coordinating with HPCS users of dominate codes used (WRF variants, FIM) to implement a parallel input/output (I/O) paradigm to improve code efficiency.

Initial investigations have been started to understand the I/O patterns of the Finite-Volume Flow-Following Icosohedral Model (FIM) and how its performance can be improved based on alternate I/O methods. One method was implemented, using I/O cachers, that improved the performance of large-scale simulations by a factor of two. Other research continues into the viability and applicability of using the open standard, MPI-IO, to accelerate application I/O on our systems and others.

Milestone 5. Support investigations of large, core-count model scalability in heterogeneous computing environments.

Due to high system utilization, little work progressed in this category. Although the topic could be of interest in the general community, it was recently decided that the value of this work would likely not exceed the amount of production science that would have to be installed to support the work.

Milestone 6. Investigate current GPU technologies and GSD applications suitable for acceleration with GPU co-processors.

During the last year, GSD has begun research into the use of Graphical Processing Units (GPUS) for future weather models. Attempts to port FIM to GPUs resulted in a 23-fold increase in speed. Also, GSD has developed a source code translator that converts standard Fortran code into CUDA, the language used by GPUs, to shorten the time needed to convert code to run efficiently on the GPU. This work has been used as a basis for architectural choices for GSD's next generational weather model, NIM.

Product: Govett, M et al. (2009), Using GPUs to meet next generation weather model computational requirements, presentation at the fall American Geophysical Union meeting.
Govett, M et al. (2009), Some optimization strategies for running weather codes efficiently on GPUs, poster presentation, Path to Petascale Workshop, University of Illinois.

AMOS-03 Prediction, Model Development, and Evaluation

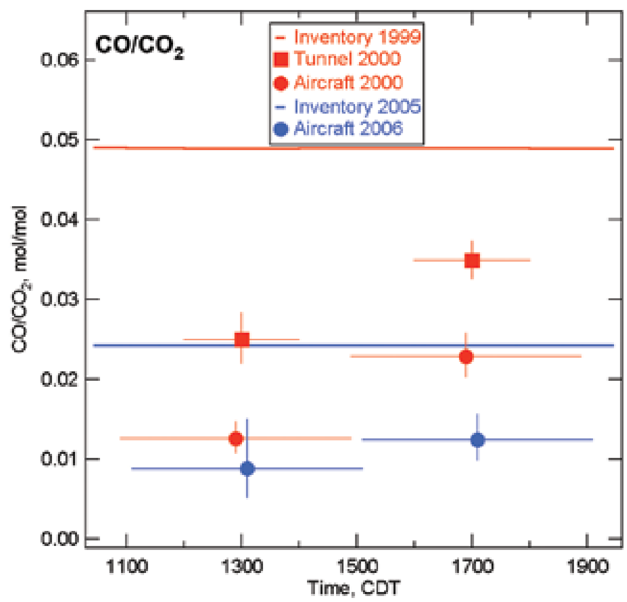
- CSD-02 Chemical Transport Model Research
- PSD-16 Raindrop Size Distributions
- PSD-17 Environmental Monitoring and Prediction
- GSD-01 Numerical Weather Prediction
- GSD-03 Verification Techniques for the Evaluation of Aviation Weather Forecasts
- GSD-05 Numerical Prediction Developmental Testbed Center
- NGDC-03 Space Weather
- SWPC-01 Solar Disturbances in the Geospace Environment
- SWPC-02 Modeling the Upper Atmosphere

CSD-02 Chemical Transport Model Research

Goal: Undertake research that contributes to the ability to forecast regional air quality and improves the understanding of the budget of ozone in the upper troposphere.

Milestone 1. Evaluate the emissions of carbon monoxide (CO), nitrogen oxides (NO_x), and carbon dioxide (CO_2) from the Houston and Dallas/Fort Worth urban areas by comparison of aircraft observations, tunnel measurements, and emission inventories.

Emission inventories catalog the pollutants released from a particular anthropogenic activity. In most U.S. urban areas, motor vehicles are major sources of CO, NO_x, and CO_2. Inventories for motor vehicles are the products of complex calculations of fuel- and vehicle-dependent emission factors, fleet composition, and vehicle activity. These inventories must therefore be independently verified, preferably using ambient observations. Previous evaluations have shown large discrepancies between observed and inventory emissions for urban areas.



A summary of measured and inventory CO/CO_2 over the Houston and Dallas/Fort Worth urban areas. Symbols represent average aircraft and tunnel measurements of this ratio, and solid lines show inventory values. Data for 1999/2000 are in red, 2005/2006 are in blue. The observations are averaged over midday and late afternoon sampling windows to demonstrate the emission changes as the distribution of motor vehicles evolves throughout the afternoon. Both the inventories and the observations show a decline in CO emissions between 1999/2000 and 2005/2006. However, there is a clear discrepancy between the observations and the inventories for both time periods.

Here we use field observations collected on NOAA research aircraft to evaluate the mobile source emission inventories for Houston and Dallas/Fort Worth, TX. As part of the 2000 and 2006 Texas Air Quality studies, ambient concentrations of NO_x, CO, and CO_2 were sampled during research flights in pollution plumes dominated by mobile source emissions. Mobile source emission ratios of CO/CO_2 and NO_x/CO_2 derived from the aircraft data are compared with observations at a Houston highway tunnel in 2000, and with the 1999 and 2005 Environmental Protection Agency (EPA) National Emission Inventories. Since CO, NO_x, and CO_2 have common sources, taking ratios of the observed ambient concentrations corrects for atmospheric dilution of pollution plumes. Inventory estimates of CO_2 emissions are thought to be relatively accurate, so comparisons of observed and inventory CO/CO_2 and NO_x/CO_2 ratios provide an evaluation of the CO and NO_x inventories.

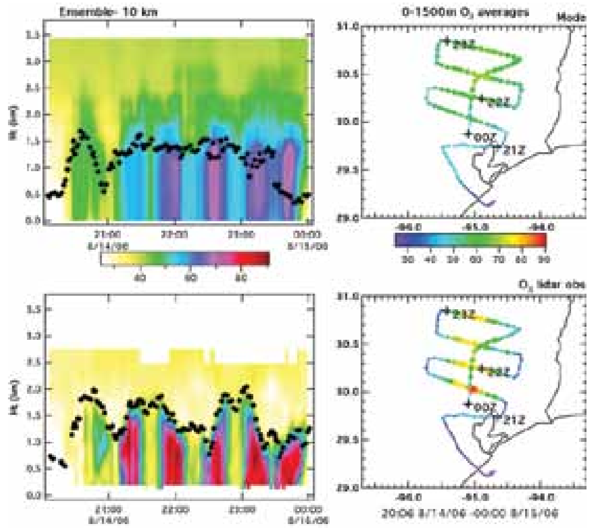
For these Texas urban areas, the observations and inventories both show roughly 50 percent decreases in mobile source CO emissions over this 6-year period. Observed estimates of mobile source CO emissions in either year are two to three times smaller than the corresponding EPA inventory values. Observed mobile source NO_x emissions declined less than observed CO emissions between 2000 and 2006. The observed mobile source NO_x emissions are in reasonable agreement with 2005 National Emission Inventories estimates.

A journal article describing these results is currently in preparation.

Milestone 2. Use measurements of ozone, aerosols, and their precursors made during the 2006 Texas Air Quality Study (TexAQS)/Gulf of Mexico Atmospheric Composition and Climate Study to evaluate the capabilities of chemical forecast models.

As part of the TexAQS, eight air quality forecast models from various forecast centers, research centers, one university, and one private corporation were operational in real-time during a six-week period that overlapped with ozone lidar measurements made below 3-km altitude by a NOAA Twin Otter aircraft. Model forecast vertical distributions of ozone (O_3) and the planetary boundary layer (PBL) depth are compared with the Twin Otter observations. The multi-model comparisons are designed to identify biases and errors in physical, photochemical, and emission parameterizations within individual forecast models. They serve as a measure of our collective scientific understanding and ability to forecast air quality over a region with roughly 4 million inhabitants.

Lidar data from 12 flights within and around the Houston urban corridor were used in the forecast model evaluation. Comparing O_3 within the PBL, all but one of the forecast models severely under-predicted the high O_3 values often observed downwind of the Houston ship channel. The likely reason is an underestimation of reactive volatile organic compound (VOC) emissions, as demonstrated by comparisons between the forecast model results and detailed, in situ observations collected aboard the NOAA WP-3 aircraft during the same field study (McKeen et al. 2009). Comparing O_3 above the PBL, the one forecast model that incorporated O_3 boundary conditions from a global model shows much higher correlation with observations compared to the other models. The eight forecasts are also combined to construct a four-dimensional (in time and space) ensemble forecast. This ensemble is shown to have good statistical skill compared to the individual forecasts for all altitudes sampled by the lidar. A web site has been constructed to display the results of the ozone and PBL statistical analysis: http://www.esrl.noaa.gov/csd/2006/modeleval/tex06/topaz/.



Comparisons of O_3 lidar curtains and PBL depths (left) between the eight-model ensemble (top) and observations collected by the NOAA Twin Otter TOPAZ lidar (bottom). Figures on the right compare the 0-1.5 km AGL O_3 averages along the flight track. Black circles on the curtain plots show the planetary boundary layer (PBL) depth for the model ensemble (top) and the PBL depths derived by a wavelet analysis of the aerosol backscatter.

Product: McKeen, S et al. (2009), An evaluation of real-time air quality forecasts and their urban emissions over Eastern Texas during the summer of 2006 TexAQS field study, *J. Geophys. Res.*, doi: 10.1029/2006JD011697.

PSD-16 Raindrop Size Distributions

Goal: Improve ground-based, airborne, and spaceborne radar rainfall estimates through increased understanding of the number and size of raindrops in precipitating cloud systems.

Milestone 1. Polarimetric scanning radars provide more accurate rainfall estimates than non-polarimetric radars because of their ability to also determine the mean raindrop diameter of the raindrop size distribution (DSD) in the radar-resolution volume. The relative errors of polarimetric scanning radar rainfall and median raindrop diameter (D0) will be quantified by comparing polarimetric retrievals with surface and vertically-pointing profiler DSD estimates. Data from Darwin, Australia, will be used in this study.

The statistical uncertainties of median raindrop diameter (D0) derived from polarimetric scanning radar were quantified by propagating the radar measurement uncertainties through the power-law D0 algorithm. Comparisons of D0 estimates from the Darwin, Australia C-band polarimetric scanning radar, made over a vertically-pointing profiler 23 km away, indicate that statistical uncertainties from both instruments were comparable with a relative error of about 8 percent. The methodology and the results from this study were published.

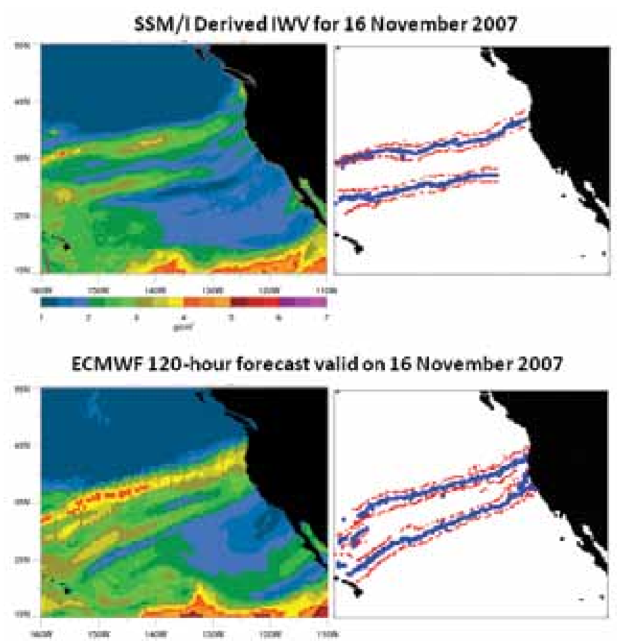
Product: Williams and May 2008.

PSD-17 Environmental Monitoring and Prediction

Goal: Improve the performance of numerical weather and climate models through model process evaluation using data streams from focused observational campaigns and space-borne measurements.

Milestone 1. Assess operational numerical weather prediction (NWP) model forecasts of water vapor and/or surface wind with Special Sensor Microwave/Imager (SSM/I) and QuikSCAT satellite observations for wintertime precipitation events along the U.S. West Coast.

A study was initiated to assess the ability of NWP forecasts contained within the THORPEX Integrated Grand Global Ensemble (TIGGE) to accurately represent the frequency and appearance of atmospheric river events impacting the U.S. West Coast. Atmospheric rivers are narrow plumes of enhanced water vapor transport responsible for the majority of recent wintertime flooding events along the west coast. Past work demonstrated that the presence of atmospheric rivers can be identified successfully through fields of integrated water vapor (IWV) content provided by passive microwave radiometers, such as the SSM/I. To quantify the ability of NWP models to predict and reproduce the atmospheric river events, atmospheric river signatures in IWV fields from the models were directly compared with corresponding retrievals from the SSM/I.



An example comparing the modeled and SSM/I-retrieved IWV signature and corresponding objectively-extracted atmospheric river characteristics.

The study is initially comparing the predicted frequency, average width, and core strength of atmospheric river events in the control, 3, 7, and 10-day forecasts from the European Centre for Medium-Range Weather Forecasts and United Kingdom Met Office with the SSM/I observations during the winters of 2006-2007 and 2007-2008. All the forecast fields are being obtained from the TIGGE archive, which began in the fall of 2006. To enable comparison of the forecasts, an automated objective routine for identifying and characterizing atmospheric river events, in both the model and satellite-retrieved IWV fields, was first developed and implemented. An example comparing the modeled and SSM/I-retrieved IWV signature and corresponding objectively-extracted atmospheric river characteristics is shown in the figure above. In general, the models are observed to reasonably predict the occurrence of atmospheric river events in 3-7 day forecasts, although representation of specific characteristics, such as width and strength, varies with forecast model and lead time.

Milestone 2. Verify and evaluate the operational prediction models' capability of reproducing the dynamical interaction between the convective cloud and the atmospheric boundary layer processes in the U.S. West Coast using special observations from the Hydrometeorological Testbed (HMT) field campaigns.

Sustained precipitation is typically enhanced and modified by complex terrain, leading to major hydrological consequences. Gaining an understanding of the physical processes in sustained precipitation events via numerical simulations is an important goal of the HMT field campaigns. In this study, the numerical prediction of precipitation associated with five cool-season atmospheric river events in northern California was analyzed and compared with observations. This work was a part of the 2005–2006 field phase of the HMT project, for which special profilers, soundings, and surface observations were implemented. Using these unique datasets, the meteorology of atmospheric river events was described in terms of dynamical processes and the microphysical structure of the cloud systems that produced most of the surface precipitation. Events were categorized as bright band (BB) or nonbright band (NBB)—the difference being the presence of significant amounts of ice aloft (or lack thereof) and a signature of higher reflectivity co-located with the melting layer produced by frozen precipitating particles descending through the 0°C isotherm.

Winds within the lowest kilometer of the troposphere are the means by which the low-level water vapor or the pollution emitted by anthropogenic activities near the earth surface is transported and dispersed. This research effort was motivated by the widely-accepted notion that it is still challenging to accurately predict/simulate low-level winds over complex topography due to the complicated processes within the atmospheric boundary layer. Michelson and Bao (2008) first reveal the sensitivity of the Weather and Research Forecasting (WRF) model-simulated low-level winds in the Central Valley of California to uncertainties in the atmospheric forcing and soil initialization. This reflects a new paradigm that the research community in NOAA is taking to improve NWP models by working directly on the very model that is being run operationally at NOAA/NCEP. The findings have been used as the background for NOAA's planning of future air quality research in California (such as CalNex 2010).

Product: Michelson and Bao 2008, and:

Jankov, I et al. (2009), Evaluation and comparison of microphysical algorithms in WRF-ARW model simulations of atmospheric river events affecting the California coast, *J. Hydromet*., in press.

GSD-01 Numerical Weather Prediction

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

Milestone 1. Continue ESRL/GSD testing of North American Rapid Refresh (RR) 1-h intermittent assimilation cycling.

Emphases will be on the performance of GSD enhancements in the use of surface observations and cloud and radar data in the Gridpoint Statistical Interpolation (GSI) analysis and initialization of hydrometeors, and to the performance of physics suites in the Weather Research and Forecasting Model (WRF) forecast component.

Work has progressed steadily toward improving and streamlining the RR 1-h cycle in preparation for porting code and testing at NCEP (see Milestone 2). CIRES staff in the Assimilation and Modeling Branch of the Global Systems Division have been critical to progress. Highlights during the last year include the following:

1) Cycling of predicted soil and snow-cover properties was revised and a procedure for trimming snow cover to conform to observations was introduced.

2) The WRF Preprocessing System code and the WRF model were upgraded to the WRF v3.1 release. This included initialization with Rapid Update Cycle (RUC) native data including hydrometeors.

3) Latest GSI release incorporating the RUC cloud/precipitation hydrometeor initialization has been running in the RR 1-h cycle since May.

4) A 10-day retrospective test period was used to examine the impacts of both satellite data assimilation and the MYNN (Mellor-Yamada-Nikonishi-Ninno) vertical mixing scheme.

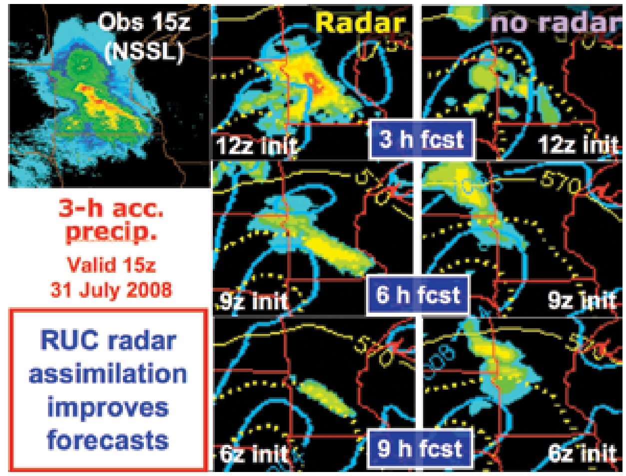
5) Alaska verification revealed a wintertime severe warm bias in the interior valleys. This led to introduction of more detailed terrain and to analysis of the use of surface observations by the GSI. Strategies for ensuring the observation innovations at the surface are given the necessary weight are being tested.

6) Warm bias in coastal regions of northwest Alaska motivated a major upgrade to the RUC Land-Surface Model (RUC LSM) used in RR. Temperature within the ice is now explicitly forecast, and snow can now accumulate and melt on top of lake or sea ice. This has substantially removed the bias.

7) The WRF postprocessor produces many new fields.

Performance of the RR is on a par with the RUC, except for winds at upper levels. In the coming months, work will focus on this winds issue, wintertime surface temperatures over interior Alaska, accurate prediction of the preconvective environment east of the Continental Divide, and a nagging boundary problem.

Much effort has gone toward the High Resolution Rapid Refresh (HRRR), which is sponsored by the Federal Aviation Administration and is in collaboration with the National Center for Atmospheric Research and Lincoln Laboratories. The HRRR is being used for airspace management in an effort to reduce weather delays due to cumulonimbus convection.The HRRR domain now covers approximately the eastern two-thirds of the continental United States. Twelve-hour forecasts using 3.1-km Horizontal grid spacing and 50 computational layers are made hourly on ESRL's supercomputer and output distributed to many users.The HRRR starts from RUC initial conditions. These are derived via the cloud-hydrometeor initialization procedure (item 3, above), including a Diabatic Digital Filter Initialization to produce a divergent horizontal wind field consistent with latent heating inferred from the 3-dimensional radar reflectivity field. The figure compares forecasted 3-h accumulated precipitation for different HRRR forecasts all valid at the same time.



Three-hour accumulated precipitation forecast by the HRRR valid 1500 UTC 31 July 2008. The "radar" column is based on the HRRR as initialized from a RUC run using the RUC radar assimilation as described in the text. The "no radar" column is a set of HRRR forecasts initialized from a RUC run without the RUC radar assimilation. The plot in the upper left is the radar reflectivity at 1500 UTC for verification. The impact of the RUC radar initialization is dramatic during the first 3h of the forecast, but in this case offers improved guidance on precipitation location even out to 9h.

Product: Alexander, CR et al. (2009), Probabilistic thunderstorm guidance from a time-lagged ensemble of High Resolution Rapid Refresh forecasts, 23rd Conf. on Weather Analysis and Forecasting, 19th Conf. on Numerical Weather Prediction.

Devenyi, D et al. (2009), Experiments with anisotropic background error correlations in the Rapid Refresh system, 23rd Conf. on Weather Analysis and Forecasting, 19th Conf. on Numerical Weather Prediction.

Hu, M et al. (2009), Adaptation and implementation of the Gridpoint Statistical Interpolation (GSI) for Rapid Refresh, 23rd Conf. on Weather Analysis and Forecasting, 19th Conf. on Numerical Weather Prediction.

Smirnova, T et al. (2009), Implementation and testing of WRF Digital Filter Initialization (DFI) at NOAA Earth System Research Laboratory, 23rd Conf. on Weather Analysis and Forecasting, 19th Conf. on Numerical Weather Prediction.

Weygandt, SS et al. (2009), Status report on Rapid Refresh development, 23rd Conf. on Weather Analysis and Forecasting, 19th Conf. on Numerical Weather Prediction.

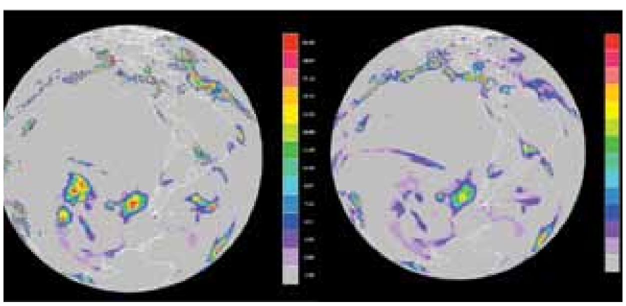
Weygandt, SS et al. (2009), The High Resolution Rapid Refresh: An hourly updated convection resolving model utilizing radar reflectivity assimilation from the RUC/RR, 23rd Conf. on Weather Analysis and Forecasting, 19th Conf. on Numerical Weather Prediction.

Milestone 2. Port well-tested ESRL/GSD code for North American Rapid Refresh to the the National Centers for Environmental Prediction (NCEP) and begin pre-implementation testing at NCEP's Environmental Modeling Center in preparation for RR implementation into NCEP operations in 2008.

Delay in installation and acceptance of an IBM Power-6-based new computer at NCEP has delayed the complete porting of code to NCEP until early 2010. Separate from this delay, CIRES has been in collaboration with GSI experts at NCEP's EMC toward modifying the code of the combined RUC-CAPS (Center for the Analysis and Prediction of Storms) cloud analysis package to conform with coding standards of the repository versions of GSI at NCEP. This work is now complete. Other changes to GSI needed for RR are also being introduced into the NCEP GSI repository code.

Milestone 3. Implement a subset of WRF physics options into FIM and compare performance with the Flow-following finite-volume Icosahedral Model (FIM) using the Global Forecast System (GFS) physics suite.

CIRES has introduced a subset of WRF physics options into FIM. These include the Grell-Devenyi convection and the Lin microphysics as adapted for interaction with aerosols, and the Goddard shortwave and longwave radiation schemes. A few test cases have been run. An example of a 0-12h forecast of total precipitation is shown in the figure. The overall character of the precipitation in the tropics (west of Central America, for example) shows much more granularity for this particular choice of WRF physics than for the GFS physics, which uses the Simplified-Arakawa-Schubert convective scheme of Grell (1993) highly tuned for use in the GFS. There are also appreciable differences in the grid-scale precipitation off the west coast of Chile. A CIRES scientist is currently working on a simplified aerosol scheme to add to FIM, and plans to introduce the WRF version of the RUC land-surface scheme (see item 6 under Milestone 1 accomplishments for recent modifications to this scheme that would be important for global application). This researcher is also working toward adding other elements of WRF-Chem into FIM. This is all part of a low-key, but long-term plan to build FIM into a versatile model that could be used as a research tool within ESRL.



An example of a FIM 0-12h forecast of total precipitation, with WRF (left) or GFS (right) physics.

Product: Bleck, R et al. (2009), On the use of an arbitrary Lagrangian-Eulerian vertical coordinate in global atmospheric modeling, *Mon. Wea. Rev.*, submitted.

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

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

Milestone 1. Provide quality assessment reports summarizing the Graphical Turbulence Guidance (GTG3) product and the National Ceiling and Visibility Analysis product. The reports are provided to the Aviation Weather Technology Transfer Technical Review Panel. The Panel members use the information as evidence to determine whether the forecast product should transition from research to NWS operations.

Evaluation of the GTG3 product was completed. Feedback given to the research team indicated an error in the GTG3 data. As part of this evaluation, new verification techniques were explored for probabilistic forecast evaluation. In addition, techniques were developed that allowed the application of highly temporal in situ turbulence observations to be used for the verification of the GTG3 forecasts.

Milestone 2. Demonstrate the Network-Enabled Verification Service (NEVS) prototype for evaluating convective forecast quality. NEVS is a service that will replace the Real-Time Verification System (RTVS).

A prototype of NEVS was completed in early January 2009. The prototype included demonstration of the integration layer and access to the results through a web interface. Engineering techniques developed for NEVS has enabled on-the-fly and nearly instantaneous application of bootstrapped confidence intervals to any request.

Milestone 3. Provide a real-time verification capability for assessing the forecast lead time from ceiling and visibility forecasts.

The lead-time verification capability for NWS ceiling and visibility forecast (known as the Terminal Aerodrome Forecast, TAF) is running and available for a subset of users. Training materials were developed and provided to the NWS staff. The forecast decoder has been upgraded to allow longer lead forecast products to be decoded for evaluation. NWS users provided feedback and suggestions for operational use. Access to the lead-time verification capability will be available to all NWS staff by the end of August 2009.

GSD-05 Numerical Prediction Developmental Testbed Center

Goal: Develop and maintain a version of the Hurricane Weather Research and Forecasting (HWRF) modeling system that is to be supplied to the weather research modeling community through the Developmental Testbed Center (DTC).

Milestone 1. Define an approach to the problem and assign tasks in conjunction with NCEP and DTC staff. Develop a schedule for completion of tasks 1-4 as described in the project approach.

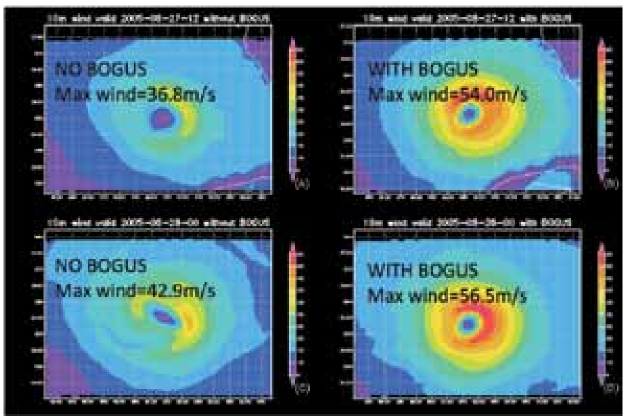
This was completed.

Milestone 2. Meet with the HWRF development team at NCEP to identify what needs to be understood about the software to enable porting of the system to Boulder computers.

CIRES and NOAA staff met with HWRF model development staff at the National Centers for Environmental Prediction (NCEP) in July 2008, to gain an understanding of the problem and to develop an approach with a schedule for porting, testing, and supporting the HWRF at the DTC. Since October 2008, CIRES staff have been coordinating closely with the HWRF development manager at NCEP, who has been at the DTC in Boulder this past year. CIRES staff returned to NCEP in April 2009 to coordinate a plan for testing the ported HWRF system and for preparing the first-ever HWRF tutorial, scheduled for February 2010.

Milestone 3. Develop the atmospheric Nonhydrostatic Mesoscale Model component of HWRF with static grid nesting to the DTC systems running at NCAR and ESRL to meet WRF repository standards.

CIRES staff successfully ported the HWRF with static and vortex-following grid nesting. CIRES ported the hurricane 'bogus' vortex initialization scheme unique to HWRF from NCEP to the DTC supercomputers at ESRL and at the National Center for Atmospheric Research. The HWRF physics were ported and model regression tests successfully conducted. HWRF surface layer and land surface physics schemes were entered into the WRF Repository v3.0.1. in December 2008. The HWRF simplified Arakawa-Schubert (SAS) cumulus, planetary boundary layer (PBL), and microphysics were raised to v.3.0 and regression tests successfully run. Those physics are being prepared for submission to the repository.



A comparison of 12- and 24-hour forecasts of windspeed at 10-m altitude with and without the HWRF 'bogus vortex initialization' scheme activated. This scheme dramatically increases the winds in the initial hurricane vortex, from which the forecast model is spawned, resulting in huge improvement in forecast hurricane strength.

Milestone 4. Verify that hurricane analyses and forecasts performed with the HWRF system completed under task #3 are acceptably similar to results produced at NCEP.

Because the physics in v.2.0 of the operational HWRF were significantly different than the ones available to the community in WRF-NMM v3.0, the physics had to be raised to the current version. Also, v2.0 uses data assimilation and contains the Princeton Ocean Model, whereas v3.0 does not. These differences complicated the testing needed to verify that the DTC version of HWRF is fully acceptable to NCEP. Testing is continuing.

Milestone 5. Complete the first draft of the documentation describing the atmospheric-only component to the HWRF system.

This work will commence once the testing and verification phases of the ported HWRF-atmosphere are completed. Documentation must be completed after all the code is in the WRF repository and before the first tutorial is given.

NGDC-03 Space Weather

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

Milestone 1. Integrate ionospheric data flows with real-time systems in support of global modeling. This includes support for the Global Assimilation of Ionospheric Measurements (GAIM) model at the Air Force Weather Agency and/or Space Weather Prediction Center.

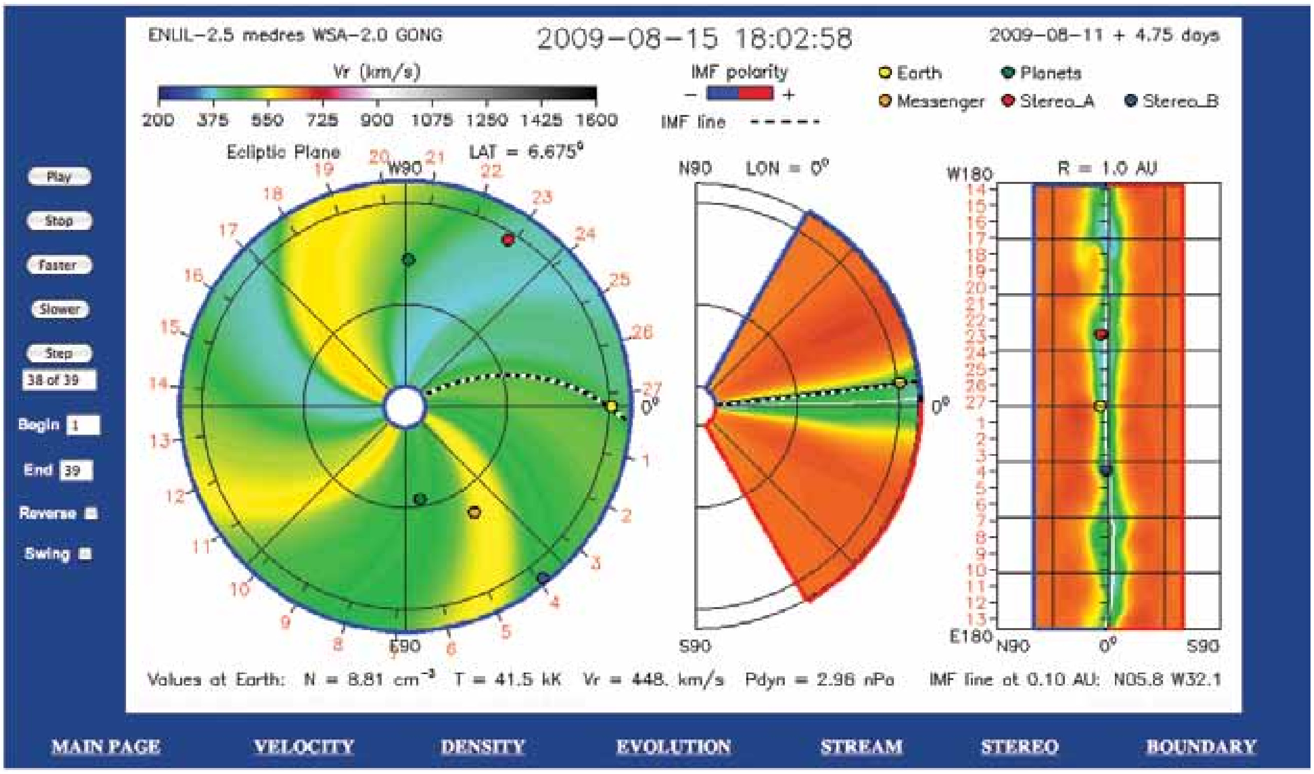
The Mirrion version 2 system was completed at NGDC. Mirrion is a ionosonde data mirror, which gathers data from around the world, processes, analyzes, and distributes it. The U.S. Air Force is one of the customers for these data, for the Air Force's GAIM real-time assimilation tool. By including ionospheric measurements from around the globe, that team is able to provide significant enhancements in data quality, accuracy, and coverage. This system also provides quality controlled data to the NGDC archive for long-term preservation and use in areas such as climate study. By providing a science quality dataset to the user community, it enables research on a global scale.

Milestone 2. Create a Global Positioning System (GPS) data system to manage, collect, and distribute the African GPS network data in support of the International Heliospheric Year (IHY). These data are key to the success of the IHY because it will allow scientists to have coverage previously not available. This system will be freely distributed via the World Data Center network.

CIRES staff associated with NGDC participated in the combined International Heliospheric Year-Africa (IHY-Africa) and Scintillation Network Decision Aid (SCINDA) workshop in Livingstone, Zambia in June of 2009. The purpose of the workshop was to provide a forum for the development of space science and education in Africa in accordance with the overall IHY-Africa objectives. The workshop also served as the culmination of a two-year partnership between CIRES and NOAA to provide a means for the GPS community to share environmental data collected in Africa. At the workshop, staff presented an overview of the data portal developed for the community and to support the work of various African data providers. Staff also participated in SCINDA workshop discussions and helped develop policies to determine how data will be handled, archived, and disseminated within the scientific community.

Milestone 3. Run the Assimilative Mapping of Ionospheric Electrodynamics (AMIE) model using a common code base for 1990-2004. This will create a long-term climate record for the high-latitude ionosphere.

The objective of this project is to generate a complete 22-year (one solar cycle) space weather representation using physically consistent, data-driven, space weather models. The project is creating a consistent, integrated historical record of the near-Earth space environment, by coupling observational data from space environmental monitoring systems archived at NGDC with data-driven, physically-based numerical models. The result is an enhanced look at the space environment on consistent grids, time resolution, coordinate systems, and containing key fields. This allows a modeling and simulation customer to quickly and easily incorporate the impact of the near-Earth space climate in environmentally sensitive models. With support from CIRES staff, there is now a 15-year archive of such data available for limited domains, representing



Predicted solar wind velocity in the inner heliosphere between 0.1 and 1.1 AU on three slices passing through Earth. Details at http://helios.swpc.noaa.gov/enlil/latest-velocity.html.

more than half of a full solar cycle. At the end of this project, there will be a full 22 years of quality checked and certified data.

SWPC-01 Solar Disturbances in the Geospace Environment

Goal: Improve the prediction of traveling solar disturbances that impact the geospace environment. Such disturbances, which are associated with both coronal holes and coronal mass ejections (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 1. GOES X-Ray instrument: Implement algorithms to optimize parametric fits to observed data from a sounding rocket solar X-ray spectrometer for new flights, and apply the results to operational products and calibration routines.

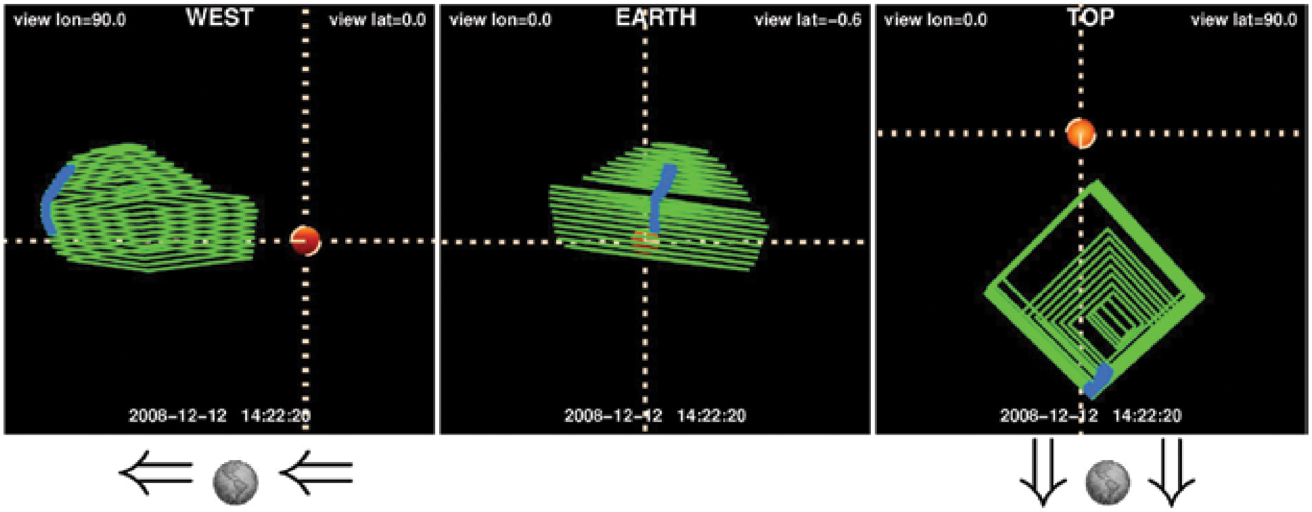
The Solar X-ray Imager (SXI) is currently flying on the GOES-13 and GOES-14 satellites. GOES-14 launched in June, 2009 and initial calibrations are underway. The imaging processing software has been defined and the implementation of that software is nearly complete. The processing required includes rotating the image so that solar north is at the top of the image; centering the image; and accounting for vignetting, background subtraction, bad pixels, and bias. Once a system is in place, these images will be available in real time for forecasting needs.

Milestone 2. Global Solar Wind Predictions: Continue sophistication of an operational prediction tool based on the Wang-Sheeley-Arge source surface model, and include evolving solar wind and tracing of magnetic field lines down to the solar photosphere.

The highlight of this year's work was the establishment of an experimental solar wind prediction web page (http://helios.swpc.noaa.gov/enlil). Both the Wang-Sheeley-Arge (WSA) and ENLIL models were implemented on the SWPC developmental testbed workstation, and it was verified that these models can be run automatically overnight to provide daily forecast for 4-5 days advance warning of oncoming solar wind disturbances. Results of this experimental/demonstration prediction system (figure above) have been used by NOAA space weather forecasters as auxiliary information at morning briefings since April 2008. In addition, operational issues—such as missing observations, broken connections, lack of disk space, model upgrades, etc.—have been addressed. An improved procedure for tracing magnetic field lines from geospace back to the inner boundary of the heliospheric model has also been developed, and work continues on tracing these lines through the solar corona down do the solar photosphere.

Milestone 3. Coronal Mass Ejection Locator: Finalize development and initiate verification and validation studies of the operational tool based on white-light corona observations from NASA STEREO spacecraft.

Since the launch of the dual STEREO spacecraft in 2006, the SWPC has worked to develop and test the geometric localization technique (Pizzo and Biesecker 2004, de Koning et al. 2009, Mierla et al. 2009), which uses a series of lines of sight from the two STEREO COR2 coronagraphs to determine gross propagation characteristics of CMEs in three-dimensional space. The underlying philosophy behind the geometric localization technique is to keep the method as



The three-dimensional spatial location of the CME at 1422 UT on 12 December 2008 at as calculated using geometric localization. The green quadrilaterals indicate the bounding volume of the CME as a whole, while the blue quadrilaterals indicate the bounding volume of the leading-edge shell. The hash marks indicate the scale used; the distance between each mark is 1 Rsun. The viewing latitudes and longitudes on the plots refer to the observers position in HEEQ coordinates. The left plot is for an observer hovering over the west limb of the Sun; Earth is on the left side of the plot. The center plot is for an observer at Earth. The right plot is for an observer looking down onto the north pole of the Sun; Earth is toward the bottom of the plot.

simple as possible, while allowing for enough potential to achieve useful, timely gains in forecast and research capabilities. The geometric localization technique is now mature and is poised to be applied for space weather forecasting, using highly-compressed, near-real-time beacon data. The method enables computation of the location and velocity, including speed and direction, for any CME observed by STEREO.

To illustrate this method, results are presented from our analysis of the 12 December 2008 CME (figure above); additional CMEs are analyzed in de Koning et al. (2009). As can be seen from the figure, application of geometric localization to COR2 beacon data returns a crude stack of quadrilaterals, indicating the volume of space wherein the CME exists. The center of quadrilaterals can readily be found by straightforward averaging of all the vertices contained within the stack. By applying this technique to successive images of the same CME, the progress of the center of quadrilaterals as a function of time can be plotted. This results in a center-of-quadrilateral speed for this CME of 244 km/s and a direction of motion of 8˚N and 6˚W of the Earth-Sun line, that is, essentially Earth-directed. Application of the technique to small segments on the leading edge of the CME can be used to calculate the leading-edge velocity. This CME had a leading-edge speed of 389 km/s and a direction of motion similar to the center-of-quadrilateral estimate. Advanced Composition Explorer (ACE) data indicated the arrival of an interplanetary CME (ICME) at Earth at 0330 UT on 17 December 2008; using geometric localization, the arrival of the ICME would have been predicted for 0128 UT on the same date. Note that this prediction would have been made on 12 December, more than four days prior to the arrival of the ICME.

Milestone 4. Extreme Ultraviolet Imaging Telescope (EIT) waves and dimmings: Investigate possible relationships between CME properties and dimmings observed by EIT and validate with spacecraft observations.

Coronal dimmings are a phenomenon frequently associated with CMEs. A statistical analysis of CME-associated dimming regions observed with the EIT on board the Solar and Heliospheric Observatory (SOHO) spacecraft has been conducted. It was found that all CMEs with speeds exceeding 800 km/s have an associated dimming. A paper summarizing these results has been submitted to the Astrophysical Journal. These results have important implications for understanding and predicting CME initiations.

SWPC-02 Modeling the Upper Atmosphere

Goal: Understand responses of the upper atmosphere to solar, magnetospheric, and lower atmosphere forcing, and the coupling between the neighboring regions. Since many 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 1. Couple the Global Ionosphere Plasmasphere (GIP) code, including an electrodynamics module, with the Whole Atmosphere Model (WAM). Clear signatures have emerged of the impact of terrestrial weather on the spatial structure and temporal variability of the upper atmosphere. The coupling will begin to elucidate the physical processes responsible for the ionospheric variability and the impact on space weather.

1) Simulation of the midnight temperature maximum (MTM) using a WAM (Figure 1 opposite page).

A coupled general circulation model (GCM) of Integrated Dynamics through Earth's Atmosphere (IDEA) has been developed to address the physical processes responsible for the impact of terrestrial weather on the upper atmosphere and ionosphere. IDEA consists of a WAM coupled to a GIP model, including electrodynamics processes. WAM is built on an existing operational Global Forecast System (GFS) model used by the NWS for medium-range weather prediction. To create WAM, the GFS code was extended from 64 layers to 150 layers, with the top pressure level raised from 62 km to 600 km.

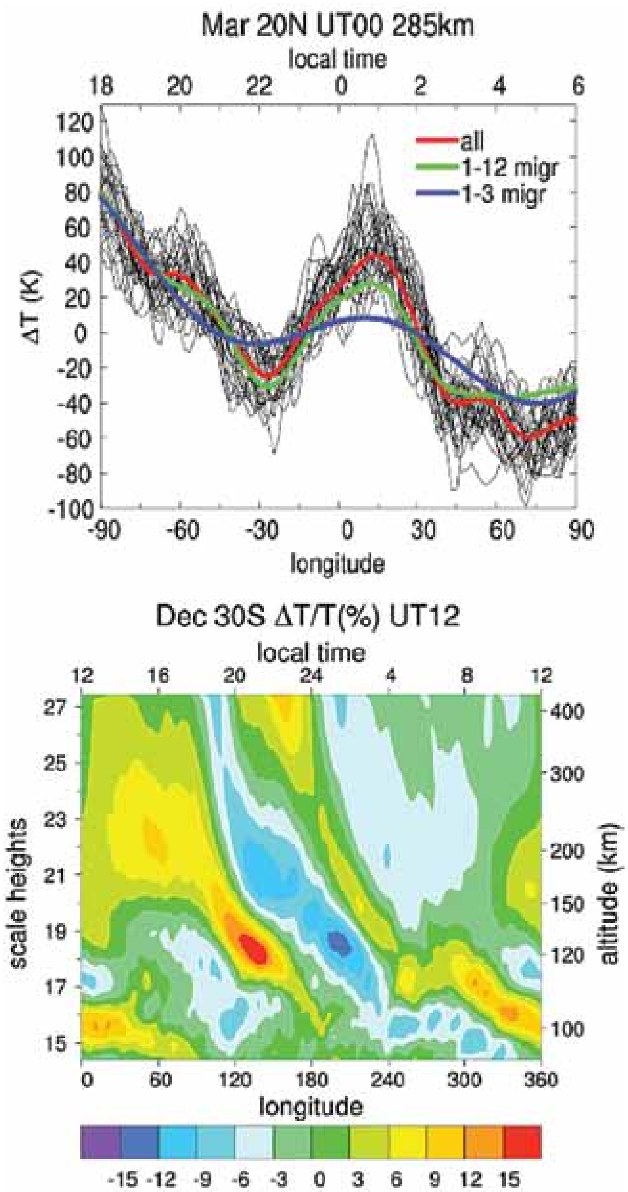


Figure 1: *Top: Nighttime temperatures from WAM at 285 km altitude and 0 UT for every day in March at 20°N geographic latitude. The nighttime temperature peak occurs routinely just after midnight with a typical amplitude of 100 K, peak to trough. Bottom: A vertical cut through WAM across local time or longitude at 12 UT in December and at 30°N. The propagation from the lower altitudes is clearly seen..*

WAM was run for a one-year period following initialization from the GFS Gridpoint Statistical Interpolation (GSI) data assimilation system. One of the exciting results from the yearlong simulation was the signature of a strong MTM in the thermosphere, never before successfully simulated. The MTM is a large-scale anomalous feature of the upper thermosphere temperature that has widespread influence on the nighttime thermosphere and ionosphere.

2) Quantifying the flow of energy from the magnetosphere to upper atmosphere (Figure 2).

In addition to the forcing from the lower atmosphere, the thermosphere-ionosphere is also strongly forced by the magnetosphere from above. During a geomagnetic storm, this energy source can increase 20-fold, and can overwhelm the solar radiation and lower atmosphere energy inputs, both as sources of variability, and in terms of the total energy injected. The magnetosphere energy injection causes a thermal expansion and an increase in atmospheric density at low Earth orbiting (LEO) satellite altitudes. The accelerometer onboard the CHAMP satellite measures the neutral mass density at around 400 km, and therefore is a good measure of this thermal expansion and can be used to quantify the energy injection.

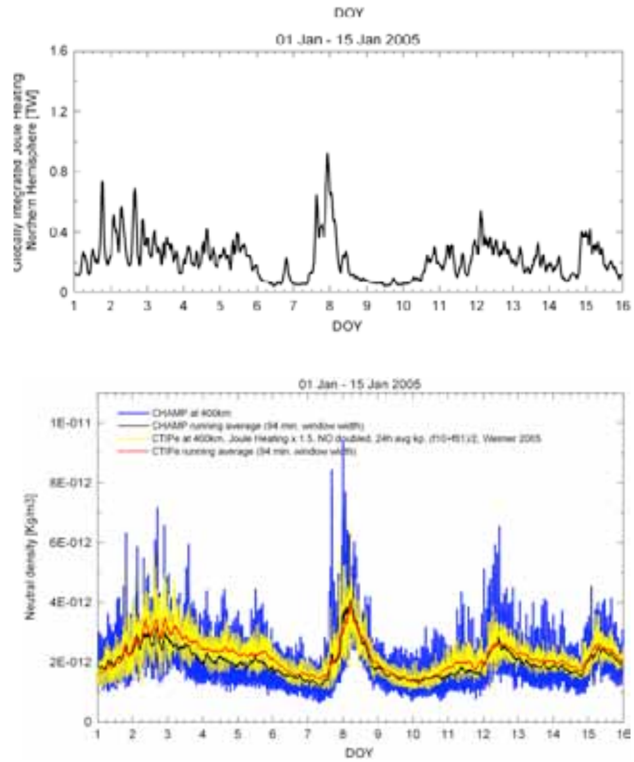


Figure 2: *Top: A comparison of CHAMP satellite orbit-averaged neutral density (black) with a physics-based model prediction (red). Bottom: The energy flow from the magnetosphere to the northern hemisphere upper atmosphere in the form of Joule heating. The combined global rate of energy injection exceeds 2 TW.*

Product: Akmaev, RA et al. (2009), Midnight temperature maximum in Whole Atmosphere Model simulations, *Geophys. Res. Lett*., doi: 10.1029/2009GL037759.

AMOS-04 Observing Facilities, Campaigns, and Networks

- GMD-02 Surface Radiation Network
- PSD-10 Cloud and Aerosol Processes
- GSD-04 Unmanned Aircraft Systems

GMD-02 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 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.

This project is still in progress. As time allows in the future, work on this project will continue.

A Yankee Total Sky Imager at Eglin Air Force Base in Florida.

Milestone 2. Complete the reconstruction of the multi-filter rotating shadow-band radiometer (MFRSR) angular response measurement database for the Atmospheric Radiation Measurement (ARM) program, and use the results to determine the sensitivity of changing angular responses on the retrieval of aerosol optical depths from MFRSR measurements. Publish the results.

The historical calibration dataset is complete. As part of this process, the angular response data for each instrument that has been fielded since 1993 was organized, with each file in a common format. The reprocessing of all the historical ARM MFRSR data is nearing completion. Once finished, it will allow an examination of how the changing sensitivity of individual angular response functions affect the retrieval of aerosol optical depths.

PSD-10 Cloud and Aerosol Processes

Goal: Make observations of clouds, aerosols, and water vapor over a variety of ice, land, and sea surfaces using a multi-sensor, multi-platform approach to improve retrieval techniques useful for satellite validation studies.

Milestone 1. Participate in VOCALS-REX research cruises in October/November 2008, deploy cloud radar, radiometer, and flux systems to measure key surface marine boundary layer parameters, and low-cloud macrophysical, microphysical, and radiative properties.

ESRL's Physical Sciences Division (PSD) air-sea interaction group participated in both legs of the VOCALS cruise. All PSD systems functioned well, with the exception of a W-band radar preamp problem on leg 1. Data from PSD systems are available at ftp://ftp.etl.noaa.gov/et6/cruises/VOCALS_2008/RHB. A summary of the data can be found at ftp://ftp.etl.noaa.gov/et6/cruises/VOCALS_2008/RHB/Scientific_analysis/reports/PSD_data_sum_VOCALS08_v7doc.pdf.

Product: Fairall, CW et al. (2009), Surface-layer and boundary-layer observations from the VOCALS-REX field program: Preliminary look at observations from the NOAA ship *Ronald H. Brown*, AMS annual meeting.

Milestone 2: Submit synthesis paper of stratocumulus cruises.

A draft copy of the paper submitted to the *Journal of Climate* is available at ftp://ftp.etl.noaa.gov/user/cfairall/epic_stratus_integrated/deszoeke_synthesis_09.

Product: DeSzoeke, SP et al. (2009), Surface flux observations in the southeastern tropical Pacific and attribution of SST errors in coupled ocean-atmosphere models, *J. Climate*, submitted.

Milestone 3. Participate in African Monsoon Multidisciplinary Analysis (AMMA) research cruises in May 2009; deploy cloud radar, radiometer, and flux systems to measure key surface marine boundary layer parameters, low-cloud macrophysical, microphysical, and radiative properties.

The series of AMMA/PIRATA Northeast Extension (PNE) cruises have been superseded by cruises to the Woods Hole Oceanographic Institution climate reference buoy in the North Atlantic (NTAS). This cruise will occur June 17-July 4, 2009. The AMMA/PNE cruise will follow the NTAS cruise scheduled for June 17-July 4, 2009, and the PSD equipment will remain on board and be operated byAtlantic Oceanographic and Meteorological Laboratory personnel.

Milestone 4. Deploy suite of cloud and boundary-layer remote-sensing instrumentation at the North Pole during the Arctic Summer Cloud Ocean Study (ASCOS) in August-September 2008 through extensive international collaboration. Begin processing and analysis of ASCOS data.

An extensive suite of instruments was deployed on the icebreaker Oden for ASCOS during the summer of 2008. These instruments included: 60-GHz scanning radiometer, microwave radiometer, 449-MHz windprofiler, K- and S-band radars, and a ceilometer. Measurements from these instruments provide temperature profiles in the boundary layer, total column amounts of water vapor and liquid water, three-dimensional winds up to 4 km, and a comprehensive view of clouds. Preliminary datasets are available for all instruments, while some final datasets have also been produced. Initial analyses suggest a rich dataset, providing a detailed perspective on the interactions between clouds and the boundary layer structure.

Milestone 5. In collaboration with the NOAA, the CU-Boulder Center for Environmental Technology, and the University of Leeds, obtain airborne spatial measurements near the ASCOS site at the North Pole of synoptic/meso-scale atmospheric structure, cloud distribution, cloud microphysics, and aerosols. This is the Arctic Mechanisms of Interaction between the Surface and the Atmosphere (AMISA) project. Begin processing and analysis of data.

The AMISA aircraft campaign took place in August 2008. Measurements made by the aircraft include basic meteorological measurements, cloud microphysics, aerosol concentrations, radiometry, and dropsondes for obtaining atmospheric thermodynamic profiles. The campaign consisted of six science flights aimed at addressing a number of scientific objectives. These included mapping surface ice and melt pond distributions, profiling low-level mixed-phase clouds, observing the atmospheric thermodynamic state in the area surrounding the ASCOS campaign, and making measurements in the transition zone between open ocean and sea ice. Initial processing of datasets has started.

Milestone 6. Produce cloud macrophysical and microphysical datasets for Arctic Atmospheric Observatories.

Hourly cloud occurrence and macrophysical properties datasets have been produced for six Arctic atmospheric observatories. While some of these sites were in operation for only one year, others have been operating for many years, resulting in a total of 33 years of cloud data. These datasets have been archived with the Cooperative Arctic Data and Information Service (CADIS) archive.

In addition, cloud microphysics datasets have been produced for three Arctic atmospheric observatories. Cloud properties include the characteristic particle size and water content for both liquid and ice hydrometeors. While these datasets are not yet available at an archive, they have been presented at a number of meetings, have contributed to multiple publications, and are used in ongoing studies.

Product: Datasets submitted to CADIS archive, Shupe et al. 2008, Klein et al. 2008, Morrison et al. 2008, and:

Remillard, J et al. (2009), Three Years of Cloud Climatology and Phase at Eureka Using Synergetic Radar/Lidar Measurements, *J. Geoph. Res.*, submitted.

Milestone 7. Develop a climatology of back trajectories for Arctic stations to provide context for cloud and aerosol analysis.

A database of back trajectories, which estimate the source regions and pathways for air parcels reaching Arctic atmospheric observatories, has been created. The Hybrid Single-Particle Lagrangian-Integrated Trajectory (HYSPLIT4) model, forced with NCEP/NCAR reanalyses, was used to produce past trajectories for Alert and Eureka (Canada), Barrow (Alaska), Ny Alesund (Norway), and Tiksi (Russia). Trajectories for each site were then distinguished into physically-based flow regimes to statistically characterize the monthly and seasonal trajectories experienced at a given site.

Product: Database of air mass source trajectories.

GSD-04 Unmanned Aircraft Systems

Goal: Test and evaluate a variety of unmanned aircraft systems to collect scientifically valuable environmental data. The tests will be carried out in a variety of situations in support of multiple scientific goals. Results of funded unmanned aircraft projects will be provided in written reports that can be shared within NOAA and the general scientific community.

Milestone 1. Test the capabilities of low-altitude long-endurance unmanned aircraft for taking measurements over ice and open water.

Successful flights over Greenland's meltponds took place in July 2008, in collaboration with Advanced Ceramics Research, which owned and operated the unmanned aircraft. Scientific data collected included depth and volume of lakes. The work provided a high level of detail, not previously attained, on the structure of meltponds after they had drained for the season. More than 30 hours of missions flights resulted in several gigabytes of data.

In September 2008, NOAA, the National Aeronautics and Space Administration, and the U.S. Federal Aviation Administration (FAA) representatives met at the State Department to brief Arctic officials on the need for international coordination, to enable critical environmental measurements with unmanned aircraft.

In October 2008, at the request of the Arctic Council, CIRES staff co-chaired a meeting of civil aviation authorities to discuss possibilities and existing barriers to using unmanned aircraft in the Arctic. More than 20 attendees, including Arctic scientists, met in Oslo, Norway to discuss potential steps forward. The meeting report was submitted to the Senior Arctic Officials and was received favorably by the Arctic representatives.

In October 2008, test flights near Seattle, WA off of the NOAA vessel *Oscar Dyson* demonstrated the capability to launch and recover unmanned aircraft from a ship. The flights demonstrated capability and proved to the FAA that such flights could take place safely. Launching involved a catapult system, and successful recovery involved having the aircraft fly into a vertical line using differential GPS technology.

In April 2009, the Arctic Council approved documents from the Arctic Monitoring and Assessment Program to promote use of unmanned aircraft in a circum-Arctic manner. The Arctic Council supported the plan to have regular meetings between civil aviation authorities and scientists to enable such activities. The statements, agreed on unanimously by representatives from the eight Arctic countries, were the culmination of a two-and-a-half-year effort to establish international support for use of unmanned aircraft in the Arctic.

In May 2009, flights off the NOAA vessel *McArthur* resulted in more than 30,000 images of seals, taken using a Scan Eagle unmanned aircraft. Almost 50 hours of flights took place during one month of operation. The flights represented the first time NOAA was able to fulfill its mandate to survey seal populations near Alaska without relying on another agency's ships. (NOAA does not own a ship capable of launching and recovering manned aircraft and therefore has had to partner with agencies such as the U.S. Coast Guard and Navy).

CLIMATE SYSTEM VARIABILITY

CSV-01 Detection of Climate Models, Trends and Variability

■ GMD-03 Climate Trend Analysis

■ PSD-04 Decadal Climate and Global Change Research

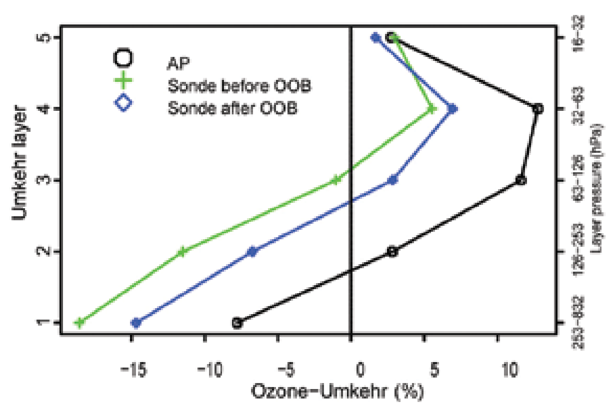
■ NGDC-04 Paleoclimatology: Understanding Decadal- to Millennial-Scale Climate Variability

GMD-03 Climate Trend Analysis

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

Milestone 1: Develop new products for Brewer NOAA network, such as tropospheric ozone and nitrogen dioxide (NO_2) column. Evaluate and characterize new products against well-established and co-located measurements. Provide data to OMI/AURA satellite validation campaigns.

The stray light interference in the ground-based Dobson and Brewer Umkehr measurements (or out-of-band, OOB) influences the retrieved vertical ozone profile distribution. The OOB contribution varies between instruments and is dependent on total ozone and solar zenith angle. The application of OOB empirical correction to Umkehr measurements prior to retrieval reduces the noise in retrieved data and addresses the long-standing bias in stratospheric ozone measured by different systems.

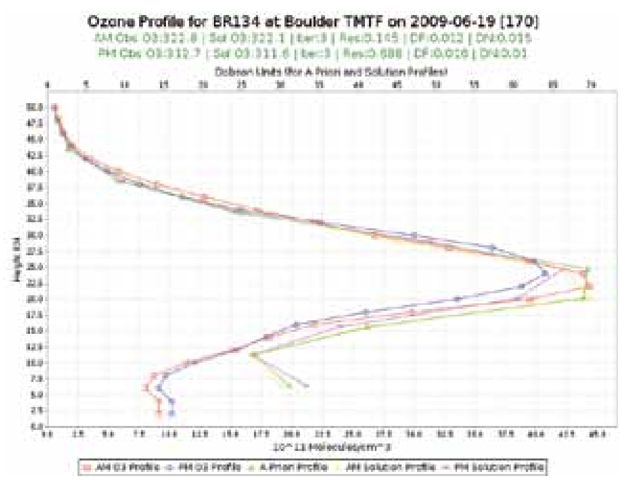


Comparison between AK-smoothed sounding and Umkehr retrievals, before (green pluses) and after (blue diamonds) OOB correction. The Umkehr a priori comparison against the sounding is also shown for a reference.

Comparisons to the ozone sounding in Boulder indicate some improvement in the Umkehr retrieved tropospheric ozone. The bias is reduced from 12 to 7 percent in Umkehr layer 2 and from 18 to 15 percent in layer 1. Comparisons between Solar Backscatter UltraViolet (SBUV) and Umkehr ozone profiles show that OOB correction tends to reduce bias in derived stratospheric ozone, however the vertically distributed bias does not disappear completely (Petropavlovskikh et al. 2009). There is a need for more careful measurements of the OOB effect on the Umkehr measurement (i.e., Evans et al. 2009).

Milestone 2: Develop an ozone profile retrieval algorithm for use with automated Dobson and Brewer radiometric measurements. Implement an operational ozone profile processing and retrieval system that will provide expanded capability for detection and tracking of projected stratospheric ozone recovery and validation of satellite profile observations.

The new Brewer ozone algorithm software called O_3 Umkehr was developed in collaboration with Martin Stanek of the International Ozone Service, Canada. The Brewer Umkehr ozone profile retrieval algorithm is implemented at all NEUBrew sites (NOAA-U.S. Environmental Protection Agency Brewer Spectrophotometer UV and Ozone Network) to derive daily ozone profiles. The work to further optimize the Brewer ozone profile retrieval has continued through 2008. For example, the option was added to the processing of the Brewer data to adjust total ozone information for drifts in the standard lamp readings (http://esrl.noaa.gov/gmd/grad/neubrew/index.jsp). Another implementation to the software was a "raw data" panel to evaluate cloudy periods on a daily basis (Flynn et al. 2008).



Web-based daily Brewer ozone profiles from Boulder, CO.

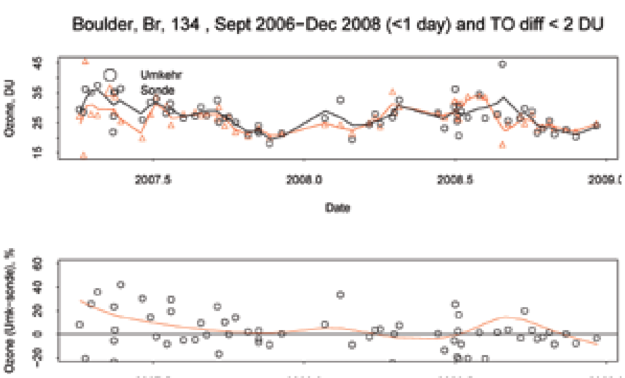
The Dobson Boulder station instrument was recently rebuilt using the Japanese operational system and with the help of a visiting scientist from the Japanese Meteorological Agency (figure next page). New data-processing software was implemented. The new hardware installation included development and production of a new Sun-tracking pedestal driver for the Dobson instrument in addition to the components available from the Japanese system. The new software creates incompatibilities in the NOAA/ESRL/GMD total ozone data stream, due to data formats, databases used in quality control, and operational or experience/training issues. Once fully implemented, the new operational system will provide Umkehr and total ozone data on a quick turn-around basis.

Newly rebuilt Dobson in Boulder, CO.

Product: Flynn et al. 2008.

Milestone 3: Investigate the impact of stray light in Dobson and Brewer instruments on the consistency of ozone retrievals from Umkehr measurements to improve these observations for trend analysis and satellite validation.

This work evaluated the quality of tropospheric ozone information derived from the ground-based Brewer zenith sky measurements. Monitoring of the day-to-day and diurnal tropospheric ozone changes is one of the science objectives of this grant. Tropospheric ozone data are evaluated through comparisons with co-incident ozonesonde measurements of high vertical resolution. Since the Umkehr method provides vertical profile information that is smoothed over an altitude range, the Umkehr smoothing functions (or averaging kernels, AK) can be used for comparisons with other high-resolution ozone profile datasets.



Tropospheric ozone time series are shown for 2006-2008 in Boulder, CO. Brewer Umkehr data and integrated ozone sounding data are plotted for comparisons. The data are selected to be less than 1 day and2 DU apart in total ozone column comparisons.

The analysis concentrated on short-term and long-term tropospheric ozone variability detected by co-incident and co-located Brewer data along with ozone profiles from ozonesondes available from Boulder, CO. Five Brewer instruments in Boulder were used in the analysis.

The studies of the day-to-day variability in the tropospheric ozone suggest that no more than one day separation is allowed between the ozonesonde launch and Brewer Umkehr measurement. This appears to be especially important in the winter and spring in the Boulder area, when there is a high frequency of high-latitude air-mass intrusions in the middle latitudes. Nevertheless, analysis suggest that Umkehr technique performed by the well-calibrated Brewer is capable of monitoring short term variability in tropospheric ozone. It can explain about 50 percent of the variability measured by ozonesonde.

Product: Petropavlovskikh et al. 2008.

PSD-04 Decadal Climate and Global Change Research

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

Milestone 1: Investigate the relative contributions of El Niño-Southern Oscillation (ENSO) related and ENSO-unrelated tropical sea surface temperature (SST) variations on global climate changes over the last 130 years.

An important question in assessing 20th century climate change is to what extent have ENSO-related variations contributed to the observed trends. Isolating such contributions is challenging for several reasons, including ambiguities arising from how ENSO itself is defined. In a recently completed study, ENSO was identified with the four dynamical eigenvectors of tropical SST evolution that are most important in the observed evolution of ENSO events. This definition was used to isolate the ENSO-related component of global SST variations on a month-by-month basis in the 136-yr (1871-2006) Hadley Centre Global Sea Ice and Sea Surface Temperature (HadISST) dataset. The analysis showed that previously identified multi-decadal variations in the Pacific, Indian, and Atlantic oceans all have substantial ENSO components. The long-term warming trends over these oceans were also found to have appreciable ENSO components, in some instances up to 40 percent of the total trend. The ENSO-unrelated component of 5-yr average SST variations, obtained by removing the ENSO-related component, was interpreted as a combination of anthropogenic, naturally forced, and internally generated coherent multi-decadal variations. Two surprising aspects of these ENSO-unrelated variations were noted: 1) a strong cooling trend in the eastern equatorial Pacific Ocean, and 2) a nearly zonally symmetric multi-decadal Tropical-Extratropical seesaw that has amplified in recent decades. The latter has played a major role in modulating SSTs over the Indian Ocean.

Milestone 2: Continue assessing importance of coupled air-sea interactions, decadal ocean dynamics, land-surface feedbacks, and land-use changes on decadal and longer-term atmospheric variability.

A recently completed study sought to assess the extent to which tropical climate variability is forced from the North Pacific through oceanic pathways, as opposed to being locally generated or forced through the atmosphere. To address this question, the study employed an anomaly-coupled model, consisting of a global atmospheric GCM and a 4.5-layer reduced-gravity Pacific-Ocean model. Three solutions were obtained: 1) with coupling over the entire basin (CNT), 2) with coupling confined to the tropics and wind stresses and heat fluxes in the North and South Pacific specified by climatology, and 3) with coupling confined to the Tropics and wind stresses and heat fluxes in the North Pacific specified by output from CNT.

It was found that there are two distinct signals forced in the North Pacific that can affect the tropics through oceanic pathways. These two signals are forced by wind stress and surface heat flux anomalies in the subtropical North Pacific. The first signal is relatively fast, impacts tropical variability less than a year after forcing, is triggered from November to March, and propagates as a first-mode baroclinic Rossby wave. The second signal is only triggered during springtime when buoyancy forcing can effectively generate higher-order baroclinic modes through subduction anomalies into the permanent thermocline, and it reaches the equator 4-5 years after forcing. The slow signal excites tropical variability more efficiently than the fast signal. These extratropical influences on tropical variability can be large enough to shift the erroneous 2-yr period of ENSO obtained in a tropics-only simulation to a more realistic period of 2-6 years.

Product: Solomon et al. 2008.

Milestone 3: Diagnose impacts of subseasonal tropical and stratospheric variability on longer-term global climate variability and the mean climate.

A recently completed study provided evidence that misrepresenting subseasonal diabatic heating variability over the Indian Ocean can adversely affect simulations of multidecadal variability and trends in regions as remote as the North Atlantic and Europe. The influence of the Indian Ocean on global climate has traditionally been assessed by forcing atmospheric GCMs with prescribed anomalous SSTs in the Indian Ocean. Such an approach assumes that the Indian Ocean anomalies act as a forcing, when in fact they are often largely a response to changes in the Walker circulation associated with ENSO. In this study, the global impacts of such remotely forced Indian Ocean changes were investigated in GCM simulations with and without anomalous air-sea coupling in the Indian Ocean. A dramatically stronger North Atlantic Oscillation (NAO) response was obtained in the coupled simulations. The weaker response in the prescribed-SST simulations was due to a previously unappreciated spurious transient-eddy feedback. Briefly, the erroneous surface heat fluxes in those simulations generated spuriously larger deep convective heating variability on subseasonal timescales over the Indian Ocean, stronger eddies in the circumpolar upper tropospheric jet stream waveguide, and enhanced eddy-mean flow interactions over the Atlantic. This spurious enhancement was associated with stronger incursions of low potential vorticity subtropical air into the northern Atlantic middle latitudes, whose net effect was to force a negative-NAO error pattern reminiscent of the classic pattern of north Atlantic blocking. The excitation of such spurious multi-timescale interactions may be the basic reason why numerous previous prescribed-SST simulations have severely underestimated the magnitude of the observed NAO trend over the past half century.

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

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

Milestone 1: Respond to increased community interest in abrupt climate change by revising the Paleo Perspective on Abrupt Climate Change web pages, soliciting new abrupt climate change datasets, and cataloging significant datasets currently in the archive.

The revised "Paleo Perspective on Abrupt Climate Change" web site is now live. This set of web pages describes, for a non-scientific audience, the evidence for past abrupt climate change and explores some of the possible causes. The site ranks second in a Google search for "abrupt climate change" and receives more than 1000 hits per month. As part of the paleo perspective, nearly 50 of the highest-quality datasets related to abrupt climate change were cataloged, improving access for the non-specialist. Also, 20 new datasets were archived as part of a targeted solicitation of the most groundbreaking new research in this area. The archive provides the nation with many of the scientific datasets cited in the U.S. Climate Change Science Program's report, Abrupt Climate Change, whose co-authors included two CIRES scientists. In response to increased interest in abrupt climate change in the scientific community, a new partnership with researchers was started to create a database of the most important paleoclimate records of the last 21,000 years for use in testing climate models.

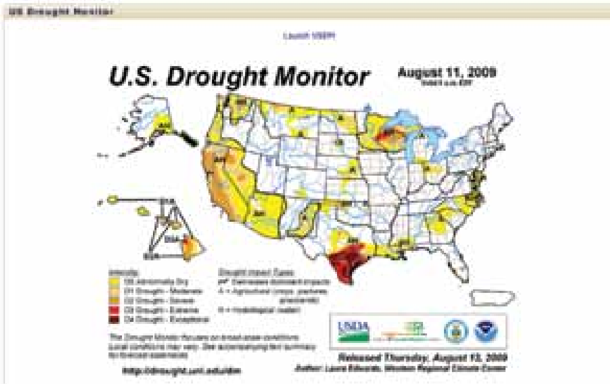
Product: www.ncdc.noaa.gov/paleo/abrupt/index.html

Milestone 2: Enhance discovery of records at the NOAA Paleoclimatology web site by adding the capability to search Extensible Markup Language (XML) records by age and geographic coordinates, as well as through an ArcIMS interface.

XML records for each dataset in the paleoclimatology archive are now searchable by age and geographic coordinates. Since many users come to the web site with a climate-related question about a particular time or place, this new search significantly enhances data discovery. The ArcIMS interface, which allows data to be found through an interactive mapping system, has been upgraded to include an automatic update system and the ability to show data from partner data centers. Due to efforts in FY09, a total of 7,161 records are now searchable, including 126 new datasets archived this year.

Milestone 3: Contribute to the goals of National Integrated Drought Information System for new portal content and for establishing partnerships with U.S. and international agencies.

The U.S. Drought Portal (www.drought.gov) is part of an interactive system to provide early warning about emerging and anticipated droughts, to give information about past droughts for comparison, to understand current conditions, and to explain how to plan for and manage the impacts of droughts. This project involves a partnership with the National Drought Mitigation Center, U.S. Department of Agriculture, U.S. Geological Survey, and Desert Research Institute. In FY09, information technology support was provided to this project, including coordination of content management and review and integration of additional content into the portal.



www.drought.gov is part of a system that provides information on current and past drought conditions, and provides early warning against emerging and anticipated droughts.

CSV-02 Mechanism and Forcings of Climate Variability

■ CSD-03 Chemistry, Radiative Forcing, and Climate

■ PSD-01 Modeling of Seasonal to Interannual Variability

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

■ GMD-04 Climate Forcing

CSD-03 Chemistry, Radiative Forcing, and Climate

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

Milestone 1. Evaluate the global and regional surface emission inventories used to simulate the evolution of the composition of the atmosphere over the past 100 years. Participate in the organization of the work of an international group that will compare existing inventories at global and regional scales.

The goal of the work is to create a consistent, gridded emissions dataset from 1850-2100 for modeling studies in support of Intergovernmental Panel on Climate Change's (IPCC) Fifth Assessment Report (AR5). These emissions will be used 1) as boundary conditions for chemistry model simulations, and 2) for the calculation of concentrations that will be prescribed as boundary conditions in Earth system models and general circulation models that do not have interactive chemistry.

Emissions of gaseous and particulate species (i.e., aerosols, ozone, and aerosol precursors) from anthropogenic activities and biomass burning have been estimated over the full period, using the 2000 dataset for harmonization of the past, and current 1850-2000 emissions with the future emissions determined by the Integrated Assessment models.

We used expert judgment to combine existing historical and present-day datasets to generate a best estimate and most up-to-date emissions datasets from the preindustrial (1850) period to present (2000).

Projections of future emissions use the 2000 emissions as a starting point. This "handshake" requirement therefore ensures continuity in emissions between historical and future distributions.

Product: Lamarque, JF et al. (2009), Gridded emissions in support of IPCC AR5, *IGAC Newsletter*, June.

Milestone 2. Use measurements to evaluate the climate impact of ship emissions.

Analysis of these data has resulted in several high-impact publications on the aerosol emissions from ships, especially black carbon. The work has been extensively cited not only in the scientific literature but also in the media and shipping industry trade publications. It is the definitive work on particulate emissions from ships, with a database larger than all other publications on the subject combined.

Work during the year also included laboratory measurements of black carbon at Boston College. These provide some of the first data clearly showing the theoretical enhancement in absorption from non-absorbing coatings on soot. These laboratory measurements also provide a firm basis for the calibration and relative accuracy of various instruments to measure ship emissions. In 2008, the design and development of a new aircraft photoacoustic system was initiated. This project is continuing and will produce an operational instrument sometime in late 2009.

Product: Lack et al. 2008a, Lack et al. 2008b, and:

Massoli, P et al. (2009), Aerosol optical and hygroscopic properties during TexAQS-GoMACCS 2006 and their impact on aerosol direct radiative forcing, *J. Geophys. Res.-Atmos.*, doi: 10.1029/2008JD011604.

Lack, D et al. (2009), Particulate emissions from commercial shipping: Chemical, physical, and optical properties, *J. Geophys. Res.-Atmos.*, doi: 10.1029/2008JD01130.

Milestone 3. Examine the impact of tropical cyclones on the distribution of water vapor and other radiatively important trace gases in the upper troposphere and lower stratosphere (UT/LS).

The tropical UT/LS is an important region for climate and global change. Deep convection and transport associated with intense tropical cyclones can have a significant impact on the chemical composition and radiative balance of this region. As part of ongoing analysis of the effects of tropical cyclones on the UT/LS, we have used Atmospheric Infrared Sounder (AIRS) satellite measurements to estimate the contribution of tropical cyclones to the total water vapor budget of the tropical UT/LS. The primary finding is that during the Northern Hemisphere summer and fall (May-October), tropical cyclones (on average) are the second largest contributor to the tropical UT/LS water vapor budget, after the Asian monsoon region.

This is summarized in Figure 1, which shows the average percentage difference from the tropical mean during May-October, 2003-2008, for tropical cyclones and four other regions. The Indian monsoon region is clearly the largest source during this period but the tropical cyclones are larger than any other tropical source region. An example map of the tropics for a week in September 2006 shows the large water vapor anomalies from three tropical cyclones that occurred just before, or during, this week, indicated by the black boxes (Figure 2). This result suggests that future changes in tropical cyclone strength, frequency, or location may have a significant feedback on tropical UT/LS water vapor—and thus global climate.

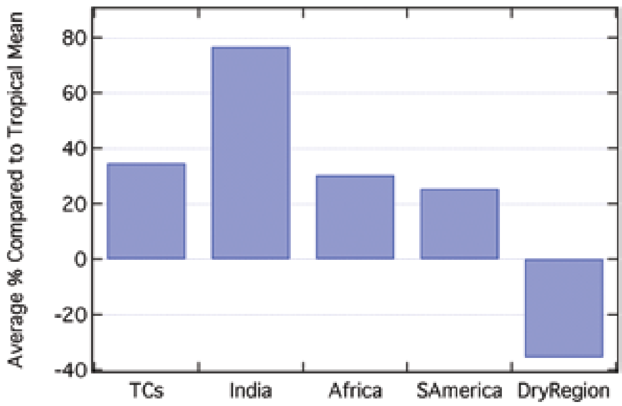


Figure 1: *The average percentage difference from the tropical mean during May-October, 2003-2008, for tropical cyclones and four other regions.*

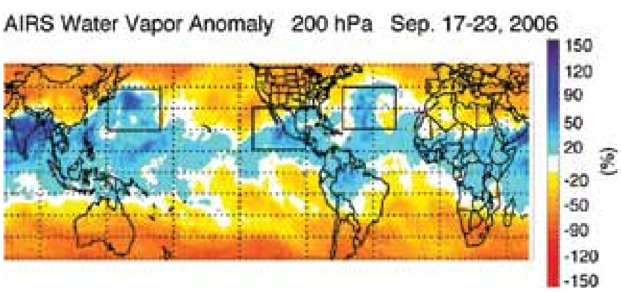


Figure 2: *In September, 2006, three tropical cyclones generated large water vapor anomalies, denoted by the black boxes.*

Milestone 4. Archive and begin analysis of the data from the International Chemistry Experiment in the Arctic Lower Troposphere (ICEALOT) field mission.

Current scientific understanding indicates that the Arctic is warming more rapidly than other regions of the planet, with the most notable effect being the loss of sea ice. This loss is providing opportunities for development in the Arctic, from offshore oil and gas extraction to shortened sea routes for ocean-going cargo vessels. These activities will increase the burden of pollution in this relatively pristine region, possibly enhancing warming via direct emissions of light-absorbing particles and by increases in short-lived photochemically-produced pollutants (e.g., ozone). Few datasets are available to evaluate increases in surface pollutants over the ice-free waters of the Greenland, Norwegian, and Barents seas, where energy development and increased shipping will occur. The most extensive data are from the station at Ny Alesund (Svalbard) atop Mt. Zeppelin, but these measurements are taken at 500 meters above the water surface.

Two primary objectives of the International Chemistry Experiment in the Arctic Lower Troposphere (ICEALOT) were 1) to characterize the existing levels of pollutants (i.e., baseline data) at the surface, and 2) to evaluate sources of pollutants and transport patterns that bring these pollutants into the region. The ICEALOT study was conducted aboard the research vessel *Knorr*, based in Woods Hole, MA, starting at Woods Hole on 19 March and ending at Reykjavik, Iceland, on 23 April, 2008. The data taken during the cruise are currently undergoing final quality assurance and control and will be available shortly. For this project, data analysis will focus on the levels and composition of total reactive nitrogen in the Arctic (Williams et al. 2009a) and an in-depth case study of an ozone depletion event (Lerner et al. 2009). The data collected on the ICEALOT research cruise are the most extensive and complete available for the ice-free Arctic. In addition to the above topics, we expect the data will be used by other research groups for both model validation and satellite ground-truth efforts.

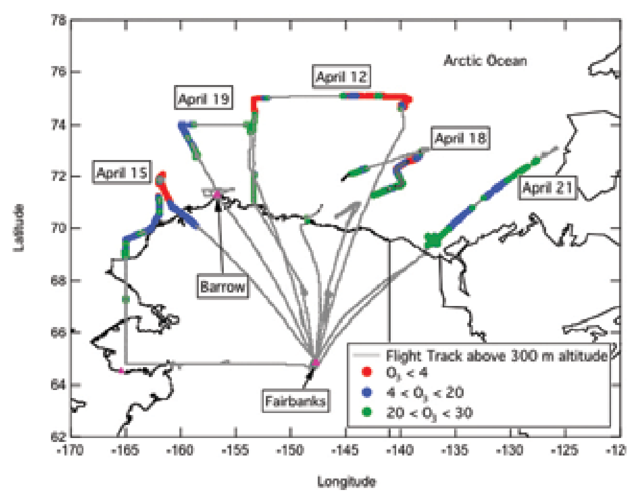
Product: Gilman, JB et al. (2009), Long-range transport of ozone-depleted airmasses as evidenced by VOC ratios, manuscript in preparation.

Lerner, BM et al. (2009), Dimethyl sulfide and halogen ratios in ozone-depleted air encountered during ICEALOT 2008, manuscript in preparation.

Williams, EJ (2009a), Measurements of reactive nitrogen species during ICEALOT, manuscript in preparation.

Williams, EJ (2009b), Nitryl chloride observed over Long Island Sound and the North Atlantic Ocean during March, 2008, manuscript in preparation.

Milestone 5. Archive and begin analysis of data from the Aerosol, Radiation, and Cloud Processes affecting Arctic Climate (ARCPAC) field mission.



Research aircraft tracks during flights that sampled the Arctic boundary layer in April, 2008. Ozone-depleted air was consistently observed at low altitudes over the Arctic Ocean. During the mission, ozone depletion was not observed at higher altitudes in the troposphere.

Tropospheric ozone depletion was observed from the NOAA WP-3 aircraft in the springtime Arctic during ARCPAC, conducted from Fairbanks, AK in April 2008 (figure above). Ozone destruction has been observed in this region for more than two decades, but the origin and geographical extent of these ozone perturbations are not known. A complete description of the processes that control ozone abundance in the Arctic is necessary to assess their possible climatic importance. Ozone depletion was observed on the five aircraft flights that sampled the Arctic boundary layer. Bromine-containing compounds were observed in ozone-depleted air and provide further insights into the halogen chemistry that destroys ozone. The data from the field campaign have been archived, and analysis of the relationship between halogens and ozone is in progress.

PSD-01 Modeling of Seasonal to Interannual Variability

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

Milestone 1. Assess the legitimacy of atmospheric GCM simulations with prescribed sea surface temperature (SST) boundary conditions to estimate atmospheric predictability associated with SST changes, through clean comparisons with corresponding coupled GCM integrations.

The utility of atmospheric GCM integrations with prescribed SSTs is increasingly being questioned in the contexts of climate diagnosis, climate model error diagnosis, and short-term climate predictions. The basic issue is to what extent the errors in surface heat fluxes caused by decoupling air-sea interactions in this manner affect climate variability and the mean climate. This issue was addressed by generating and comparing multicentury coupled atmospheric GCM simulations with corresponding atmospheric GCM simulations in which the SSTs were prescribed from the coupled simulations. When the SST time series was prescribed at the full (half-hourly) temporal resolution of the coupled model output, the uncoupled simulations had a negligibly small mean climate bias, small variance errors on subseasonal scales, and slightly larger variance errors on interannual and decadal scales. When the SSTs were prescribed at monthly temporal resolution, the mean bias remained small, but the variance errors became larger, especially on subseasonal scales. When only the long-term mean SST seasonal cycle was prescribed, the variance errors became large, not surprisingly, also on the interannual and decadal scales. There was now also an appreciable mean bias, arising mainly from the atmospheric GCM's response to El Niño SST anomalies being larger than La Niña SST anomalies. Overall, these results show that the errors introduced by prescribing SSTs in atmospheric GCMs, although not negligible, are generally much smaller than the atmospheric response to the SSTs themselves. To that extent, they justify performing and using such uncoupled integrations for diagnostic and prediction purposes.

Milestone 2. Continue 20th century reanalysis efforts in collaboration with NCEP, NCAR, NCDC, ECMWF, University of East Anglia, Environment Canada, ETH-Zurich, and the UK Hadley Centre.

Production of version 1 of a global atmospheric circulation dataset for 1908-1958, using only daily surface pressure observations and an ensemble Kalman-filter-based data assimilation system, was completed. The dataset was made widely available through a web interface. Production of version 2 of the global atmospheric circulation dataset for 1891-2008 was started. This newer version is based on both a longer and improved surface pressure database and an improved model for assimilatingthose data. The improved model includes better specifications of time-varying CO_2 and aerosol radiative forcings during the assimilation period. This effort will extend our ability to quantify 20th century climate variability, provide uncertainty estimates for climate change detection, and aid attribution efforts to inform climate policy decisions.

Product: www.esrl.noaa.gov/psd/data/gridded/data.20thC_Rean.html

Milestone 3. Assess the importance of the global nonlinear impacts of central equatorial Pacific SST changes.

A comprehensive atmospheric GCM experiment with anomalous SST prescribed only in the Niño-4 area of central tropical Pacific was found to capture all the major elements of the global response obtained in several multidecadal GCM integrations with prescribed observed global SST variations over the past half century. This area lies at the western edge of the region of warmest anomalous SST during El Niño events, but accounts for most of the global climate anomalies associated with El Niño. The global response to SST changes in this area was also found to be significantly nonlinear in large ensembles of GCM integrations with prescribed positive and negative SST anomalies in the region. The response remained similar in pattern, but varied nonlinearly in amplitude as the anomalous SST was varied from a 5°C cooling to a 5°C warming. As expected, the precipitation response saturated for strong cooling, but varied remarkably linearly from the weak cooling to the strong warming cases. The global circulation response, on the other hand, saturated for both strong cooling and strong warming, but at different amplitudes. The negative saturation was closely, but not exclusively, linked to the negative saturation of the precipitation response. The positive saturation could not be so linked; it had a dynamical origin. This asymmetry of the circulation response was clearly evident in the Pacific-North Atlantic, North Atlantic Oscillation, and Arctic Oscillation regions of strong regional climate variability.

The asymmetric saturation of the circulation response to warming and cooling of the central tropical Pacific has large implications for the global response to anthropogenic forcing. Because of it, one may expect the global climate to be affected not just by a mean SST change in this area, but also by a change in its variability associated with a change in ENSO dynamics.

Milestone 4. Assess the predictability of Northern American precipitation, associated with the ENSO-related and ENSO-unrelated components of anomalous SST fields, using a number of atmospheric general circulation models.

Although there is strong evidence that anomalous seasonal precipitation over North America is linked to anomalous tropical SSTs, the degree to which that link is associated only with ENSO is less clear. Can ENSO-unrelated tropical SST changes, especially those associated with global warming, also have a large impact? To answer such a question, one first needs a rational method to separate out the tropical SST variations into ENSO-related and ENSO-unrelated contributions. As discussed earlier in PSD01, Milestone 4, isolating such contributions is challenging for several reasons, including ambiguities arising from how ENSO itself is defined. In particular, defining ENSO in terms of a single index and ENSO-related variations in terms of regressions on that index (as done in almost all previous studies) can lead to wrong conclusions. In a recently completed study, it was argued that ENSO is best viewed not as a number, but as an evolving dynamical process for this purpose. Specifically, ENSO was identified with the four dynamical eigenvectors of tropical SST evolution that are most important in the observed evolution of ENSO events. This definition was used to isolate the ENSO-related and ENSO-unrelated components of the tropical SST variations on a month-by-month basis in the 136-yr (1871-2006) Hadley Centre Global Sea Ice and Sea Surface Temperature (HadISST) dataset. We plan to use this SST dataset in the next phase of the project to isolate the contributions of the ENSO-related and ENSO-unrelated parts of the SST variations to the observed variations of North American precipitation during the last century. To the extent that the predictable precipitation variations are SST-forced, such an analysis will also assess the predictability of North American precipitation associated with the ENSO-related and ENSO-unrelated SSTs.

Product: Compo, GP and PD Sardeshmukh (2009), Removing ENSO-related variations from the climate record, *J. Clim*., in review.

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

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

Milestone 1. Use an empirical-dynamical coupled atmosphere-ocean model of tropical subseasonal variations to assess the impact of air-sea coupling on the Madden-Julian Oscillation (MJO).

The effect of air-sea coupling on tropical climate variability was investigated in a coupled linear inverse model (LIM) derived from the simultaneous and 1-week lag covariances of observed 7-day running mean departures of tropical atmospheric and oceanic variables from the annual cycle. Such a model predicts the covariances at all other lags. The predicted and observed lag covariances, as well as the associated power spectra, were generally found to agree within sampling uncertainty. This validated the LIM's basic premise that beyond daily time scales, the evolution of tropical atmospheric and oceanic anomalies is effectively linear and stochastically driven. It also justifies a linear diagnosis of air-sea coupling in the system.

An extensive linear diagnosis showed that air-sea coupling has a very small effect on subseasonal atmospheric variability. It has much larger effects on longer-term variability, in both the atmosphere and ocean, including greatly increasing the amplitude of ENSO and lengthening its dominant period from two to four years. Consistent with these results, the eigenvectors of the system's dynamical evolution operator also separate into two distinct sets: a set governing the nearly uncoupled subseasonal dynamics, and another governing the strongly coupled longer-term dynamics. One implication of this remarkably clean separation of the uncoupled and coupled dynamics is that GCM errors in anomalous tropical air-sea coupling may cause substantial errors on interannual and longer time scales, but probably not on the subseasonal scales associated with the MJO.

Product: Newman, M et al. (2009), How important is air–sea coupling in ENSO and MJO Evolution? *J. Clim.*, doi: 10.1175/2008JCLI2659.1.

Milestone 2. Continue investigating the variability and predictability of extratropical subseasonal variations in all seasons of the year using a linear empirical-dynamical model that includes air-sea coupled tropical and stratospheric influences. Assess the predictability from deterministic and probabilistic perspectives, particularly in regard to the case-by-case and regime-dependent variations of predictability.

The relative impacts of tropical diabatic heating and stratospheric circulation anomalies on wintertime extratropical tropospheric variability were investigated in a LIM derived from the observed zero-lag and 5-day lag covariances of 7-day running mean departures from the annual cycle. Such a model predicts the covariances at all other lags than the training lag. The predicted and observed lag covariances were generally found to be in excellent agreement, even at the much longer lag of 21 days. This validated the LIM's basic premise that the dynamics of atmospheric weekly averages are effectively linear and stochastically driven, justifying further linear diagnosis of the system.

Analysis of interactions among the LIM's variables showed that tropical diabatic heating greatly enhances persistent variability over most of the Northern Hemisphere, especially over the Pacific Ocean and North America. Stratospheric effects are largely confined to the polar region, where they ensure that the dominant pattern of sea-level pressure variability is the annular Arctic Oscillation rather than the more localized North Atlantic Oscillation. Over the North Atlantic, both effects are important, although some of the stratospheric influence is ultimately traceable to tropical forcing. In general, the tropically forced anomalies extend through the depth of the troposphere and into the stratosphere, whereas stratospherically generated anomalies tend to be largest at the surface and relatively weak at midtropospheric levels. Overall, tropical influences were generally found to be larger than stratospheric influences on extratropical tropospheric variability, and to have a pronounced impact on the persistent, and therefore the potentially predictable, portion of that variability.

Product: Newman and Sardeshmukh 2008.

GMD-04 Climate Forcing

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

Milestone 1. Complete the development of an instrument to measure the aerosol absorption coefficient.

The physical design and building of the aerosol absorption spectrometer is near complete. After data acquisition software has been written to read data from the instrument, the instrument will be fully tested and calibrated. Projected deployment of this instrument is for the fall of 2009.

Milestone 2. Complete merging of the mesoscale model B-RAMS with global transport model TM5 (completion of ongoing project initiated in FY07).

High resolution B-RAMS model runs were completed for South America for the period May-November 2004. This demonstrated that TM5 could be interfaced successfully with B-RAMS. Work is ongoing to a) compare B-RAMS simulations to observations of CO_2 made in South America during the simulation period, and b) compare B-RAMS to TM5 1-degree resolution simulations for the same period.

Milestone 3. Initiate project to use $^{14}CO_2$ (radio-carbon) to calibrate promising candidate atmospheric gas species for use as fossil fuel tracers.

$^{14}CO_2$ observations were correlated with a wide variety of anthropogenic trace gases. Compared with correlations of total CO_2, the $^{14}CO_2$ correlations were robust, even in summer. The best correlations seen so far have been with hydrofluorocarbons HFC-152, HFC,134a, SF_6, and carbon monoxide. This suggests that these species may be good candidates for proxies of anthropogenic carbon emissions.

Milestone 4. Establish two new, temporary tall-tower sites (in conjunction with the NOAA/ESRL North American Carbon Observing System-Carbon America) in the San Francisco and Sacramento, CA area to characterize and understand urban influences on the tall-tower network measurements.

Two towers were instrumented through a collaborative effort with the U.S. Department of Energy's Lawrence Berkeley National Laboratory. The California Energy Commission is funding the project through its Public Interest Energy Research Program. One tower site, at Walnut Grove, CA (near Sacramento) is equipped to provide continuous measurements of carbon dioxide (CO_2), carbon monoxide (CO), and methane (CH_4). It is the first tall tower site in the network with continuous CH_4 measurements. The second tower site is a San Francisco landmark and is our first site located in an urban center. Both tower sites are instrumented with automated flask sampling systems that provide daily measurements of a suite of greenhouse gases, carbon isotopes, halocarbons, and other compounds.

Milestone 5. Establish one new tall-tower site in the NOAA/ESRL Carbon America tall-tower network to aid in reducing the uncertainty of carbon uptake by the North American continent and to better characterize regional terrestrial carbon flux estimates.

Two new tall-tower sites were established. Instrumentation was installed on the KWKB-TV tower near West Branch, IA, in partnership with the University of Iowa. This site samples agricultural ecosystems in the corn belt. Summertime CO_2 levels in this region are among the lowest in North America, due to strong uptake by corn and other crops. It is expected that the CO_2 seasonal cycle will exhibit interannual variability related to crop yields, which are carefully tracked.

The Boulder Atmospheric Observatory (BAO) tower has been operated by the NOAA ESRL's Physical Sciences Division since the 1970s, and serves as a unique facility for monitoring the Earth's atmospheric boundary layer. Leveraging this existing NOAA platform, instrumentation for monitoring CO_2 and CO was installed on the tower, which is near Boulder, CO. Because of its proximity to the Denver metropolitan area, measurements from the BAO tower will provide detailed information about urban and industrial sources of CO_2.

Milestone 6. Initiate project using a Lagrangian source-receptor approach to diagnose the impact of long-range transport on atmospheric carbon dioxide concentrations (at local scale for the NOAA/ESRL Carbon America tall-tower measurements; at global scale for the surface seasonal cycle at different latitudes as measured by the NOAA/ESRL Cooperative Global Atmospheric Sampling Network).

The project has been initiated and work is ongoing.

CSV-03 Stratospheric Ozone Depletion

■ CSD-04 Photochemical and Dynamical Processes that Influence Upper Troposphere/ Lower Stratosphere Ozone

■ GMD-05 Ozone Depletion

CSD-04 Photochemical and Dynamical Processes that Influence Upper Troposphere/ Lower Stratosphere Ozone

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

Milestone 1. Further study the transport processes associated with the subtropical jet stream using airborne and high-resolution model output.

Airborne measurements of trace gases such as ozone and water vapor in the tropopause region provide important insight into the transport and mixing between the stratosphere and troposphere. CIRES staff were involved in flight planning and data analysis for two unique aircraft missions focused on measurements in the upper troposphere and lower stratosphere on a global scale. The Stratosphere-Troposphere Analyses of Regional Transport (START-08) campaign took place April-June 2008, and the first phase of the HIPPO campaign was in January 2009. Each campaign used the NCAR Gulfstream-V aircraft. In preliminary analysis of the trace gas measurements, we have focused on species undergoing strong growth, such as sulfur hexafluoride (SF_6) and CO_2, since these can be useful to infer transport time scales and source regions for air in the upper troposphere and lower stratosphere. Figure 1 (next page) shows latitude vs. altitude distributions of SF_6 and CO_2 during the HIAPER Pole-to-Pole Observations (HIPPO) campaign. There has never been a global cross-section of this kind produced by any previous measurement campaign. There are many interesting features

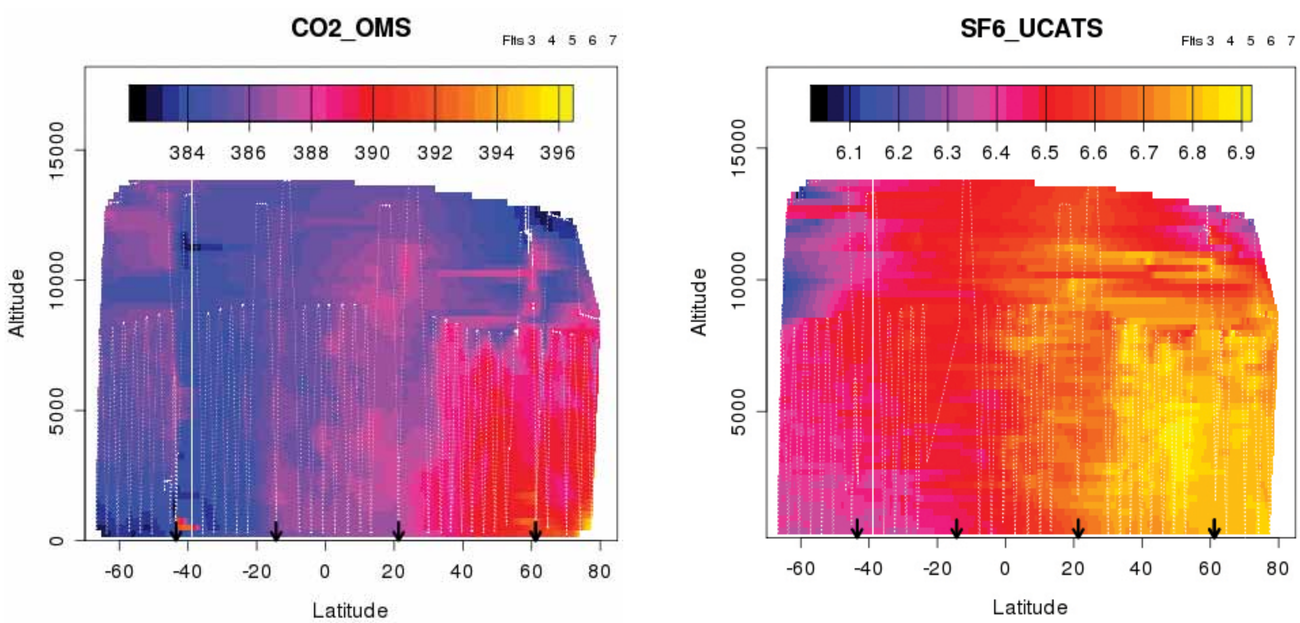


Figure 1: *Latitude vs. altitude distributions of CO_2 and SF_6 during HIPPO.*

in these plots, including the variation of the interhemispheric gradient with altitude, which suggests preferred altitudes for transport of air between the Northern and Southern hemispheres. We expect further analysis to produce important new information on large-scale transport characteristics of the troposphere and lower stratosphere.

GMD-05 Ozone Depletion

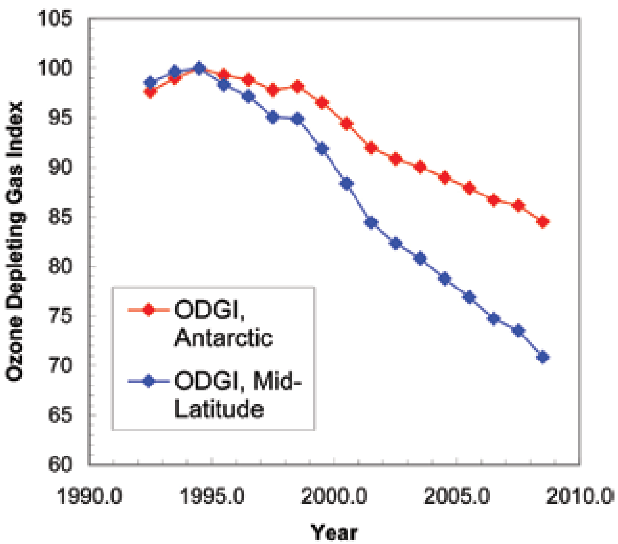
Goal: *Stratospheric Ozone Measurements*: Measure ozone declines during the past two decades at northern hemispheric mid-latitudes and the tropics, and characterize dramatic ozone depletions over Antarctica. *Ozone-Depleting Gases*: Conduct research in the troposphere, stratosphere, oceans, polar snowpack,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

Milestone 1. The Ozone Depleting Gas Index will be

NSF/NCAR Gulfstreav-V aircraft in Anchorage, AK during HIPPO.

updated and refined, as needed, with continued measurements of ozone-depleting gases.

Measurements of long-lived substances that deplete ozone were continued at remote sites during 2008. Accelerated increases in atmospheric accumulation rates of a class of substitute chemicals that have a reduced impact on ozone, the hydrochlorofluorocarbons (HCFCs), were observed (Montzka et al. 2009). The Ozone-Depleting Gas Index has been updated, as shown in the figure below. These results show a continued overall decline in the atmospheric abundance of ozone-depleting substances (ODS), despite more rapid increases of HCFCs.



The updated Ozone-Depleting Gas Index shows a continued overal decline in ozone-depleting substances.

Product: Hofmann, DJ and SA Montzka (2009), Recovery of the Ozone Layer:The Ozone Depleting Gas Index, *EOS Trans. AGU*.

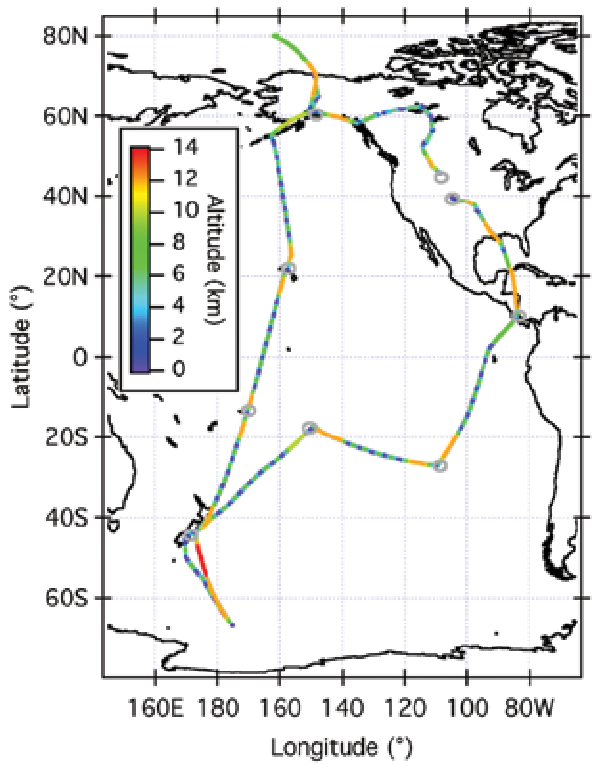
Montzka, SA et al. (2009), Accelerated increases observed for hydrofluorocarbons since 2004 in the global atmosphere, *Geophys. Res. Lett.*, doi: 10.1029/2008GL036475.

Milestone 2. Utilize medium- and high-altitude aircraft and stratospheric balloon platforms to validate tropospheric and stratospheric measurements of ozone-depleting gases (N_2O, CFC-11, CFC-12) by spaceborne instrumentation aboard the Aura satellite.

There were no specific aircraft- or balloon-based Aura validation missions during the period covered by this report. However, the wealth of three-dimensional ozone-depleting substance, ozone, and water vapor distribution data obtained from the aircraft-based campaigns described in Milestones 3 and 4 can be used to validate satellite-based measurements of ozone-depleting substances, ozone, and water vapor. One example is the vertical and latitudinal distribution of sulfur hexafluoride (SF_6) measured by the Unmanned Aircraft System Chromatograph for Atmospheric Trace Species instrument during the first HIAPER Pole-to-Pole Observations (HIPPO) mission (Figure 1, opposite page).

Milestone 3. Utilize the NSF/NCAR Gulfstream-V aircraft to measure the latitudinal, longitudinal, and vertical distributions of ozone-depleting gases above a large region of the Pacific Ocean during different seasons.

The first of five HIPPO missions was conducted in January 2009 using the NSF/NCAR Gulfstream-V aircraft. Ten long-distance (3,200-5,400 km) flight legs, each with four to eight deep vertical profile 'dips' (between altitudes <0.8 km and >7.9 km), comprised a large-scale (43,000 km) flight circuit spanning latitudes 80°N-67°S in the Pacific region. Two onboard instruments (UCATS and PANTHER [Peroxyl Acetyl Nitrate and other Trace Hydro-halocarbon ExpeRiment]) measured numerous ODS in situ, while a whole air sampler filled nearly 450 flasks for home laboratory analysis of many ODS. The data from these three sources will provide (nearly) pole-to-pole, three-dimensional views of ODS distributions over the Pacific Ocean, from the marine boundary layer (MBL) to the extratropical lower stratosphere. This very unique dataset is proving extremely valuable in studies of tropospheric dynamics, namely interhemisheric transport and gas exchange between the MBL and lower free troposphere, and in quantifying oceanic fluxes of ODSs and other climate-related gases.



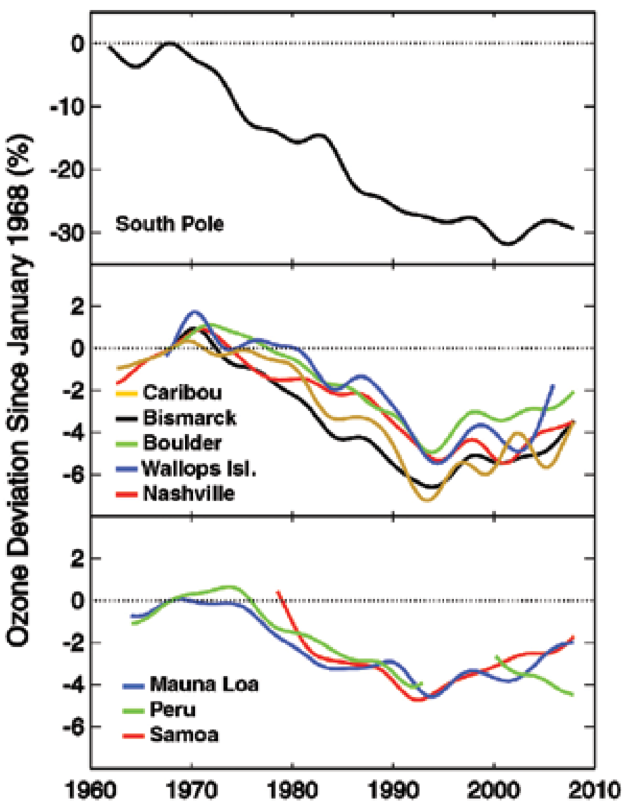
Color-coded flight tracks of the 43,000-km HIPPO mission, showing the 58 deep vertical profiles (<0.8 km to >7.9 km altitude) obtained during 10 flight legs. Gray circles depict landing or takeoff locations. The northern and southern spurs were out-and-back flights from Anchorage, AK, and Christchurch, New Zealand, respectively.

Milestone 4. Continue a study of cross-tropopause transport in the northern mid-latitudes using the NSF/NCAR Gulfstream-V aircraft and in situ measurements of ozone-depleting and other gases, including ozone and water vapor.

The Stratosphere-Troposphere Analysis of Regional Transport 2008 (START-08) project was an examination of dynamical processes that exchange gases between the upper troposphere and lower stratosphere (UT/LS) in the northern middle latitudes. Eighteen flights of the NSF/NCAR Gulfstream-V aircraft were conducted across swaths of North America, with emphasis on flight tracks in the UT/LS region. UCATS and PANTHER made in situ measurements of ODSs, ozone, and water vapor during these flights. Anomalous structure (e.g., double tropopauses) and transport (e.g., stratosphere to troposphere exchange) were targeted and probed. The data obtained are being used in detailed analyses of dynamical processes that influence the composition of the UT/LS. Such analyses may reveal how ODSs and other climate gases can be transported directly into the northern middle latitude stratosphere without first entering the tropical upwelling region.

Milestone 5. Several statistical techniques will be applied to the total column ozone observations from the Dobson network to evaluate indicators for stratospheric ozone change for their sensitivity and capability to detect projected recovery.

Column ozone data through 2007 from the U.S. Cooperative Dobson Network have been analyzed using the trend model developed by Harris et al. (2001). It is planned to use the model on this dataset updated through 2008. The updated analysis will be included with trend analyses based on other statistical models.

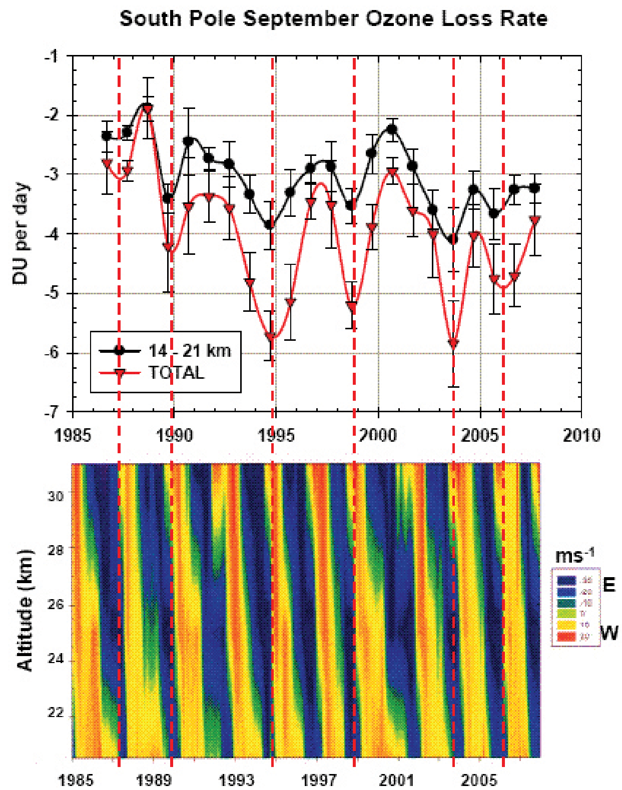


Smooth trend curves of monthly ozone values from selected Dobson stations (South Pole, continental United States, and the tropics) through 2007. Changes represented by the growth rate determined from these may be a measure of the rate of change of stratospheric ozone, and thus represent various aspects of ozone layer recovery.

Product: Harris, JM et al. (2001), A new method for describing long-term changes in total ozone, *Geophys. Res. Lett.*

Milestone 6. The longer-term ozonesonde record (more than 20 years) at South Pole will be used to look for signs of springtime stratospheric ozone recovery by testing various indicators of ozone profile changes in regions that are most sensitive to chemical ozone loss.

Owing to variations in meteorology and stability of the polar vortex, year-to-year variations in the severity of the ozone hole are expected. Analysis of the ozone loss rate in September indicates large interannual variability, suggesting a dynamic component. Detailed analysis of the 22-year record is used to search for early signs of the beginning of ozone hole recovery. The conclusion is that up to the year 2007, no definitive signs of the beginning of ozone hole recovery have been detected at South Pole Station.



South Pole September ozone loss rates for 14–21 km and total column ozone (top) and quasi-biennial oscillation (QBO) winds at Singapore (bottom). Vertical dashed lines delineate periods of high ozone loss rates, which are correlated with the westerly phase of the QBO at high altitude.

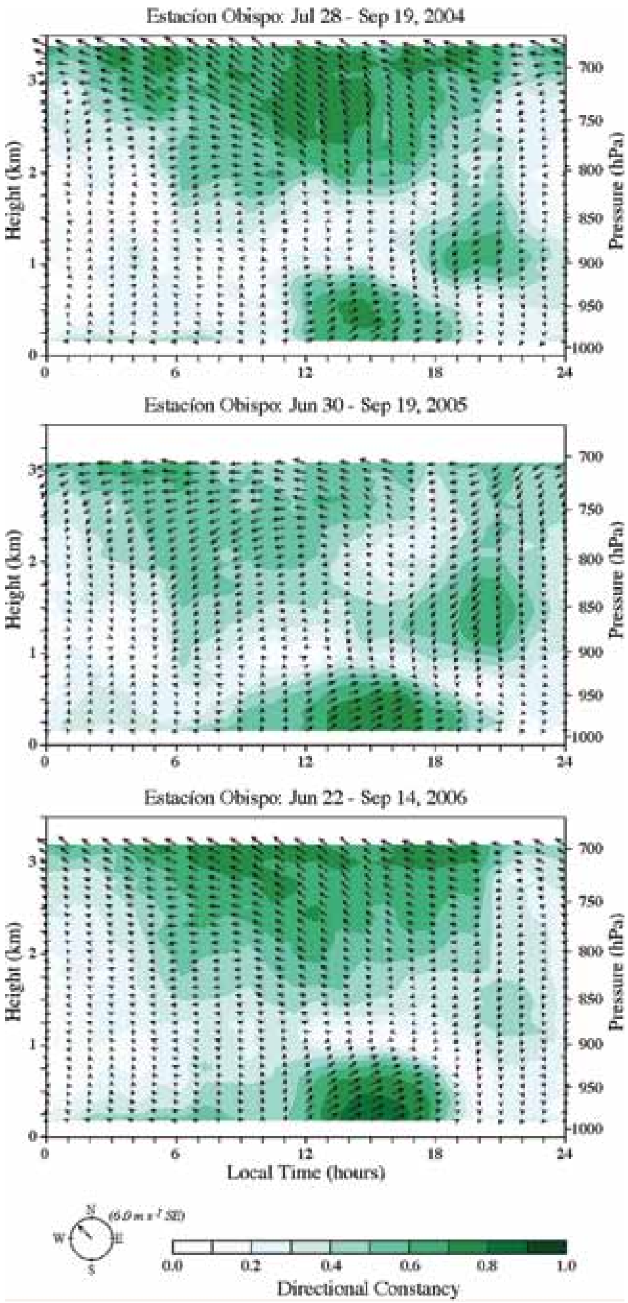
Product: Hofmann, DJ et al. (2009), Twenty two years of ozonesonde measurements at the South Pole, *Int. J. Remote Sensing*, doi: 10.1080/01431160902821932, in press.

CSV-04 Climate Dynamics

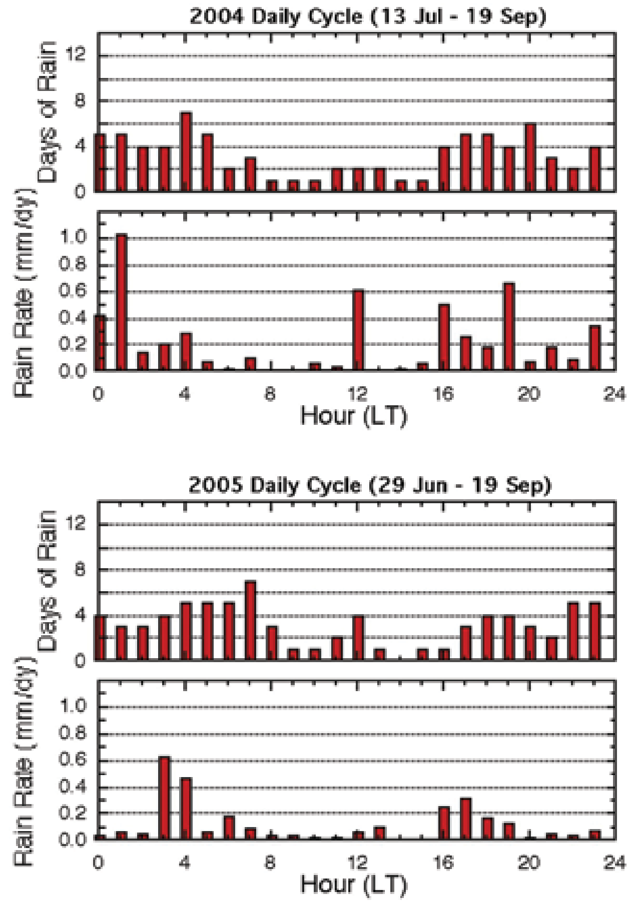
- PSD-06 Climate Dynamics
- PSD-03 Empirical and Process Studies
- PSD-15 Surface Processes

PSD-06 Climate Dynamics

Goal: Conduct research to improve understanding of tropical Pacific Ocean dynamical processes related to the subseasonal atmospheric variability, and atmospheric circulation, convection, and moisture and heat budgets associated with the El Niño phenomenon and the North American Monsoon (NAM).



Vector-mean daily cycle overlaid on the directional constancy (shading) during the a) 2004, b) 2005, and c) 2006 deployments at Estación Obispo, Mexico. A 6.0 m/s reference vector is shown below the plots. Local time is calculated by subtracting seven hours from UTC time.



The daily cycle of precipitation observed during the 2004, 2005, and 2006 deployments at Estación Obispo. The top panel shows the number of days on which rain fell during each hour of the day; the bottom panel shows the total amount of rain during each hour divided by the number of days data were collected during that hour.

Milestone 1. Quantify the spatial variability of the daily cycles of precipitation observed during the NAM along the Gulf of California. This will be done by comparing daily cycles of precipitation observed by satellite and during multi-year NAM experiment (NAME) instrument deployments.

A suite of instruments, including a 915-MHz lower-tropospheric wind profiling radar, was deployed at Estación Obispo, Mexico during the summers of 2004, 2005, and 2006 as part of NAME. The profiler measured winds from about 200 m to 3,000 m, which have been processed into hourly wind profiles. During FY09, research focused on daily and interannual variability of lower-tropospheric winds and precipitation.

Deployment-mean wind profiles from Estación Obispo display a very similar structure across the three observed summers, with low-level southwesterlies and easterlies near 3,000 m. The flow aloft was more northeasterly in 2005 compared with other years, due to weaker-than-usual ridging at 700 hPa. 2005 was the driest year of the three, with five days having about 20-50 mm of rain. More rain fell in 2004, despite the monsoon starting fairly late, and there were distinct active and break periods. 2006 was by far the wettest year, with many days having 20-50 mm of rain.

Deployment-mean daily cycles of wind are also, to a first approximation, quite similar. A feature that looks like a sea breeze is evident in all three years, although its directional constancy varied from year-to-year. (Directional constancy is the ratio of the vector mean wind speed to the scalar mean wind speed. When it equals one, the direction was constant throughout the time period, and when it equals zero, the direction was either evenly divided between two different directions or was evenly distributed among all directions.)

Preliminary investigations led to the identification of a sea breeze on about 60 percent of the days in 2005, most commonly in July and September. These sea breezes tended to begin by noon, quickly reaching a depth of about 750 m, and ended at about 5 p.m.local time. Aloft, there were subdaily variations in southeasterlies at 3,000 m in 2004 and 2006, whereas, in 2005 easterlies persisted throughout most of the day (with less directional constancy than during 2004 and 2006). The daily cycle of rainfall was similar during 2004 and 2005, with rain least likely to fall from about 7 a.m. to 6 p.m. local time. Rainfall was more evenly distributed during the day in 2006; rain was least likely in the mid-morning and late afternoon, and most likely around noontime and from 9 p.m. to 2 a.m. local time.

PSD-03 Empirical and Process Studies

Goal: Improve understanding of basic physical processes that contribute to climate variability across a broad spectrum of scales, with emphasis on moist atmospheric convection, radiative transfer in cloudy areas, and air-sea interaction.

Milestone 1. Develop empirical models of daily sea-surface temperature (SST) and near-surface air temperature variations at all oceanic grid points from observations and climate model simulations.

In a recently completed study, the impact of rapid wind variability on air-sea thermal coupling outside the tropical regions was clarified. The basic effect of thermal coupling (called Reduced Thermal Damping) is to enhance the variance of SSTs and air temperatures (AIRT) by decreasing the energy flux between the atmosphere and ocean. The study showed that rapidly varying surface winds, through their influence on the turbulent surface heat fluxes that drive this coupling, act to effectively weaken the coupling and thus partially counteract the reduced thermal damping. In effect, rapid fluctuations in wind speed partially insulate the atmosphere and ocean from each other.

The nonlinear relationship between rapid wind speed fluctuations and SST and AIRT anomalies results in a rapidly varying component of the surface heat fluxes. The strong separation between the dynamical time scales of the ocean and atmosphere allows this rapidly varying flux to be approximated as Gaussian white noise whose amplitude is modulated by the more slowly evolving thermal anomalies. Such a state-dependent (multiplicative) noise can alter the dynamics of atmosphere-ocean coupling, because it induces an additional heat flux term, the noise-induced drift, that effectively acts to weaken both coupling and dissipation. Successful verification of these effects in long-term observational records from several ocean weather ships suggests that a proper accounting of such a state-dependent noise is crucial for understanding and modeling atmosphere-ocean coupling.

Product: Sura and Newman 2008.

Milestone 2. Continue assessing stochastic influences on climate variability and predictability through 1) linear and nonlinear inverse modeling, and 2) development and implementation of stochastic parameterizations in weather and climate models.

The skewness and kurtosis of daily SST variations were found to be strongly linked at most locations around the globe in a new, high-resolution observational dataset, and were analyzed in terms of a simple stochastically forced mixed-layer ocean model. The predictions of the analytic theory were in remarkably good agreement with observations, strongly suggesting that a univariate linear model of daily SST variations with a mixture of SST-independent (additive) and SST-dependent (multiplicative) noise forcing is sufficient to account for the skewness-kurtosis link. Such a model of non-Gaussian SST dynamics should be useful in predicting the likelihood of extreme events in climate, since many important weather and climate phenomena—such as hurricanes, El Niño-Southern Oscillation, and the North Atlantic Oscillation—depend on a detailed knowledge of the underlying local SSTs.

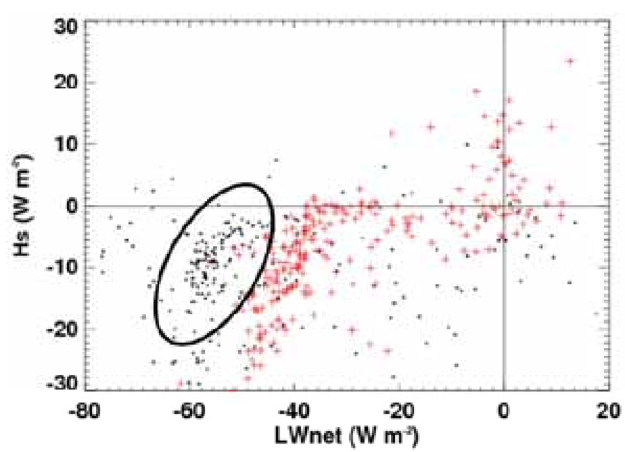
Product: Sura and Sardeshmukh 2008.

PSD-15 Surface Processes

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

Milestone 1. Determine accuracy of ERA-40 surface turbulent fluxes over the Arctic pack ice, and devise methods of improvement through a combination of satellite measurements and modeling.

Comparisons between ERA-40 reanalysis surface fluxes and surface conditions for the Surface Heat and Energy Budget of the Arctic (SHEBA) year are being done. Results suggest that turbulent sensible heat flux may be approximately correct, and the net longwave radiation is too low (Wheeler et al. 2009). This may be a result of either too-low values in downwelling longwave radiation (cloud errors) and / or errors in surface temperature because the sea ice in the European Centre for Medium-Range Weather Forecasts (ECMWF) model does not have snow on it. The evaluation of the ERA-40 and other reanalysis data is planned for completion in the fall of 2009.



Observations (red +) and ERA-40 (black dot) values of turbulent sensible heat flux (Hs) as a function of net longwave radiation (LWnet) during the winter. The ERA-40 points are taken at the grid point following the SHEBA site. The circled points show ERA-40 cluster that has erroneous LWnet through either erroneous downwelling longwave radiation or erroneous surface temperature.

The modeling component of this project is described in Milestone 3.

Product: Persson et al. 2008, and:

Persson, P et al. (2009), Impact of synoptic and mesoscale disturbances on the end of the summer melt season over sea ice, AIMSA/AISPO/AICS 2009 Joint Assembly, Montreal, Canada, presentation J14.8, MOCA-09.

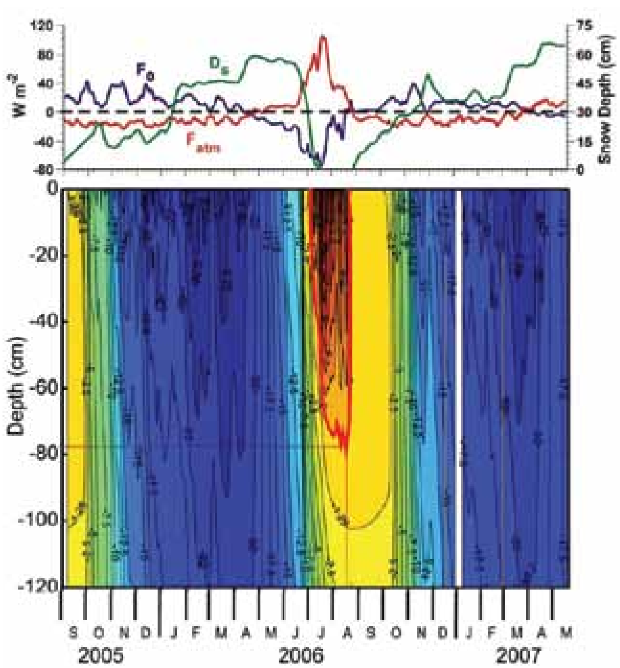
Milestone 2. Determine the turbulent flux characteristics and associated processes at the Study of Environmental Arctic Change (SEARCH) sites at Alert and Eureka. Determine the extent to which Monin-Obukhov Similarity (MOS) applies at these locations. Consider if a non-MOS (non-local) flux scheme is necessary and, if so, suggest a process-based algorithm.

Studies describing the processes that govern the surface energy budget (SEB) have been conducted at the long-term SEARCH observatory at Alert, Nunavut. The results of these process and surface energy studies follow:

1) At Alert Global Atmospheric Watch (GAW) site, the near-surface climate is dominated by effects of mesoscale processes, with one of three distinct wind regimes governing the conditions more than 70 percent of the time.

2) These mesoclimates affect the spatial and temporal variability of the primary atmospheric parameters and the SEB. They also likely affect the climate response at each site to large-scale climatic changes.

3) The net annual atmospheric energy flux (F_{atm}) to the surface of 2.8 W m^{-2} is almost identical to the value of 2.5 W m^{-2} observed on the pack ice during the SHEBA year. However, most of the terms in the SEB differ significantly between Alert and SHEBA, with generally much larger annual amplitudes at Alert. The SEB differences between the sites appear to be due to the combination of the effects of mesoscale processes at the terrestrial site and the different surface characteristics.



Soil temperature (°C) at Alert GAW site from September 2005 to May 2007. Top panel shows the coincident time series of Fatm, F0, and snow depth. The heavy red isopleth shows the 0 °C isotherm, while the thin red lines show the date and depth of its maximum depth.

4) A preliminary analysis of 2.5 years (9/04-4/07) of SEB data at Alert (figure), including measurements of the energy flux into the soil (F0) shows:

a) The measurements are of high quality with only a small annual residual.
b) The atmosphere cools the surface from September-March and warms it May-August.
c) The length of the snow-free time is crucial for the annual net SEB.
d) Synoptic/mesoscale events in both summer and winter impact the SEB terms, F_{atm}, and F0.
e) The soil active layer begins at surface near July 2, reaches maximum depth of 77 cm in mid-August, and is gone by August 22.
f) Pulses (thermal waves) from synoptic/mesoscale atmospheric events reach to 120 cm into soil, even in winter.

At Eureka, an analysis of 6 years of soundings shows that the atmosphere is always stable in the mean. In winter, a surface-based inversion extends to 1,200 m and clouds are common near 200 m. In summer, a surface-based inversion extends to 100-200 m, and the moisture is typically a maximum near the fjord surface. The vertical profiles of the wind roses are strongly controlled by the orientation of the local fjord and an elevated valley. Because of the high, complex terrain; the presence of water and ice caps; and large atmospheric stability, the long-term data being collected may only represent a local region around the measurement site. Due to budget constraints, evaluation of turbulent flux data at Eureka has been limited to CO_2 fluxes.

Product: Persson and Stone 2008, and:

Persson, P et al. (2007), Evidence of forcing of Arctic regional climates by mesoscale processes, Symposium on Connections between Mesoscale Processes and Climate Variability, Amer. Meteor. Soc., San Antonio, TX.

Milestone 3. Incorporate the Surface Heat Budget of the Arctic Ocean (SHEBA) flux scheme and the double-moment microphysics scheme into the Weather Research and Forecast (WRF) model and evaluate their effect on simulated surface energy and boundary-layer processes.

An improved microphysical parameterization scheme has been included into the WRF mesoscale model and shown to have significant effects on the surface radiative and turbulent fluxes. An improved turbulent flux scheme based on the SHEBA observations has been completed and released (Andreas et al. 2009). It includes the new stability correction terms described by Grachev et al. (2007), effects of partial ice cover on the roughness length during the summer, and a roughness length parameterization that eliminates the self-correlation problem and is consistent with measurements at all of the SHEBA data sites. This new turbulent flux scheme is currently being incorporated into the WRF model. In addition, the modeling of surface albedo over sea ice is being tested and improved. When completed, the WRF configuration will be used in combination with TOVS and AVHRR satellite data to generate surface fluxes that we hope will be an improvement on those available through current observational methods.

Product: Andreas, EL et al. (2008), Parameterizing turbulent exchange over sea ice in winter. *J. Hydrometeor.*, submitted.

Persson, P et al. (2009), Impacts of improved cloud microphysics and surface flux schemes on WRF simulations in the Arctic, AIMSA/AISPO/AICS 2009 Joint Assembly, Montreal, Canada, Presentation J02.6, MOCA-09.

Solomon, A et al. (2008), Investigation of microphysical parameterizations of snow and ice in Arctic clouds during M-PACE through model-observation comparisons, *J. Atmos. Sci.*, in press.

Wheeler, C et al. (2009), Comparing Arctic cloud cover and surface energy fluxes in the ERA-40, SHEBA, and other datasets, 10th Polar Meteorology and Oceanography Conference, Madison, WI

Milestone 4. Using remote sensors deployed during the Arctic Mechanisms of Interaction between Surface and Atmosphere (AMISA) mission in collaboration with NOAA's Center for Environmental Technology, obtain airborne measurements of the spatial distribution of surface characteristics of the Arctic pack ice in the vicinity of the icebreaker *Oden* during the Arctic Summer Cloud Ocean Study (ASCOS).

One of the main objectives of joint ASCOS and AMISA field programs was to provide the data for improving our understanding of many of the microphysical and dynamical processes affecting key properties of Arctic clouds and their interaction with the sea ice. ASCOS/AMISA was conducted in August and September 2008 near the North Pole using two primary platforms, the Swedish ice breaker *Oden* and the U.S. National Aeronautic and Space Administration (NASA) DC-8 research aircraft (Figure 1). The NASA DC-8 aircraft flown during AMISA provided in situ, remote-sensing, and dropsonde observations of the macro- and microphysical structure of the Arctic clouds, the associated thermal and kinematic structure of the Arctic boundary layer, and the structure of the ice surface conditions. Airborne remote sensors provided high-resolution microwave imagery of sea ice using the Polarimetric Scanning Radiometer (PSR/A) system, potential discrimination of fresh water meltponds using the LRAD L-band radiometer, and direct sampling of thermodynamic and cloud variables over wide areas using in situ cloud probes, dropsondes, and radiometric profiling. In situ aircraft measurements included cloud liquid water, cloud and aerosol particle size distributions, and aerosol composition. Coincident microphysical and thermodynamic observations will be available through remote-sensing retrieval methods (Figure 2). These observations have been summarized in several conference posters and numerous conference presentations. Data processing and quality control is ongoing. Analysis of the synoptic conditions for all AMISA flights have been done and written up as a report.

Product: Persson, P et al. (2009), High temporal resolution observations of the thermal and kinematic vertical structure in the Arctic boundary-layer during the Arctic Summer Cloud-Ocean Study (ASCOS), AIMSA/AISPO/AICS 2009 Joint Assembly, Montreal, Canada, presentation J14.10, MOCA-09.

Persson, P et al. (2009), ASCOS/AMISA 2008 Field Program: Accomplishments and First Results, AIMSA/AISPO/AICS 2009 Joint Assembly, Montreal, Canada, poster J03.13, MOCA-09.

Brooks, IM et al. (2009), The Arctic Summer Cloud-Ocean Study–ASCOS, United Kingdom Arctic Science Conference, July 13-15, Southampton.

Brooks, IM et al. (2009), Ice-cloud coupling in the

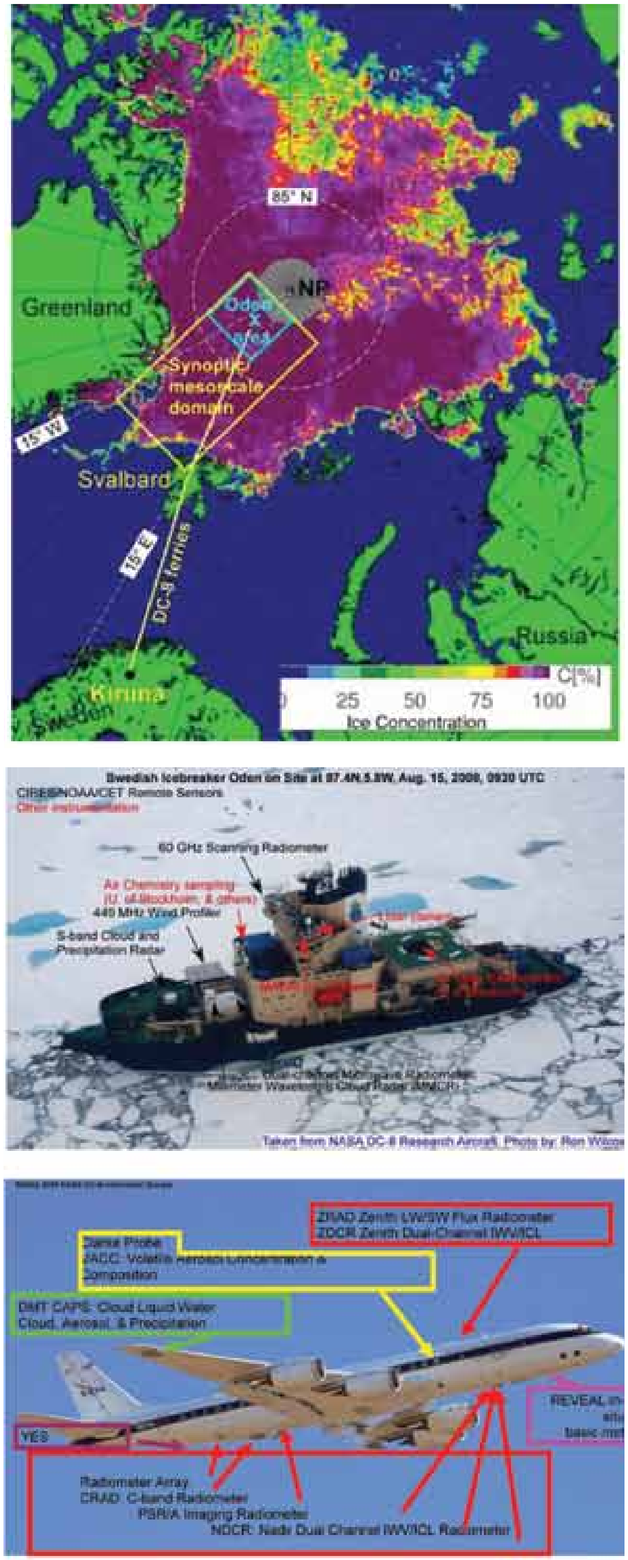


Figure 1: Locations of the NASA DC-8 flights over the ice breaker Oden *near the North Pole. Instrumentation on the b) icebreaker* Oden *and c) the NASA DC-8 during ASCOS/AMISA.*

Central Arctic Ocean-Measurements from the ASCOS campaign. Poster, United Kingdom Arctic Science Conference, Southampton.

Persson, P et al. (2009), Aircraft observations during the ASCOS/AMISA field program: Overview of the synoptic/mesoscale environment, boundary-layer structure, and cloud microphysics, 10th Polar Meteorology and Oceanography Conference, Madison, WI

Persson, P et al. (2009), High-temporal resolution observations of the thermal and kinematic vertical structure in the Arctic boundary layer during ASCOS, 10th Polar Meteorology and Oceanography Conference, Madison, Wisc.,

Shupe, M et al. (2009), Surface-based remote-sensing of clouds during ASCOS, 10th Polar Meteorology and Oceanography Conference, Madison, WI

Gasiewski, A et al. (2009), Radiometeric observations of the Arctic environment during the 2008 Arctic Mechanisms of Interaction between the Surface and the Atmosphere (AMISA) campaign, 10th Polar Meteorology and Oceanography Conference, Madison, WI

Gasiewski, A (2009), Use of a new generation of dropsondes during the 2008 Arctic Mechanisms of Interaction between the Surface and the Atmosphere (AMISA) campaign, 10th Polar Meteorology and Oceanography Conference, Madison, WI

Persson, P et al. (2009), High temporal resolution observations of the thermal and kinematic vertical structure in the Arctic boundary layer during ASCOS, Boundary Layers in High Latitudes, European Geophysical Union General Assembly, Vienna, Austria.

Persson, P et al. (2009), Integrating AMISA/ASCOS data to obtain a meteorological perspective of the AMISA DC-8 flights,First ASCOS Workshop, Lund, Sweden.

Persson, P et al. (2009), The 2008 Arctic Mechanisms of Interaction Between the Surface and Atmosphere (AMISA) campaign: Observation summary and data processing update, First ASCOS Workshop, Lund, Sweden.

Shupe, M et al. (2009), Clouds during ASCOS, First ASCOS Workshop, Lund, Sweden.

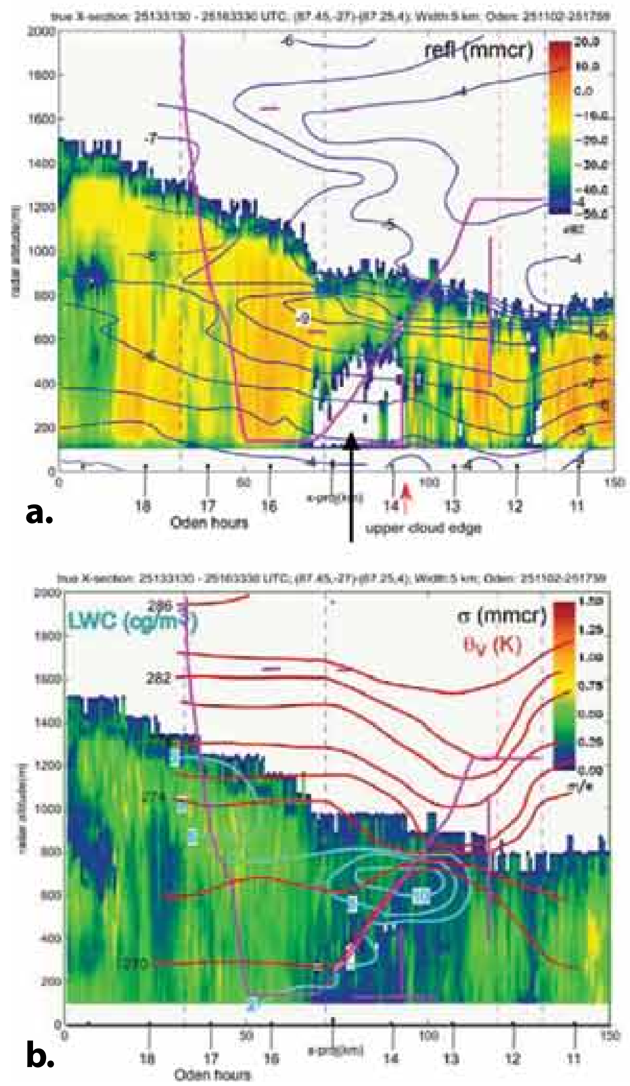


Figure 2: *Time-height cross-sections of a) radar reflectivity and temperature and b) radar spectral width and liquid water content on Aug. 25, 2008. The radar data are from the Ka-band cloud radar on the* Oden *and the analyses are derived from the aircraft dropsondes and in situ data.*

Austin Post captured this photograph of Winthrop Glacier, in Washington State, in September 1960. Researchers study historical photographs of glaciers for evidence of their past condition. Glaciers are very sensitive to temperature, and may serve as indicators of climate change. NSIDC holds more than 20,000 photographs and 100,000 microfilm images of glaciers in its archives, and has been working to digitize the images to make them more accessible to researchers.

CSV-05 Climate Research Database Development

■ NSIDC-01 Digitization of Analog Cryospheric Data under the Climate Database Modernization Program

■ NSIDC-03 World Data Center for Glaciology, Boulder-Current Programs

NSIDC-01 Digitization of Analog Cryospheric Data under the Climate Database Modernization Program

Goal: Scan and make available online data from NSIDC's analog collections so that it is more easily located, browsed, and obtained by users.

Milestone 1. Add the Austin Post collection of thousands of glacier photographs to the Online Glacier Photograph Database, in collaboration with the University of Alaska, NOAA's National Geophysical Data Center, and the NOAA Climate Data Modernization Program.

During FY09, 4,136 glacier photographs were added to the online database. Of these, 3,682 were part of the Ice and Climate Project/Austin Post collection.

Product: The NSIDC/World Data Center for Glaciology's glacier photograph collection is available at http://nsidc.org/data/g00472.html

NSIDC-03 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, reduced sea ice cover, thawing permafrost, and changes in precipitation patterns.

Milestone 1. Maintain and update existing research datasets (e.g., the Sea Ice Index). Publish new datasets and improve data visualization tools, including Google Earth.

The following are highlights of NSIDC's new and updated datasets:

Sea Ice Index (nsidc.org/data/seaice_index/daily.html)

• Daily plots of sea ice extent are now available from the Sea Ice Index (SII) site. The process was automated to create SII monthly shapefiles, which can be used in GIS applications.

• The SMMR-SSM/I (Scanning Multichannel Microwave Radiometer and the Special Sensor Microwave/Imager) was intercalibrated with the AMSR-E (Advanced Microwave Scanning Radiometer-Earth Observing System) records, by developing data quality fields for each concentration field and implementing improved metadata and preservation standards. Intersensor calibration was performed with F13 for both F15 and AMSR-E at the brightness temperature level. F13 and F15 are Defense Meteorological Satellite Program satellites.

Central Asia Temperature and Precipitation Data, 1879-2003 (nsidc.org/data/g02174.html)

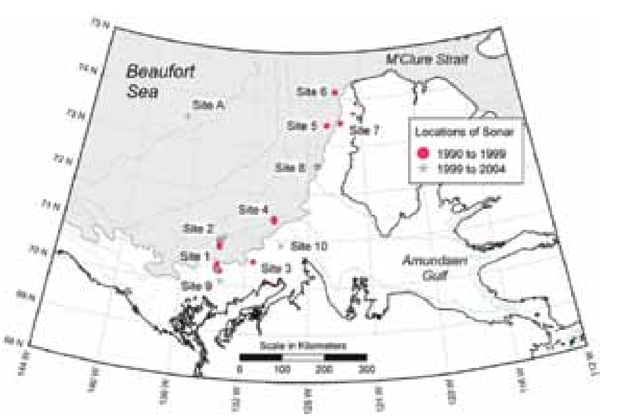
• Long-term data in high-elevation regions of Central Asia are sparse. Existing data were often recorded in handwritten documents (in Russian) that have not been digitized. This dataset extends publicly available Central Asia station data forward in time, and also encompasses new station data.

• The NOAA Global Historical Climate Network (GHCN) of quality-controlled meteorological records was expanded to include records from 298 stations in Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan. Data were subjected to rigorous quality control and homogeneity assessment procedures, consistent with those used for the GHCN. This project involved collaboration with the Institute for Arctic and Alpine Research at CU-Boulder.

Ice Draft and Ice Velocity Data in the Beaufort Sea, 1990-2003 (nsidc.org/data/g02177.html)

• Measurement of sea ice draft (m) and the movement of sea ice (cm/s)

• Two types of self-contained upward looking sonar moored near the seafloor: an ice profiling sonar to obtain ice draft data and an acoustic Doppler current profiler to obtain the ice velocity data.



The locations of sonar used to measure sea ice draft and movement in the Beaufort Sea.

Arctic Sea Ice Melt Pond Statistics and Maps, 1999, 2000, and 2001 (nsidc.org/data/g02159.html), produced in collaboration with the U.S. Geological Survey's Rocky Mountain Geographic Science Center.

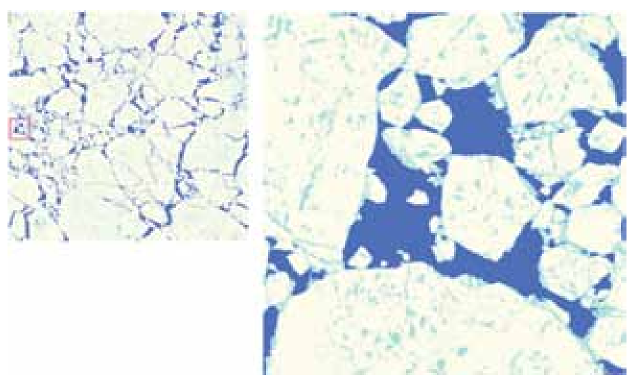
• Melt ponds form in summer when snow melts. These data provide information on the timing and extent of melt pond formation, information that is needed to fully understand the impact of ponds on ice thermodynamics and to improve parameterizations of albedo in models.

• Visible band imagery from high-resolution satellites were acquired over four sites.

• Data include pond coverage and size statistics for 500-m^2 cells within 10-km^2 images.

• One-meter surface type maps with either two (water and ice) or three (pond, open water, and ice) classes were created using supervised maximum likelihood classification of high-resolution visible band imagery.

Researchers in this photograph study melt ponds in situ, hoping to learn more about the impact of ponds on ice thermodynamics. With thousands of melt ponds forming each summer, remote-sensing imagery adds significant information to this effort.



Melt pond images were produced at high resolution. At left, a GeoTIFF image covers 10 km by 10 km at 1 m resolution. At right, a zoomed view of the surface map within the red square shows the detail visible in the image.

Climate Datasets on Google Earth (nsidc.org/data/virtual_globes/)

• Several new Keyhole markup language (KML) files of climate-related data were created this year, enabling users to browse these data on an interactive, virtual globe. The KML files include background science information and links to more information for understanding the data.

• PC World (September 2008) included NSIDC's sea ice KML file in "10 Amazing Google Earth Add-Ons."

• This work has made science information and data readily available to a wide audience. In addition to Google Earth (350+ million installations by early 2008), the KML files are compatible with a wide range of other virtual globe and mapping applications, such as NASA's World-Wind and ESRI's Explorer.

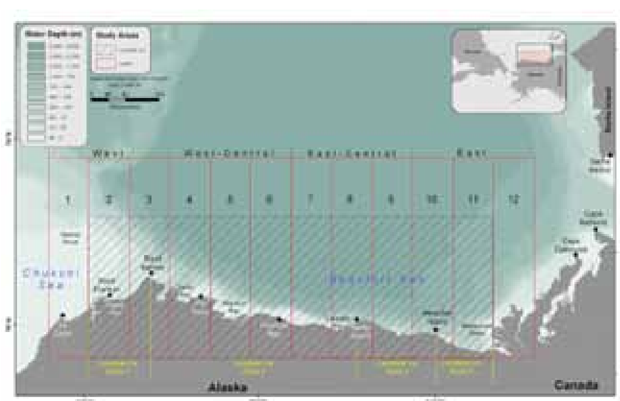
September 2008 Arctic sea ice data overlaid on Google Earth. Users can animate a series of September sea ice minimum data images from 1979-2008, helping illustrate the downward trend in extent.

Recurring Spring Leads and Landfast Ice in the Beaufort and Chukchi Seas, 1993-2004 (nsidc.org/data/g02173.html)

• In the Beaufort and Chukchi Seas, the most significant sea ice anomalies have occurred in the summer ice extent, and there has been a considerable decline in the multiyear ice pack in this region.

• To help understand these anomalies, this dataset contains information on recurring spring leads and landfast ice extent in this area.

• This dataset maps and documents the spatial and temporal distribution of recurring leads and landfast ice off the coast of northern Alaska in the Chukchi and Beaufort Seas (Eicken et al. 2006). The leads data span 1993-2004 and are based on visible and infrared Advanced Very High Resolution Radiometer (AVHRR) data onboard the NOAA 12, 14, 15, 16, and 17 satellites.



Beaufort Sea and Chukchi Sea with the subregions where leads were examined outlined in red. Black, hatched areas are the subregions where landfast ice was identified.

Milestone 2. Make research information available through the NSIDC Information Center, acquire and catalog cryospheric materials in the NSIDC library, and maintain NSIDC's analog datasets.

The information center added and catalogued 681 items and fulfilled 82 unique reference and research requests. A total of 250 items were checked out, and users returned 194. In-house patrons accessed 328 items.

CSV-07 Climate Services

- PSD-05 Experimental Regional Climate Services
- PSD-07 Experimental Climate Data and Web Services

PSD-05 Experimental Regional Climate Services

Goal: Couple enhanced observations and research in regions of strong climate variability and societal impact with analysis of past data and improved modeling. Determine factors influencing the occurrence of extreme events. Improve the diagnosis, modeling, and prediction of the regional consequences of climate change and variability on time scales of days to decades on hydrological variables of relevance to society.

Milestone 1. Continue monitoring daily, seasonal, and longer-term precipitation variability over the western United States. Continue downscaling National Centers for Environmental Prediction (NCEP) Week Two ensemble forecasts for Colorado water-resource managers. Continue developing seasonal forecast guidance tools for the United States based on the predictability of tropical sea-surface temperatures (SSTs) several seasons in advance.

Experimental seasonal guidance in the form of Colorado and Interior Southwest forecasts have been produced on a regular basis, incorporating the monitoring of daily, seasonal, and longer-term precipitation variability over the western United States. The experimental guidance discussion draws on information such as 1) the current status of the El Niño/Southern Oscillation (ENSO) phenomenon and prospects for the next 6-9 months, 2) regional climate background information, 3) most recent Climate Prediction Center seasonal outlooks, 4) most recent experimental forecast guidance based on statistical forecasts that incorporate SST and atmospheric circulation anomalies beyond ENSO.

NCEP Week 2 Probabilistic forecasts, developed at ESRL's Physical Sciences Division, are being tested for their use in making probabilistic forecasts of potential evapotranspiration—an indicator of irrigated crop water demand. This work is in collaboration with the U.S. Bureau of Reclamation Lower Colorado office, and the project was developed with close stakeholder interaction. The potential for useful skill is still being evaluated, but recent work with a NOAA Hollings Scholar has shown that reliable forecasts can be made. Additional work has been done on web site development.

Product: Monthly updated web page: www.cdc.noaa.gov/people/klaus.wolter/SWcasts/

Milestone 2. Continue programmatic development and impact assessments of climate, weather, and water

services, especially in conjunction with the National Integrated Drought Information Service (NIDIS).

Staff continued participating in monthly Colorado Water Availability Task Force meetings, to assess drought conditions in the state and the prospects of relief. Participation included regular invited presentations on weekly to seasonal precipitation outlooks. A Drought Subcommittee has been formed within this task force to work on improving the Colorado Drought Plan with a particular focus on the Surface Water Supply Index (SWSI)—staff from NIDIS and ESRL's Physical Sciences Division are participating.

Input to the U.S. Drought Monitor is continuing for the 10th year, now being coordinated with the state climatologist and Colorado participants in the U.S. Drought Monitor email alert system. This activity includes input to the seasonal U.S. Drought Outlook, in the form of experimental seasonal forecast guidance for the interior southwestern United States.

Product: Input to the U.S. Drought Monitor for current conditions: www.drought.gov/portal/server.pt/community/drought_indicators/us_drought_monitor

Input to the U.S. Drought Outlook for next season: www.drought.gov/portal/server.pt/community/forecasting

PSD-07 Experimental Climate Data and Web Services

Goal: Improve public access to climate information and forecast products to facilitate research, to inform public planning and policy decisions, and to assist any interested parties impacted by climate.

Milestone 1. Continue updating the extensive, publicly-accessible climate data holdings on the Climate Diagnostic Center/Physical Sciences Division web site. Continue acquisition of new precipitation and soil moisture datasets.

All of the major datasets have continued to be updated, including the National Centers for Environmental Prediction (NCEP)/ National Center for Atmospheric Research (NCAR) Reanalysis I, and the North American Region Reanalysis (NARR). In addition, the 20th Century Reanalysis (1908-1958) and some of the Carbon Tracker data have been added. For precipitation and soil moisture (Figure 1), in addition to the variables in the 20th Century dataset, the Global Historical Climatology Network version 2 gridded precipitation (1900-present) was added. The Global Precipitation Climatology Center precipitation dataset has been updated to a new version that starts in 1900. There is also a revised version of the Climate Prediction Center (CPC) soil moisture.

Milestone 2. Continue with acquisition and major updating of South and North American historical daily precipitation datasets.

A full update for Brazil daily precipitation data through 2008 has been acquired and incorporated into recently updated South America gridded data files (Figure 2). The South American dataset is publicly available and contains data from 1940 onwards (1x1 and 2.5 grids). The CPC 'Unified' precipitation and the precipitation from the Climate Data Assimilation System NCEP Reanalysis Model are being continually updated. The NCEP/U.S. Department of Energy Reanalysis 2 has been updated through 2008. The NARR has been updated through 2008 in-house and will be available for the public soon.

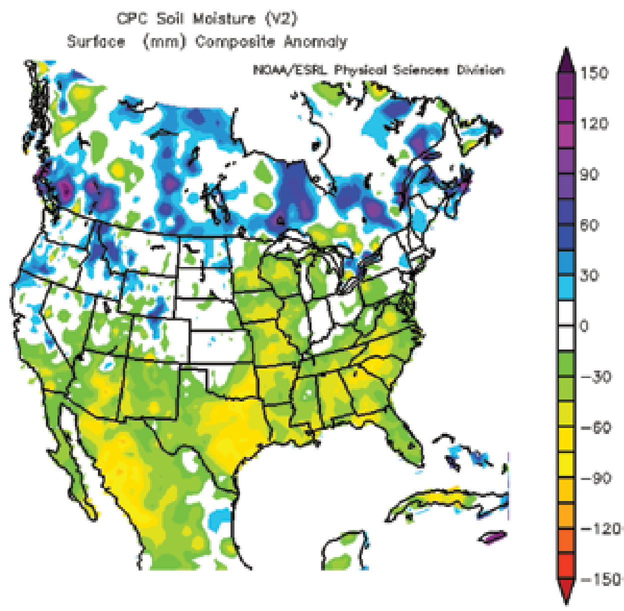


Figure 1: *Spring U.S. soil moisture anomalies during La Niña.*

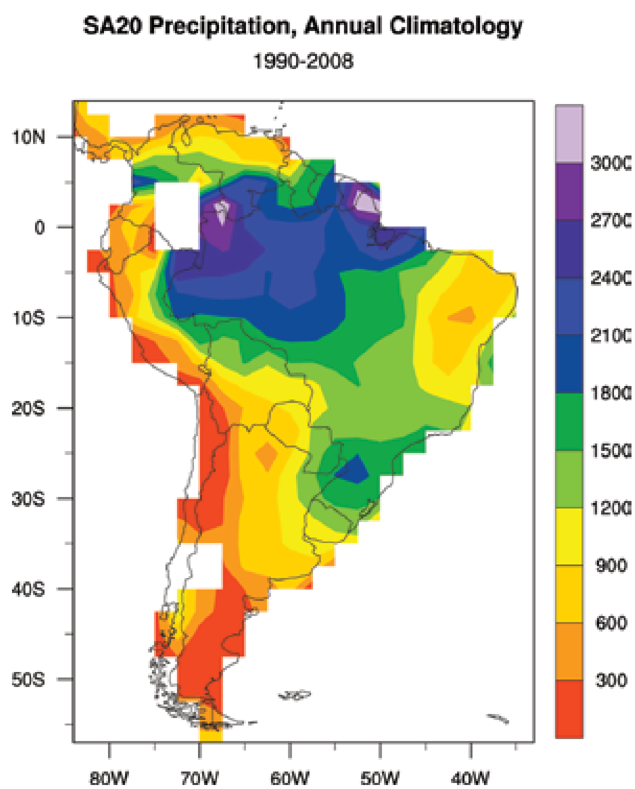
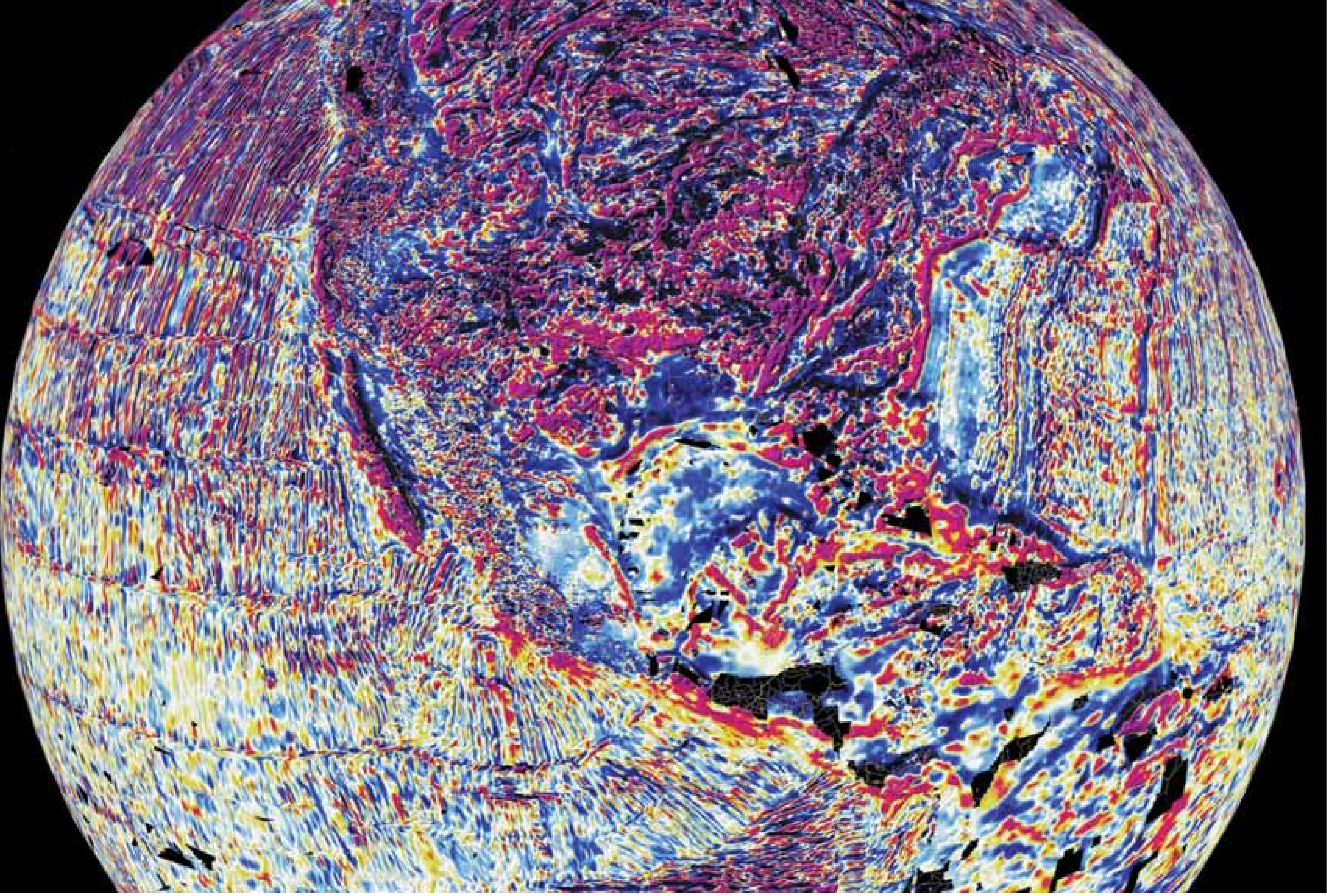


Figure 2: *The updated South American dataset is publicly available and contains data from 1940 onwards.*



The Earth Magnetic Anomoly Grid as seen on Google Earth.

GEODYNAMICS

GEO-01 Geophysical Data Systems

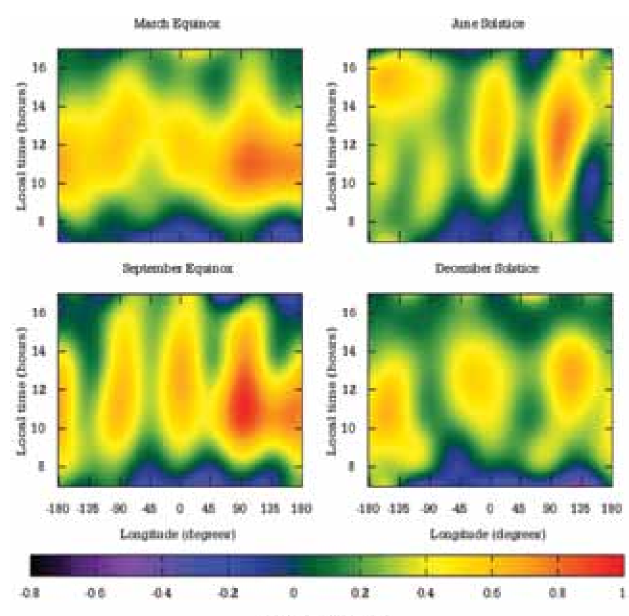
■ NGDC-05 Improved Integration and Modeling of Geomagnetic Data

NGDC-05 Improved Integration and Modeling of Geomagnetic Data

Goal: Produce reference models of the geomagnetic field for land, sea, air and spaceborne magnetic navigation and attitude/heading systems. Develop real-time models of the magnetic field for advanced magnetic accuracy requirements and space weather applications. Derive ionospheric parameters from magnetic field observations to monitor and predict ionospheric disturbances affecting global positioning systems and radio communication.

Milestone 1: Produce and distribute a new model of the day-side eastward electric field in the equatorial ionosphere.

The Equatorial Electric Field Model (EEFM1) was released. The Equatorial Electric Field (EEF) is a unique feature of the Earth's ionosphere (80- to 800-km altitude).



The EEF as a function of longitude and local time for different seasons.

It is generated by a dynamo process in which winds carry ions across geomagnetic field lines. Charge buildup at the dawn and dusk terminators sets up an eastward electric field along the magnetic equator. The EEF is one of the primary drivers of the equatorial ionosphere. Accurate ionospheric specification is important for predicting radio communication and navigation performance and outages, particularly in the equatorial region.

Six years of satellite magnetic measurements from the Challenging Minisatellite Payload (CHAMP) satellite have been used to model the EEF at 108-km altitude. The model was derived by inverting the satellite-observed magnetic signature of the equatorial electrojet for the current density, solving Maxwell's equations to obtain the EEF, and then estimating a climatological model from the resulting dataset. The model provides the mean and variance of the EEF as a function of longitude, local time, season, solar flux, and lunar local time (figure previous page, bottom).

Product: The model and software are available for download at http://geomag.org/models/EEF.html

Alken, P and S Maus (2009), Electric fields in the equatorial ionosphere derived from individual CHAMP satellite orbits, *J. Atm. Sol.-Ter. Phys.*, in press.

Milestone 2: Produce and distribute updated global magnetic anomaly map at 3-arc-minute resolution, compiled from marine, airborne, and satellite magnetic measurements.

An Earth Magnetic Anomaly Grid (EMAG2) has been compiled from satellite, ship, and airborne magnetic measurements, provided by more than 100 institutions worldwide.

Magnetic anomaly maps provide insights into the subsurface structure and composition of the Earth's crust. They are widely used in the geological sciences and in resource exploration. Furthermore, the global magnetic map is useful in science education to illustrate plate tectonics, crustal interaction with the deep mantle, and other aspects of Earth evolution. Distinct patterns and magnetic signatures on magnetic anomaly maps can be attributed to the formation (seafloor spreading) and destruction (subduction zones) of oceanic crust, the formation of continental crust by accretion of terranes to cratonic areas, and large scale volcanism.

For EMAG2 the grid resolution was improved to 2 arc minutes, down from 3 arc minutes of the earlier EMAG3 (Maus et al. 2007). In this revision, additional grid and trackline data over land and oceans have been included. Moreover, interpolation between sparse tracklines in the oceans was improved by directional gridding and extrapolation using an oceanic crustal age model (http://www.ngdc.noaa.gov/mgg/ocean_age/ocean_age_2008.html).

Product: The EMAG2 digital grid, images, and various derived products, including the keyhole markup language (KMZ) file enabling visualization in Google Earth® (figure previous page, top), are available on the EMAG2 home page (http://geomag.org/models/emag2.html).

Maus, S et al. (2009), EMAG2: A 2-arc-minute resolution Earth Magnetic Anomaly Grid compiled from satellite, airborne and marine magnetic measurements, *Geochem. Geophys. Geosyst.*, in press.

Maus, S., Earth Magnetic Anomaly Grid (EMAG2) released, *EOS Trans. AGU*, in press.

PLANETARY METABOLISM

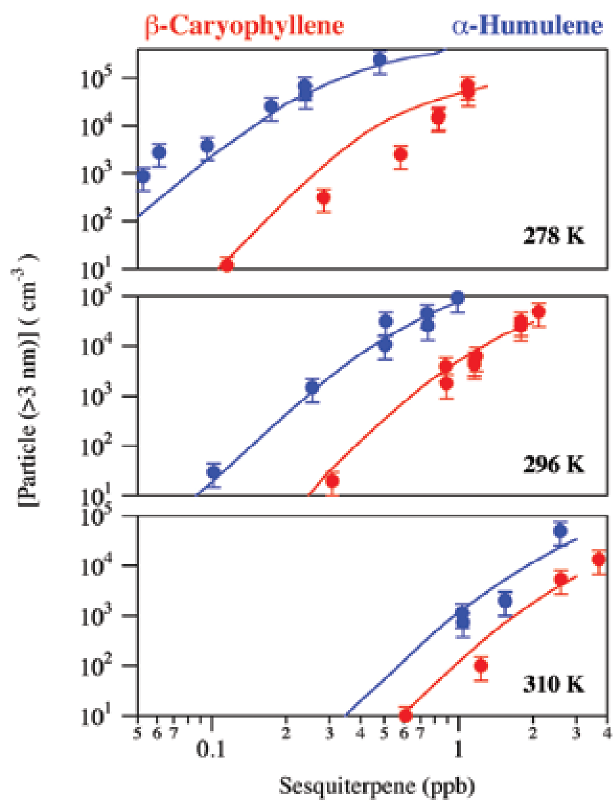
PM-01 Biosphere-Atmosphere Interactions

■ CSD-07 Biosphere-Atmospere Exchange

CSD-07 Biosphere-Atmosphere Exchange

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

Milestone 1: Measure particle nucleation and growth rates in laboratory experiments following the gas-phase oxidation of biogenic sesquiterpene ($C_{15}H_{24}$) compounds by ozone (O_3) and the hydroxyl radical.



Laboratory results for the particle nucleation following the gas-phase oxidation of the atmospherically most abundant sesquiterpenes: beta-caryophyllene and alpha-humulene.

Aerosol formation following the tropospheric oxidation of naturally emitted terpenes can affect human health, regional haze, and climate. The figure summarizes laboratory results for particle nucleation following the gas-phase oxidation (ozonolysis) of the atmospherically most abundant sesquiterpenes: beta-caryophyllene and alpha-humulene. Experiments were performed in a small volume Teflon bag reactor across a range of reactant concentrations at temperatures between 278 and 310 K. New particle formation was found to be efficient even at low sesquiterpene concentrations, less than 100 ppt. A molecular level nucleation model was used to interpret the exper-

Chicago at night as seen from the International Space Station. The increase in spatial and spectral resolution reveal a multitude of features not visible in current nighttime satellite imagery. The defined mission concept will increase spatial and spectral resolution over our current capabilities.

imental data and parameterize the nucleation process for future input into regional aerosol models. Aerosol model calculations are needed to evaluate the possible impact of sesquiterpenes on new particle and secondary organic aerosol formation under atmospheric conditions.

Milestone 2: Measure the emissions of acidic and other trace gases from biomass burning at the Fire Sciences Laboratory in Missoula, MT, using a new chemical ionization mass spectrometry (CIMS) method.

Measurements of gaseous emissions from burning vegetation were made using four different instruments. A gas chromatography-mass spectrometry (GC-MS) instrument quantified several tens of volatile organic compounds (VOCs). A proton-transfer-reaction mass spectrometry instrument followed many of these species with a fast time response during the ignition, flaming, and smoldering phases. A proton-transfer ion-trap mass spectrometry instrument did the same, but was extended with a GC column for post-burn analyses of VOCs sampled during the burn. Finally, a new chemical ionization mass spectrometry (CIMS) instrument was used for measurements of organic acids and other acidic gases. Several new findings were made. Very large emissions of nitrous acid (HONO) were observed by CIMS and the measurements were confirmed by Fourier-transform infrared spectroscopy. Emissions of HONO are potentially very important in the atmosphere, as they are direct radical sources and could lead to rapid chemical changes in forest fire plumes, of which our understanding is still very limited. Finally, iso-cyanic acid (HNCO) was identified as a large emission from burning vegetation. This species has not been observed in the atmosphere, so the implications of this finding are currently being researched.

PM-02 Response of Natural Systems to Perturbations

■ NGDC-07 Anthropogenic Remote Sensing

NGDC-07 Anthropogenic Remote Sensing

Goal: Provide spatial and temporal depictions of human activities based on satellite detection and mapping of population centers, fires, gas flares, and heavily-lit fishing boats.

Milestone 1: Develop intercomparable radiance calibrated nighttime lights datasets for 1996-97, 2000-01, and 2005-06.

A dataset was compiled that includes radiance calibrated nighttime lights for 1996-97, 2000-01, and 2005-06. These data have been inter-calibrated to aid in comparison between years.

The continental United States, from the 2005-06 satellite F16 dataset.

Product: Three data products were completed one for 1996-97, one for 2000-01, and one for 2005-06.

Milestone 2: Complete geospatial depiction of global economic activity based on satellite-observed nighttime lights.

Global economic activity was depicted based on satellite-observed nighttime lights.

Product: A data table of economic activity for countries around the globe was created based on satellite-observed nighttime lights.

Ghosh, T et al. (2009), Estimation of Mexico's informal economy and remittances using nighttime imagery, *Sens.-Rem. Sens.*, in press.

Ghosh, T et al. (2009), Estimation of Mexico's Informal Economy Using DMSP Nighttime Lights Data, *Proc. Urban Rem. Sens*.

Sutton, P et al. (2007), Estimation of Gorss Domestic Product at Sub-National Scales Using Nighttime Satellite Imagery, *Int. J. Ecolog. Econ. Stats.*

Milestone 3: Develop an Earth observation mission concept for moderate resolution nighttime lights.

A mission concept for the collection of moderate resolution nighttime lights data was completed. CIRES participated in two NASA mission planning workshops.

Product: Data are available at http://www.ngdc.noaa.gov/dmsp/nightsat.html

Elvidge, CD et al. (2007), Potential for global mapping of development via a Nightsat mission, *GeoJournal*, 69.

Elvidge, CD et al. (2007), The Nightsat mission concept, *International Journal of Remote Sensing*, 28(12).

REGIONAL PROCESSES

RP-01 Regional Hydrological Cycles in Weather and Climate

■ PSD-11 Water Cycle

PSD-11 Water Cycle

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

Milestone 1. Plan and execute the 2009 Hydrometeorological Testbed (HMT)-West field campaign, conducted in the American River Basin, located in the Sierra Nevada Mountains west of Lake Tahoe and east of Sacramento, CA CIRES investigators will be key participants and contributors to these activities.

The fourth year of full-scale field operations for HMT in the American River Basin (HMT-West 2009) was conducted from 5 December 2008-23 March 2009. Concentrated arrays of unattended instruments, including wind profilers, S-band precipitation profilers, various disdrometers, conventional and experimental precipitation and snow gauges, soil moisture sensors, stream level gauges, and surface meteorological stations monitored atmospheric and hydrologic conditions continuously for the entire field season. In contrast to the previous three field seasons, no gap-filling scanning radars or special balloon soundings were employed during the field deployment. As a result, there were no declared intensive operating periods. Experimental, high-resolution (3 km) numerical weather prediction models were run daily by ESRL's Global Systems Division and produced probabilistic forecasts of various precipitation amounts in the region. Project status was discussed on weekly conference calls among the NWS and ESRL participants of HMT-West 2009. In addition, project status and observations were available online (http://www.esrl.noaa.gov/psd/programs/2009/hmt/). Advanced Linux prototype system workstations (ALPS) were installed in the Sacramento, Monterey, and Eureka weather forecast offices and the California-Nevada River Forecast Center in Sacramento, in late December. A large fraction of the forecast products along with some of the observational datasets were accessible on these workstations, which essentially mimic the Advanced Weather Interactive Processing System workstations used operationally. Relative to HMT-West 2008, the performance of the ALPS workstations was dramatically improved, with much faster forecast product loading.

Approximate total precipitation accumulation over the course of the season was 44 in. at Norden (2,100 m), 36 in. at Blue Canyon (1,610 m), 18 in. at Colfax (726 m), 9 in. at Truckee in the lee of the Sierra Crest (1,805 m), and 7 in. at Sloughhouse (47 m). Fourteen distinct precipitation events occurred over the course of the field season. Precipitation accumulations were comparable to those observed during the preceding two field seasons (HMT-West 2007 and 2008), but still far below the precipitation accumulations observed during HMT-West 2006. Likewise, streamflow during HMT-West 2009 was comparable to the previous two field seasons, but more than an order of magnitude lower than the peak discharge observed during HMT-West 2006. The low streamflow observed during HMT-West 2009 can be partially attributed to the relatively low snow levels that were associated with many of the storms that impacted the American River Basin. With the cold storms, snow accumulation was high. In early March, approximate snow depths were 5 ft at Blue Canyon (1,610 m), 6 ft at Ward Creek in the lee of the Sierra crest (2,015 m), 7 ft at Onion Creek (1,886 m), and 9 ft at Huysink (2,011 m).

The most noteworthy storm of HMT-West 2009 occurred during 3-5 March. This extended event produced more than 8 in. of liquid equivalent at Norden, more than 6 in. of liquid equivalent at Blue Canyon, and almost 3 in. of liquid equivalent at Truckee.

Milestone 2. Using a suite of wind-profiling radar, Global Positioning Systems (GPS), and meteorological in situ instrumentation deployed during the NOAA HMT 2008, a prototype of a graphical decision-making support tool will be designed and developed to aid in the forecasting of extreme orographic precipitation events. Model forecast data will also be integrated into the tool to provide verification of quantitative precipitation forecasts, and to aid in identifying and isolating deficiencies in modeled precipitation-forcing processes. Feedback from weather forecasters and water-resource and emergency managers will be gathered to determine the most applicable way to represent the tool for efficient use in near-real-time decision-making.

A prototype of a graphical decision-making support tool was designed and developed to use wind profiler, GPS, and meteorological in situ data for diagnosing and forecasting extreme orographic precipitation events. Based on published research conducted by NOAA's Physical Sciences Division (PSD), objective forecast guidance was integrated into the tool to help identify favorable environmental conditions for heavy orographic precipitation. In addition, rapid refresh model forecast data from NOAA's Global Systems Division (GSD), were integrated into the product to provide both historical model verification and short-term precipitation forecasts. The graphical tool was automatically updated hourly and was made available to forecasters through the PSD web site, as new data were ingested from both the remote field sites and GSD. Discussions with NOAA's NWS in San Francisco were used to customize the tool for best utilization in an operational environment. After a successful demonstration of the tool during the latter part of the NOAA HMT-West 2009 campaign, efforts are now under way to integrate the tool into the NWS real-time operational data and display system.

Milestone 3. Develop and test a remote-sensing method to retrieve precipitation parameters from CloudSat. Model the hydrometeor and gaseous attenuation at W-band and estimate the multiple scattering effects for the CloudSat configuration. Modeled results will be used to develop a method that will relate rainfall rate to the gradients of the observed CloudSat measurements in the rain layer. The cloud absorption will be estimated and statistically analyzed. The developed method will be tested on a number of case studies of rainfalls of different intensity. The results of CloudSat rainfall retrievals will be quantitatively compared with available surface measurements (e.g., from the ground-based precipitation radars). The retrieval errors of the CloudSat retrievals will be assessed.

An attenuation-based method for retrievals of rainfall rate profiles from CloudSat data was developed and tested. This method is based on relating the vertical gradients of the observed (i.e., attenuated) reflectivity measurements in the liquid hydrometer layer containing rainfall. These gradients are related to the attenuation coefficient of the W-band radiation in rainfall after corrections for the gaseous and cloud absorption are made. The procedures for these two corrections were developed based on modeling results. It was shown that multiple scattering effects do not significantly affect the estimates of the attenuation coefficient from the gradient reflectivity measurements for rainfall rates (R) up to about 5-6 mm/h. The estimated attenuation coefficient is then related to rainfall rate. The proposed rainfall rate retrieval method is immune to uncertainties in the absolute calibration of the CloudSat radar and is applicable to observations above both land and water surfaces. A typical uncertainty of the retrievals is about 30-40 percent for stratiform precipitation with $R > 1$ mm/h. For a number of observational cases, the CloudSat-based retrieval results were compared to the quantitative precipitation estimates made with the Weather Surveillance Radar 88 Doppler (WSR-88D) radars. These comparisons showed a general agreement between spaceborne and ground-based rainfall measurements. The differences between CloudSat and WSR-88D measurements were mostly within retrieval uncertainties.

Milestone 4. The height of the freezing level of precipitation is important for predicting the amount of runoff that will occur in hydrologic catchments during wintertime storms. A feasibility study will evaluate if X-band polarimetric scanning radar observations can be used to identify the precipitation freezing level. Observations from the NOAA-HMT-2006 field campaign will be used in this feasibility study.

The feasibility of using scanning X-band polarimetric observations to identify the snow level of precipitating cloud systems was conducted using observations collected during the HMT-06 winter season. It was determined that the correlation coefficient between the horizontal and vertical polarized reflectivities provides a robust signal to identify the mixed phase precipitation that occurs near the freezing level. It was determined that correlation coefficients obtained during Plan Position Indicator (PPI) and the Range Height Indicator (RHI) scans could be used to identify the mixed phase precipitation.

RP-02 Surface/Atmosphere Exchange

■ PSD-12 Air-Sea Interaction

PSD-12 Air-Sea Interaction

Goal: Perform cutting-edge micrometeorological and climatological research over the open ocean aboard research vessels, sea-based towers, and buoys.

Milestone 1. Complete a synthesis dataset for EPIC extended monitoring cruises.

The synthesis dataset has been completed through the 6 Stratus cruise (2001, 2003-2007). The synthesis web site, where data and publications can be downloaded, is at http://www.esrl.noaa.gov/psd/psd3/synthesis/.

Product: de Szoeke et al. 2008, and:

de Szoeke, SP et al. (2008), Ship observations coasting South America in the tropical Pacific Ocean, *J. Climate*, submitted.

Milestone 2. Continue parameterization of sea spray as part of the NOAA hurricane studies.

Physics to include the buoyancy effect of spray mass were added and work continues on improved formulations of the wind stress and energy flux to wave breaking. The spray parameterization was rewritten to allow three different feedback schemes. The current version (9) is available at ftp://ftp.etl.noaa.gov/user/cfairall/onr_droplet/parameterization/version9/.

Product: Bao J-W et al. (2009), Impact of sea spray on the balance of turbulent kinetic energy in the hurricane surface boundary layer, 63rd Interdepartmental Hurricane Conference, Saint Petersburg FL

Fairall, CW et al. (2008), Investigation of the physical scaling of sea spray spume droplet production, *J. Geophys., Res*., in press.

Milestone 3. Analyze flux and gas transfer observations from NOAA GASEX-III field program in the Southern Ocean.

The last twelve months of this project were spent on evaluating and interpreting the time-series ozone, carbon dioxide (CO_2), dimethyl sulfide (DMS), meteorological and wind velocity measurements; and on processing and interpreting the fluxes of heat, momentum and gases. The project participants devoted a substantial amount of time to communicating preliminary results to the scientific community and are developing strategies for interpretation and improvements based on feedback obtained from these presentations. Other efforts include deepening the collaborative aspects of the work, for example, discussions with other principal investigators from the cruise. A meeting of the project's immediate collaborating groups was held at the University of Hawaii in April 2008; and a second meeting was held at NOAA ESRL in July 2008. The purpose of the workshops was to mutually inspect the datasets and to arrive at strategies for further processing, analysis and interpretation of the data. An additional meeting of collaborators was held at the University of Hawaii in March 2009 to improve the NOAA/COARE (Coupled Ocean-Atmosphere Response Experiment) gas transfer parameterization, including a blending of the high-wind speed wave-state transition impacts on the gas transfer.

A poster of the project's preliminary results was presented at the 10th Conference of the International Global Atmospheric Chemistry. Results were also presented at the AGU and AMS annual meetings.

Product: Fairall et al. 2008, Zappa et al. 2008, Hare et al. 2008, Hueber et al. 2008, and:

Cifuentes-Lorenzen, A et al. (2009), Parameterization of gas exchange from the Southern Ocean gas gxchange experiment, American Meteorological Society, 89th Annual Meeting, 16th Conference on Air-Sea Interaction.

Fairall, CW et al. (2009), Direct measurements of momentum and latent heat transfer coefficients during the GasExIII 2008 field program in the Southern Ocean: Comparisons with the COARE3.0 bulk flux algorithm, American Meteorological Society, 89th Annual Meeting, 16th Conference on Air-Sea Interaction.

Zappa, CJ et al. (2009), Influence of waves, whitecaps, and turbulence on gas transfer during the Southern Ocean gas exchange experiment, American Meteorological Society, 89th Annual Meeting, 16th Conference on Air-Sea Interaction.

Milestone 4. Parameterization of stable boundary-layers as part of the NOAA/NSF Polar Programs.

Data collected during the SHEBA (Surface Heat Budget of the Arctic Ocean Experiment) and CASES-99 (Cooperative Atmosphere-Surface Exchange Study) field programs were used to examine the flux-gradient relationship for wind velocity and temperature in the stably-stratified boundary layer by applying the direct approach of the K-theory and the gradient-based similarity. Both methods are formally equivalent to the Monin-Obukhov similarity. However, since they do not employ the Monin-Obukhov scales, these methods are more appropriate for evaluation of the turbulent fluxes from given values of the wind velocity and temperature gradients in stable conditions. The applied approach allows the assessment of the functional form of the Prandtl number in terms of the Richardson number, and also the flux-based similarity functions for wind and temperature in sub-critical and overcritical conditions.

RP-03 Regional Air Quality

- GMD-06 Baseline Air Quality
- PSD-13 Air Quality
- CSD-08 Regional Air Quality
- GSD-02 Regional Air Quality Prediction

GMD-06 Baseline Air Quality

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

Milestone 1. As part of the U.S. Department of Energy's Atmospheric Radiation Measurement Program, aerosol optical and cloud forming properties from the Anhui Province in China will be measured.

The aerosol instrumentation was deployed to the Anhui Province of China from May to December 2008 as part of the U.S. Department of Energy Atmospheric Radiation Measurement Program Mobile Facility. Data analysis was presented at the 2009 ARM Science Team Meeting.

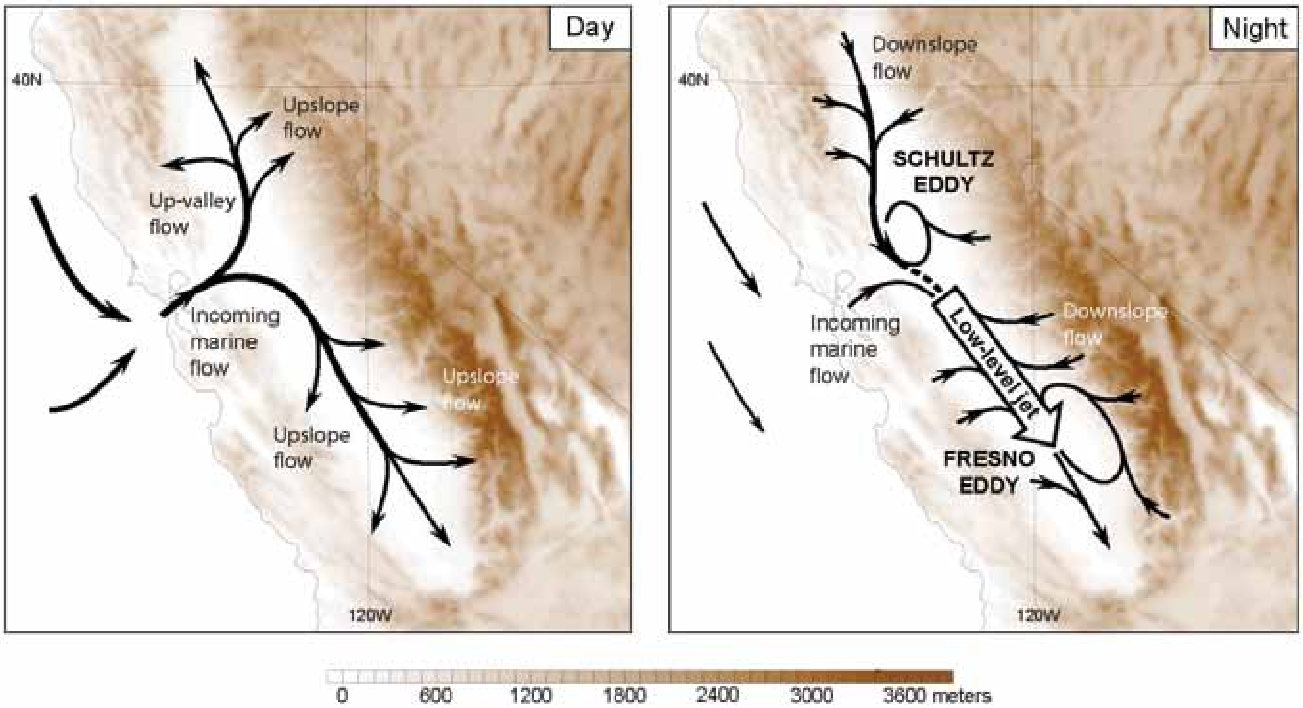
Aerosol instrumentation at the Anhui Province in China.

Product: The full edited dataset from this deployment resides in the ARM and NOAA archives.

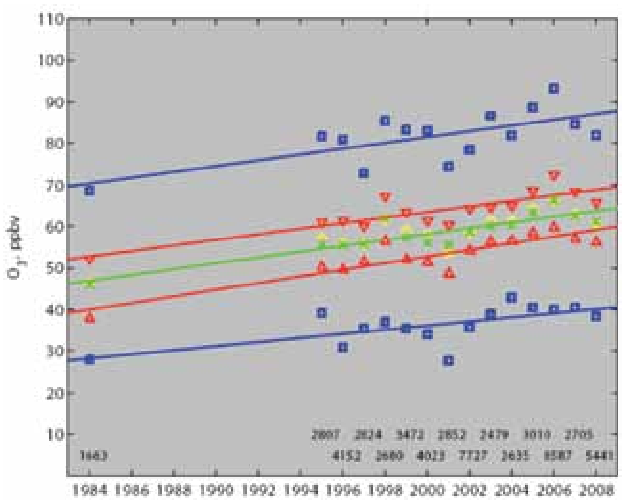
Jefferson, A and J Ogren (2009), Aerosol Observing Systems: Measurements of Aerosol Optical and Cloud-forming Properties, DOE ARM Science Team Meeting, April 2009, Louisville, KY.

Milestone 2. Analyze the surface ozone and ozone vertical profile measurements at Trinidad Head, CA, and at Mauna Loa, Hawaii, for longer-term changes that could be related to changing Asian emissions.

The six-year surface ozone data record from Trinidad Head, CA has been analyzed to identify conditions under which the data are representative of background air entering the West Coast of the United States. (Oltmans et al. 2008). In addition, the 10-year record of ozone vertical profile measurements (ozonesondes) at this site has been investigated for possible longer-term changes that might reflect the impact of changing Asian ozone precursor emissions. This relatively short record shows only small changes that are not statistically significant (Oltmans et al. 2008). However, an analysis of a more comprehensive set of ozone profile data from western North America indicates that ozone in the free troposphere has increased (Cooper et al. 2009). It has also been found that tropospheric background ozone amounts entering the West Coast of the United States as measured at Trinidad Head play a significant role in the ability of inland California locations to meet air quality standards (Parrish et al. 2009).



Conceptualization of a) the daytime and b) nighttime low-level wind regimes in California associated with summertime poor air quality in the Central Valley (CV). First, the low-level winds in the Sacramento Valley (SV) are characterized by the diurnal variation of the up-valley flow (during the day, panel a) and the down-valley flow (during the night, panel b). Second, the CV is characterized by the splitting of the incoming flow from the San Francisco Bay area (panel a). Third, the flow in the San Francisco Bay area is characterized by the diurnal variation of the strength of the incoming flow from the Pacific Ocean that moves through the Carquinez Strait. Fourth, the flow in the San Joaquin Valley (SJV) is characterized by the incoming flow that moves towards the south, where a low-level jet typically develops at night (panel b) and interacts with the downslope flows along the foothills of the eastern side of the SJV to form the Fresno Eddy. In addition to the Fresno Eddy, interaction between the northward inflow and the nocturnal down-valley flow in the SV often leads to the formation of a counterclockwise local eddy to the north or northwest of Sacramento, known as the Shultz Eddy during the night (panel b).



Ozone distributions for all data points in the troposphere (Potential Vorticity < 1.5 PVU) between 3,000 and 8,000 m, with sample sizes for each year indicated above the x-axis. Also shown are the ozone rate of increase per year and the p-value of the least squares line fit through the data for 1984-2008 and 1995-2008 (from Cooper et al. 2009).

Product: Oltmans, SJ et al. (2008), Background ozone levels of air entering the West Coast of the United States and assessment of longer-term changes, *Atmos. Environ.*, doi: 10.1016/j.atmosenv.2008.03.034.

Cooper, OR et al. (2009), Increasing ozone above western North America during springtime, *Nature*, in review.

Parrish, DD et al. (2009), Impact of background ozone inflow on summertime air quality in California's Sacramento Valley, *Geophys. Res. Lett.*, in review.

PSD-13 Air Quality

Goal: Gather and analyze atmospheric observations to characterize meteorological processes that contribute to high-pollution episodes. Compare these measurements with air-quality forecasting model predictions to assess and improve research model performance.

Milestone 1. Submit two publications on wind profiler, air/sea fluxes, ozone fluxes, and rawinsonde data onboard the NOAA research vessel *Ronald H. Brown* during the Texas Air Quality Study 2006.

So far, one paper summarizing results from the NOAA research vessel *Ronald H. Brown* during the 2006 Texas Air Quality Study has been submitted.

Product: Grachev A et al. (2009), Turbulent fluxes and transfer of trace gases from ship-based measurements during TexAQS 2006, *J. Geophys. Res.-A*, submitted.

Milestone 2. Analyze meteorological data collected during the 2008 Front Range Air Quality Study. Advise air chemistry experts on the results. During the summer of 2008, ESRL conducted a Front Range air quality study, partly in response to the region's failure to meet the U.S. Environmental Protection Agency's national ambient air-quality standard for ozone. Because of the complex terrain and

urbanization, there are complex meteorological processes that affect the transport of pollutants. Using wind profilers and a surface station on the continental divide, the meteorological processes that contribute to ozone exceedances will be investigated.

CIRES investigators used data collected by a small network of Doppler wind profilers (set up by NOAA staff) to calculate forward and backward airmass trajectories during the 2008 Front Range Air Quality Demonstration Project. This observationally-based trajectory tool was available online during the field campaign to help with mission planning for aircraft, and after the field campaign to help scientists better understand air pollution transport along the Front Range of Colorado. The trajectories identified the transport pathway for urban pollution reaching Rocky Mountain National Park, which results in reduced visibility in the Park.

Product: The wind profiler trajectory tool for the 2008 Front Range Air Quality Study is still available online at http://www.etl.noaa.gov/programs/2008/fraqs/traj/.

Milestone 3. Contribute to planning for the 2010 California Air Quality Study. In 2010, ESRL will use surface and airborne chemical and meteorological measurements to characterize the pollution events in California. CIRES investigators will help design the surface networks.

Published studies (Michelson and Bao 2008, Bao et al. 2008) identified that several major mesoscale circulation components (top figure previous page) are important in the orographic ventilation and recirculation of the atmospheric boundary layer (ABL) pollution in the Central Valley of California. Identifying these mesoscale circulation components is an important first step in understanding how the meteorological features affect air quality in California. The results from these studies have served as a scientific basis in the planning of the instrument deployment for the 2010 California Air Quality Study. Specifically, the results have brought up the following questions, which the study aims to investigate:

1) Can the ABL development and transition from the floor of the Central Valley to the slopes of the Coast Range and the Sierra Nevada be well-modeled using current parameterizations?

2) What is the role of up-/downslope flows in the vertical ventilation and recirculation?

3) What is the role of up-/downvalley flows in the vertical ventilation and recirculation?

4) What is the morphology of vertical ventilation and recirculation along the slopes of the Coast Range and the Sierra Nevada?

5) What are the characteristics of the penetration of the ABL pollution into the free troposphere by vertical mixing and orographically enhanced pumping?

6) How does entrainment of pollution from the free troposphere into the ABL affect the air quality in the Central Valley?

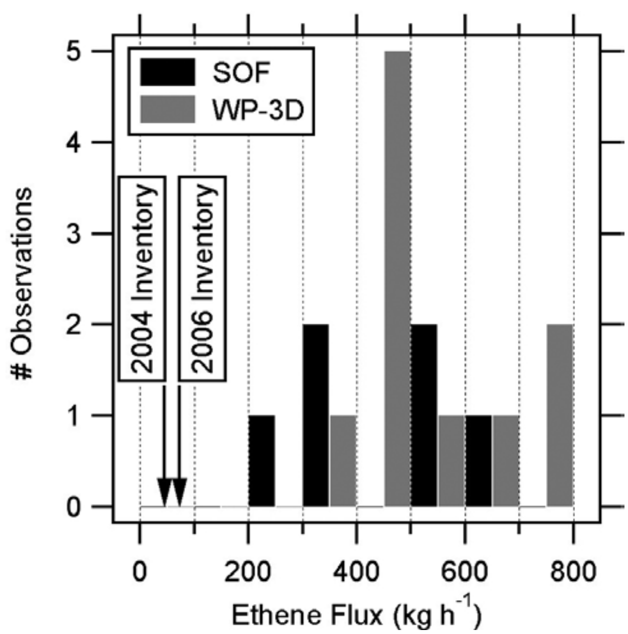
Product: Bao et al. 2008, Michelson and Bao 2008.

CSD-08 Regional Air Quality

Goal: Conduct laboratory measurements, atmospheric observations, and diagnostic analyses that characterize the chemical and meteorological processes involved in the formation of pollutant ozone and fine particles. Undertake research that contributes to the enhancement of air quality prediction and forecasting capabilities.

Milestone 1. Continue to interpret, present and publish results from the 2006 Texas Air Quality Study (TexAQS) field study.

Measurements of volatile organic compounds (VOCs) and other trace gases were performed from both the NOAA WP-3D aircraft and the NOAA research vessel *Ronald H. Brown*. In 2008, the results from the measurements were analyzed in terms of their implications for ozone and aerosol photochemistry. Measurements made using gas chromatography-mass spectrometry revealed unprecedented insight into the speciation of VOCs in the Houston area, and identified alkenes as the most important reactive VOCs near emission sources. Away from emission sources, oxygenated VOCs, such as aldehydes, carried much of the reactivity of VOCs with OH. The aircraft data were particularly useful for estimating emission fluxes of reactive VOCs. An example included the emissions of ethene, measured both with fast-time response by laser photo-acoustic spectroscopy (LPAS) and from post-flight analyses of whole air samples collected in flight. The resulting flux estimates for the Mt. Belvieu chemical complex were compared with independent measurements made by the solar occultation flux (SOF) method from a mobile laboratory underneath the emission plumes. The figure summarizes the results from the LPAS and SOF techniques, and compares the results with estimates according to emission inventories. The main finding is that estimated fluxes from measurements exceed the emissions in the inventories by approximately an order of magnitude. These results are important for air quality modeling in the Houston area and explain why models cannot reproduce the rapid ozone formation that is often observed in petrochemical plumes.



Estimated flux of ethene from the LPAS and SOF techniques described above, compared with estimates from emission inventories. Estimated fluxes from measurements exceed the emissions in the inventories by an order of magnitude.

Product: Bahreini, R et al. (2009), Organic aerosol formation in urban and industrial plumes near Houston and Dallas, TX, *J. Geophys. Res.-Atmos.*,doi: 10.1029/2008JD011493.

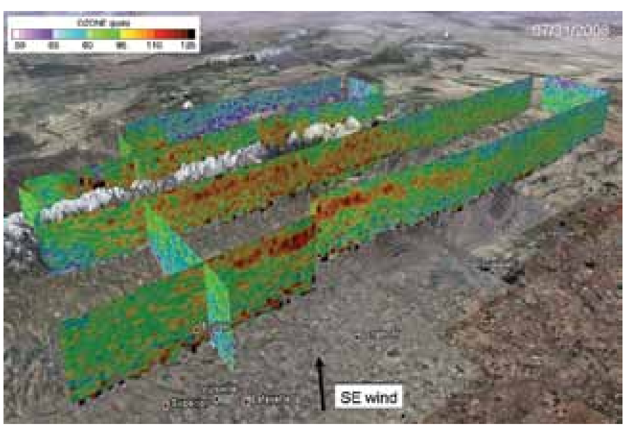
McKeen, S et al. (2009), An evaluation of real-time air quality forecasts and their urban emissions over Eastern Texas during the summer of 2006 Second Texas Air Quality Study field study, *J. Geophys. Res.-Atmos.*, D00F11, doi: 10.1029/2008JD011697.

Gilman, JB et al. (2009), Measurements of volatile organic compounds during the 2006 TexAQS/GoMACCS campaign: industrial influences, regional characteristics, and diurnal dependencies of the OH, *J. Geophys. Res.-Atmos.*, doi: 10.1029/2008JD011525.

de Gouw, JA et al. (2009), Airborne measurements of ethene from industrial sources using laser photo-acoustic spectroscopy, *Env. Sci. Tech.*, doi: 10.1021/es802701a.

Milestone 2. Contribute to an air quality study in the Colorado Front Range area in summer 2008 by deploying an ozone and Doppler wind lidar on a research aircraft.

We investigated the distribution and transport of ozone in the Colorado Front Range area by deploying NOAA's airborne ozone lidar on a Twin Otter aircraft and flying several missions in summer 2008. The aircraft typically flew at altitudes of about 5 km above sea level and the downward-looking lidar provided profiles of ozone and aerosol backscatter at high spatial and temporal resolution, from just below the aircraft to the ground. The airborne lidar measurements were complemented by a ground-based Doppler lidar, a small network of radar wind profilers, and a surface meteorological station on the Continental Divide west of Denver, to better characterize transport patterns. In addition, the Flexpart Lagrangian particle dispersion model was used, coupled with high-resolution Weather Research and Forecasting model runs, to forecast pollutant transport and guide flight planning efforts.



Ozone distribution over the Colorado Front Range area, observed with NOAA's airborne ozone lidar on the afternoon of 31 July 2008.

During most flights, polluted air from the Denver metro area was transported by easterly winds towards and into the adjacent mountains. The highest ozone levels were typically found over the western suburbs of the Denver metro area and along the eastern slope of the mountains. If the mixed layer was deep enough, the ozone plume was pushed further west across the Continental Divide. The figure above shows the ozone distribution under such a scenario, as observed with the airborne lidar on the afternoon of July 31 2008. Polluted air from the Denver metro area was transported towards and over the Continental Divide, resulting in high ozone concentrations in Rocky Mountain National Park and in Grand County, west of the Divide. In other cases, pollutants were vented into the free troposphere and transported back east over the Denver area by predominantly westerly winds above the boundary layer.

Results from this study will be presented at an international conference this fall. Also planned is a publication describing findings on transport of ozone and aerosols generated in the Front Range urban area and the interaction of these pollutants with the mountainous terrain west of the urban corridor.

Another focus of the summer 2008 experiment was the deployment and testing of a Doppler lidar on the Twin Otter aircraft. The deployment provided important insights for future Doppler lidar deployments on the Twin Otter, and yielded some valuable data on vertical mixing and turbulence over the Colorado Front Range area (see CSD-01, Milestone 2 for more detail). These lidar deployments constituted an important step towards our objective of co-deploying the ozone lidar and a Doppler wind lidar to quantify horizontal and vertical transport of pollutants from an airborne platform.

Milestone 3. Analyze high-resolution Doppler lidar (HRDL) measurements data to study nocturnal boundary layer structure and develop techniques to estimate boundary layer height.

The depth of the stable boundary layer (SBL) is a critical quantity for many applications, including the depth

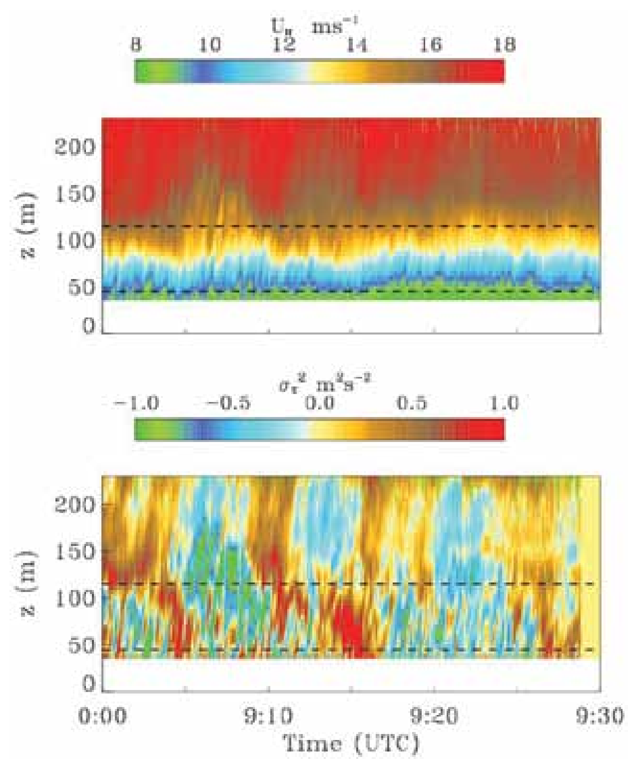


***Figure 2.** Time-height cross sections of (top) mean wind and (bottom) variance, computed from HRDL measurements show turbulent structure at the height of 1.5-MW wind turbine rotors at the Lamar site (45-115 m).*

of dilution for air quality and emergency response, and as a scaling depth for numerical weather prediction parameterizations of stable mixing processes. Accurate determinations of SBL depth has been a longstanding problem, because of its importance for applications and because of its difficulty. The most basic definition of the boundary layer—as the layer of turbulence in contact with the Earth's surface—requires measurements of profiles of turbulence that are not generally available. A paper accepted by the *Journal of Applied Meteorology* and two conference papers presented results and discussed developed techniques to estimate SBL depth estimates from lidar measurements of the mean wind profiles. The SBL depth determined from the high-resolution turbulence profiles was used as a reference for validating the accuracy of developed techniques. Mean wind profiles that were smooth enough to calculate second derivatives were obtained from HRDL profile data, taken during two nighttime field programs in the U.S. Great Plains.

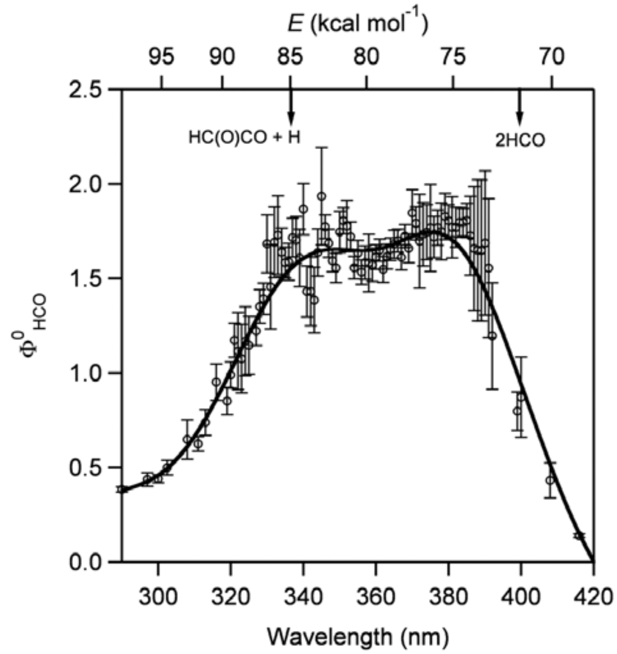
Scan data from ESRL's HRDL have been analyzed from the perspective of wind energy needs. The size of wind turbines is rapidly increasing, and modern turbines are often exposed to high variations in wind and turbulence conditions, significant wind, and directional shear across the rotor plane (Figure 2). These parameters can affect power production and structural safety. HRDL measurements, which have sufficient vertical and time resolution, provide better data on of wind regimes at turbine heights, and can reduce the uncertainty of power performance measurements and electricity production. The ability of lidar to better reflect dynamic processes in the boundary layer above the range of tower measurements makes this instrument a powerful tool for studies related to wind energy. Detailed analysis of wind flow statistics from HRDL measurements were presented at five conferences.

Product: Pichugina and Banta 2008, Pichugina et al. 2008a, Pichugina et al. 2008b, Pichugina et al. 2008c, Banta et al. 2008.

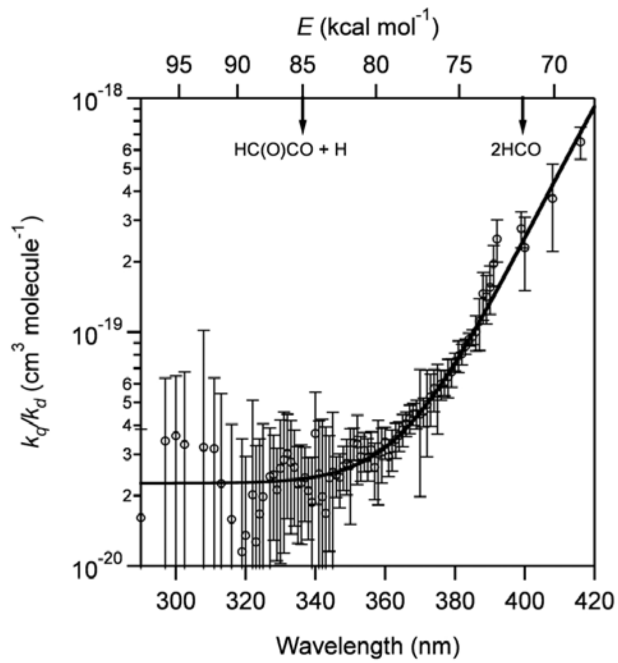
Milestone 4. Measure the quantum yields for the formyl radical (HCO) in the UV photolysis of glyoxal over a range of wavelengths and pressures relevant to the atmosphere.

Glyoxal is a relatively short-lived VOC formed in the atmosphere in the oxidation of isoprene and various aromatic compounds. Glyoxal is removed from the atmosphere primarily via two processes, reaction with OH and UV/vis photolysis, which impact the oxidative capacity of the atmosphere differently. In this laboratory study, the UV/vis photodissociation of glyoxal was measured by detecting the formation of the HCO radical photoproduct as a function of pressure (50–620 Torr, N_2) and photolysis wavelength (290–420 nm) using pulsed laser photolysis combined with cavity ring-down spectroscopy. An HCO quantum yield (Φ) and collisional quenching (kq/kd) dataset was obtained, shown in the figures at right. This extensive dataset provides information needed for input to regional air quality atmospheric model calculations.

Product: Feierabend, KJ et al.(2009), HCO Quantum Yields in the Photolysis of HC(O)C(O)H (Glyoxal) between 290 and 420 nm, *J. Phys. Chem. A*, doi: 10.1021/jp9033003.



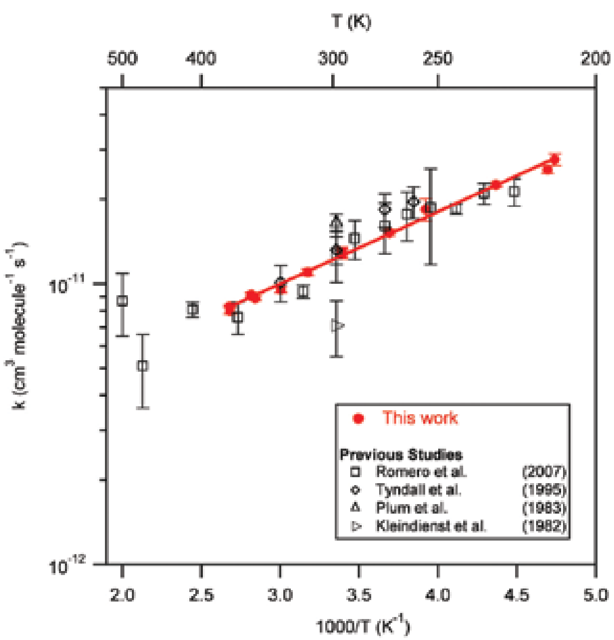
This figure shows the wavelength dependence of the zero-pressure HCO quantum yield data obtained following the UV/vis photolysis of glyoxal.



The wavelength dependence of the ratio of the N_2 collisional quenching rate coefficient, k_q, to the dissociation rate coefficient, k_d, for the UV/vis photolysis of glyoxal measured in this study.

Milestone 5. Measure the rate coefficient for the reaction of hydroxyl radical with methyl glyoxal, $CH_3C(O)C(O)H$, over the range of temperatures and pressures common to the troposphere and lower stratosphere to better elucidate the role of oxygenated hydrocarbons in radical (HO_x) and ozone production.

The atmospheric degradation of VOCs via reaction with trace species (UV/vis photolysis) or heterogeneous processes directly influences the oxidative capacity of the troposphere. In this laboratory study, the gas-phase reactivity of methyl glyoxal, a VOC formed in the atmosphere, with the hydroxyl radical was measured. Rate coefficients (k) for this reaction were measured using pulsed laser photolysis to produce hydroxyl radicals in the presence of excess methyl glyoxal, and laser-induced fluorescence to measure the hydroxyl radical temporal profile. Rate coefficients were measured across the temperature range 210–373 K, and the obtained rate coefficients are given by the Arrhenius expression $k(T) = 1.74 \times 10^{-12} \exp(590/T)$ $cm^3\ molecule^{-1}\ s^{-1}$. The experimental data and Arrhenius expression are shown in the figure below. The results from previous studies are included in the figure for comparison. This study provides information needed to evaluate the atmospheric lifetime of methyl glyoxal and its potential impact on regional air quality.



Results from an experiment to measure rate coefficients (k) for the gas-phase reactivity of methyl glyoxal with the hydroxyl radical. Also shown are data from previous studies.

GSD-02 Regional Air Quality Prediction

Goal: Design and evaluate new approaches for improving air quality prediction.

Milestone 1. Develop and test the capability to assimilate, using the Gridpoint Statistical Interpolation (GSI) analysis and observations of ozone and chemical species important in reactions involving ozone, into the WRF-chem prediction model.

The GSI analysis system was used to assimilate ozone and particulate matter to produce an optimal state of the atmosphere for both weather and air quality. The new analysis led to significant improvements in forecasting air quality, and a paper was submitted.

Product: Pagowski M et al. (2009), Three-dimensional variational data assimilation of ozone and fine particulate matter observations: Some results using the Weather Research and Forecasting–Chemistry model and Gridpoint Statistical Interpolation, *Quart. J. Royal Met. Soc.*, submitted.

Milestone 2. Prepare documentation and tutorials to support WRF-Chem as a community model.
User documentation is online at http://wrf-model.org/WG11. National and international tutorials were held in Boulder, CO; Pune, India; and Seoul, South Korea.

RP-04 Intercontinental Transport and Chemical Transformation

■ CSD-05 Tropospheric and Statospheric Transport and Chemical Transformation

CSD-05 Tropospheric and Stratospheric Transport and Chemical Transformation

Goal: Carry out modeling studies and airborne and surface measurements of chemical species in order to elucidate the processes involved in the intercontinental transport of photochemical pollution.

Milestone 1. Archive and begin analysis of the data from the International Chemistry Experiment in the Arctic Lower Troposphere (ICEALOT) field mission. ICEALOT was carried out in spring 2008 as part of the International Polar Year to examine the aerosol properties and atmospheric chemistry over an ice-free region of the Arctic. The study investigated 1) springtime sources and transport of pollutants to the Arctic, 2) evolution of aerosols and gases into and within the Arctic, 3) aerosol–radiation interactions, and 4) ozone budget and climate effects.

As discussed in Project CSD-03, Milestone 4, current scientific understanding indicates that the Arctic is warming more rapidly than other regions of the planet, with the most notable effect being the loss of sea ice. This loss is providing opportunities for development in the Arctic, from offshore oil and gas extraction to shortened sea routes for ocean-going cargo vessels. These activities will increase the burden of pollution in this relatively pristine region, possibly enhancing warming via direct emissions of light-absorbing particles and by increases in short-lived photochemically-produced pollutants (e.g., ozone). Few datasets are available to evaluate increases in surface pollutants over the ice-free waters of the Greenland, Norwegian, and Barents seas where energy development and increased shipping will occur. The most extensive data are from the station at Ny Alesund (Svalbard) atop Mt. Zeppelin, but these measurements are taken at 500 meters above the water surface.

Two primary objectives of ICEALOT were 1) to characterize the existing levels of pollutants (i.e., 'baseline'

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An Arctic haze layer is visible from the Knorr *while on station off the northern coast of Norway.*

data) at the surface and 2) to evaluate sources of pollutants and transport patterns that bring these pollutants into the region. A secondary objective of ICEALOT was to examine pollutant outflow from New York City and characterize the chemical transformations that occur in cold weather. The ICEALOT study was conducted aboard the research vessel *Knorr*, based in Woods Hole, Mass., starting at Woods Hole on 19 March and ending at Reykjavik, Iceland, on 23 April 2008. The data taken during the cruise are currently undergoing final quality assurance and control and will be available shortly.

For this project, CSD-05, data analysis will focus on near-field (Arctic region) and long-range (North Atlantic Ocean) transport and the associated chemistry (Gilman et al. 2009) and observations of nitryl chloride ($ClNO_2$) in the outflow from the New York City region into the North Atlantic Ocean (Williams et al. 2009). In addition to the above topics, the data are expected to be used by other research groups for both model validation and satellite ground-truth efforts.

Product: Gilman, JB et al. (2009), Long-range transport of ozone-depleted airmasses as evidenced by VOC ratios, manuscript in preparation.

Williams, EJ (2009), Nitryl chloride observed over Long Island Sound and the North Atlantic Ocean during March 2008, manuscript in preparation.

Milestone 2. Archive and begin analysis of data from the Aerosol, Radiation, and Cloud Processes affecting Arctic Climate (ARCPAC) field mission.

Massive biomass burning plumes were observed in the Alaskan Arctic during the spring of 2007 on multiple flights of the NOAA WP-3D research aircraft. The source of the plumes was attributed to biomass burning, particularly because of elevated levels of the trace gas acetonitrile (CH_3CN) and to a large fraction of particles containing carbon and potassium as identified by particle analysis by laser mass spectrometry. In addition, the Lagrangian transport model Flexpart was very successful in reproducing the observations, which indicated that

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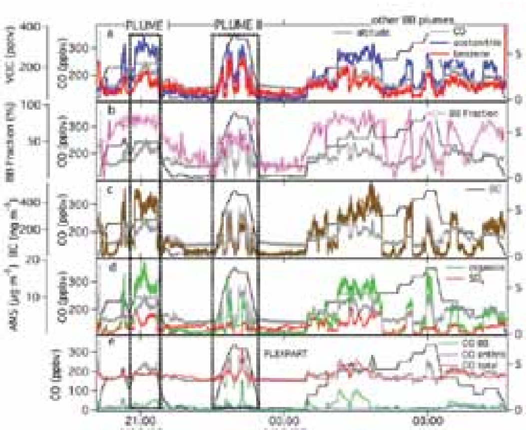
Close-up of ice encrustation on the sampling tower, inlets, and instruments on the research vessel Knorr.

NASA

Fires near Lake Baikal in Siberia in 2008.

the sampled emissions originated from forest fires in the Lake Baikal region of Siberia and from agricultural emissions in Kazakhstan further west. The figure below shows results from one research flight, which observed strong enhancements of carbon monoxide (CO), benzene, acetonitrile, black carbon (BC), and aerosol organics and sulfate (SO_4) in several distinct plumes. These findings are important as the biomass burning plumes carried relatively large amounts of BC into the Arctic, which exerts a direct radiative forcing on the climate and can also enhance the melting of the sea ice if it gets deposited at the surface. Further research is focused on determining the prevalence of such events in the springtime Arctic.



Time series of various species during the NOAA WP-3 flight on 18 April 2008 over the Alaskan Arctic. Fire plumes were observed multiple times at various altitudes.

Product: Warneke, C et al. (2009), Biomass burning in Siberia and Kazakhstan as the main source for Arctic haze over the Alaskan Arctic in April 2008, *Geophys. Res. Lett*., doi: 10.1029/2008GL036194.

RP-05 Aerosol Chemistry and Climate Implications

■ CSD-09 Aerosol Formation, Chemical Composition, and Radiative Properties

CSD-09 Aerosol Formation, Chemical Composition, and Radiative Properties

Goal: Carry out airborne, ship-borne, and ground-based experiments that characterize the chemical composition of radiatively important aerosols in the upper troposphere and at Earth's surface.

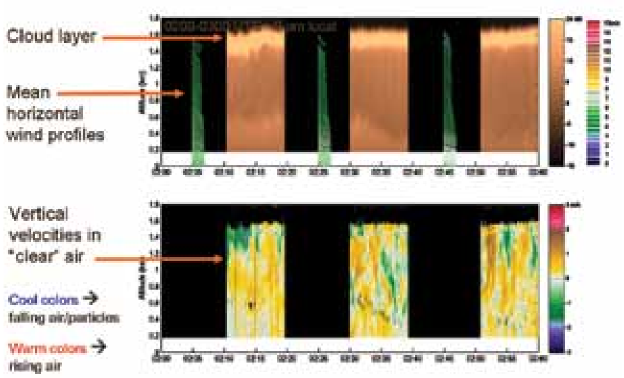
Milestone 1. Deploy a ship-based Doppler lidar to measure clear-air, sub-cloud updraft velocities, and horizontal winds over the ocean to study aerosol-cloud-precipitation dynamical interactions.

Satellite imagery of marine stratocumulus regions often reveals the existence of cellular structures that appear to be manifestations of self-organizing properties of the cloud field. These striking features present themselves as either bright cloudy cells ringed by darker edges (closed cells) or dark cellular regions ringed by bright cloudy edges (open cells). The starkly different reflectance patterns associated with these cellular structures are of great interest from the perspective of planetary albedo.

Observations and modeling studies have implicated aerosol particles, particularly those that act as cloud condensation nuclei, as one of the controls on the self-organizing properties of stratocumulus. Non-precipitating clouds that typically exist in regions of higher background aerosol loading prefer the closed cell state, while cleaner precipitating clouds favor the open cell structure.

To study these types of relationships between aerosols, dynamics, and precipitation, CIRES and NOAA researchers deployed a suite of instruments on the NOAA research vessel *Ronald H. Brown* as part of the Variability of the American Monsoon System (VAMOS) Ocean-Cloud-Atmosphere-Land Study regional Experiment (VOCALS-REx). VOCALS is an eight-week field experiment to study, in part, aerosol-cloud-precipitation-dynamical interactions in the marine atmospheric boundary layer (MABL) over the southeastern Pacific Ocean.

Immediately after development and testing of NOAA's High Resolution Doppler Lidar (HRDL) on board the NOAA Twin Otter (see CSD-01, Milestone 3), the instrument was repaired and re-integrated into its sea-going container in preparation for deployment as part of the VOCALS experiment. The instrument was installed in late September and early October 2008 on the O-2 deck of the *Ronald H. Brown*. Due to ship-related difficulties, the ship did not reach the South Pacific until 19 October 2008. Data acquisition took place 21 October-3 November, and 10-30 November 2008. The motion-stabilized scanner enabled observation of horizontal wind speed and direction profiles, vertical winds, vertical velocity variance or turbulence strength, and other two-dimensional wind and signal strength observations. Mean wind profiles were observed from just off the surface of the water up to cloud base or (when no clouds were present) up to the top of the aerosol layer (about 1.5-1.8 km during most of this study). The vertical winds, turbulence, and signal strength observations were available from 200 m up to the same maximum heights (cloud-base or aerosol layer). All of these profiles were available in near-real-time throughout the experiment and are posted at: http://www.esrl.noaa.gov/csd/lidar/vocals/.



Top panel: HRDL signal strength vs. time (x-axis) and altitude (y-axis) during zenith stares performed between 0200 and 0300 UTC on 21 November 2008. Interspersed between the signal strength profiles are the mean horizontal wind profiles, measured using a separate scanning pattern. Bottom panel: Vertical velocity measurements corresponding to the signal strength measurements above.

Of particular importance to this study are the measurements of horizontal and vertical winds beneath clouds. The system operated in a 20-minute periodic scan cycle, with the last 10 minutes of each period devoted to staring zenith for acquisition of vertical winds. An example of these winds is given in the figure.

Analysis of the HRDL VOCALS dataset is currently underway. Efforts include:

• Model validation to provide better understanding of the relationships between dynamics, cloud maintenance/thickness, and pockets of open cell cloud development

• Estimation of atmospheric boundary layer mixing heights throughout the ship-based experiment and analysis of their relationship to cloud height and liquid water path

• Characterization of boundary layer turbulence profiles and their relationship to atmospheric boundary layer decoupling

Results of the preliminary analysis will be presented at the second VOCALS data meeting in Seattle, WA, 12-14 July 2009.

Milestone 2. Analyze field data from the R/V *Knorr* during the International Chemistry Experiment in the Arctic Lower Troposphere (ICEALOT) experiment.

Aerosol extinction and scattering data were successfully obtained from the research vessel *Knorr* during the ICEALOT mission. These data will be combined with particles size distributions and chemistry measured by the NOAA Pacific Marine Environmental Laboratory, as well as other chemical and meteorological data obtained during the cruise. In addition, laboratory data on light extinction and scattering measurements from known aerosol distributions have been analyzed and combined with detailed calculations of instrument performance to provide new results on the accuracy with which single scattering albedos can be measured. Measurements of this critical climate parameter have been plagued by inadequate instrumentation, and these papers show a way forward.

Product: Cappa et al. 2008.

Massoli et al. (2009), Uncertainty in light scattering measurements by TSI nephelometer: Results from laboratory studies and implications for ambient measurements, *Aerosol Sci. Technol.*, submitted.

Milestone 3. Analyze field data from the NOAA WP-3D research aircraft during the Aerosol Radiation, and Cloud Processes affecting Arctic Climate (ARCPAC) experiment.

In April 2008, the NOAA WP-3D aircraft conducted research flights in northern Alaska and over the Arctic Circle as part of the ARCPAC field study. The study aimed to characterize the springtime background air and pollution transported to the region and to investigate effects of human activity on chemistry and climate of the Arctic. Chemical composition and optical properties of aerosol particles were measured aboard the aircraft using a compact time-of-flight aerosol mass spectrometer, a particle ablation laser mass spectrometer, a cavity ring-down spectrometer, and a particle soot absorption photometer.

Dense aerosol layers encountered above 400 m were dominated by organic aerosol (OA), with sulfate and nitrate present at different proportions depending on the origin of the air mass (figure next page, left). Flexpart back trajectories and gas- and particle-phase chemical tracers indicated that the sources of these concentrated aerosol layers were mostly biomass burning events in Siberia and Kazakhstan, with a small influence from urban/industrial regions in Europe and Asia. Aerosol optical property measurements revealed highly absorbing layers confirming strong combustion sources (e.g., biomass burning), while the relative humidity dependence of extinction measurements indicated significant processing of these absorbing layers. In regions where gas phase tracers indicated low biomass burning influence (i.e., acetonitrile < 125 pptv), aerosol mass was mostly inorganic. However, aerosol tracers suggest that the OA in these air masses was affected by mixing of biomass burning plumes into the background. Submicron aerosol mass at low altitudes over the Arctic sea ice was dominated by acidic sulfate. Some of these results on sources and characteristics of biomass burning plumes observed during ARCPAC have been published in *Geophysical Research Letters* (Warneke et al. 2009). Manuscripts summarizing results from a more detailed analysis of aerosol composition and optical properties are expected in 2009-2010.

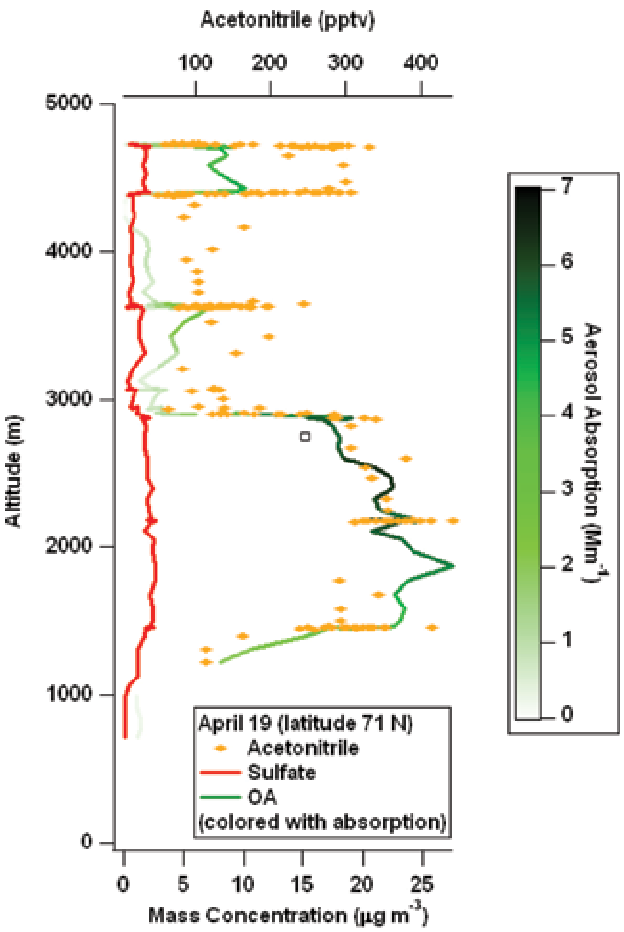


***Figure 1:** Highly absorbing aerosol layers rich in organics and showing a strong influence from biomass burning events (i.e., layers with enhanced acetonitrile, a gas-phase marker for biomass burning) were observed at altitudes up to 5 km over the Arctic Circle.*

Product: Warneke C et al. (2009), Biomass burning in Siberia and Kazakhstan as the main source for haze over the Alaskan Arctic in April 2008, *Geophy. Res. Lett.*, doi: 10.1029/2008GL036194.

Milestone 4. Use data acquired during the Gulf of Mexico Atmospheric Composition and Climate (GoMACCS) field study and models to publish findings that evaluate the radiative forcing of clouds in the Houston area and the influence of aerosols on this forcing.

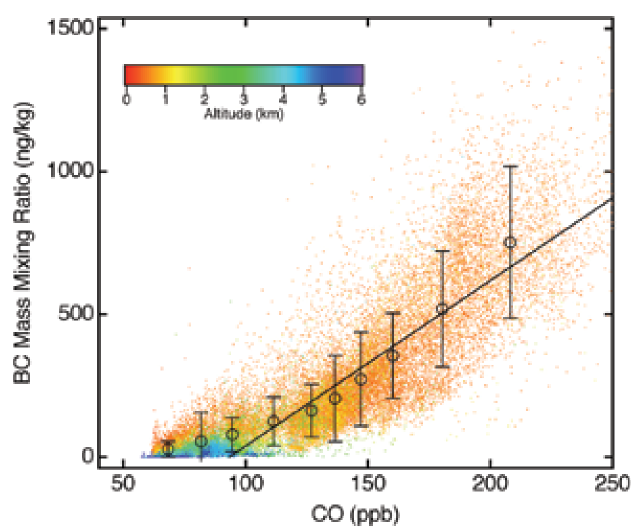
CIRES staff and colleagues have completed a study related to the radiative forcing of the aerosol-cloud system, based on observations and modeling associated with the GoMACCS field deployment of 2006.

In this study, observed radiation fields are being compared with radiation fields calculated based on the cloud fields generated by large eddy simulations. This is a very rigorous test of the ability of a model to simulate aerosol indirect effects (i.e., the effect of aerosol on cloud radiative forcing) because it requires that the model simulate both the macroscale cloud properties (cloud fraction, cloud depths, water content) and the microscale properties (cloud drop size distributions). Results show good agreement between model and observations, provided the aerosol residing between the clouds is also included in the calculations and that surface albedo is adequately accounted for. The former result was somewhat unexpected and points to the importance of cloud-enhanced scattering by aerosol residing between clouds. At 400 nm wavelength, the inclusion of aerosol increases forcing of the cloud-aerosol system by 8 percent, and absorption by 20 percent. Results have been reported in *Geophysical Research Letters* (Schmidt et al. 2009).

Product: Schmidt, KS et al. (2009), Irradiance in polluted cumulus fields: Measured and modeled cloud-aerosol effects, *Geophys. Res. Lett.*, doi: 10.1029/2008GL036848.

Milestone 5. Use data from the 2006 Texas Air Quality Study (TexAQS) to examine the relationship between black carbon (BC) aerosol and carbon monoxide (CO) in a highly polluted urban area.

Simultaneous measurements of BC and CO were acquired during more than 100 flight hours on the NOAA WP-3D research aircraft, largely in the Houston boundary layer, during the TexAQS. Observations of BC mass loadings in the lower and middle troposphere are important to constraining BC removal processes in global aerosol models, which are used to estimate the regional and global radiative forcing from BC aerosol. The BC/CO emission ratios for urban and industrial regions and biomass burning plumes are widely useful to the global climate and regional air quality modeling communities.



BC mass mixing ratio versus CO for all 16 flights. The data points are 10-s averages and color-coded by altitude. The line is the best fit for the boundary layer data (<1 km) for selected flights. Deciles are displayed as circles with vertical bars, representing one standard deviation.

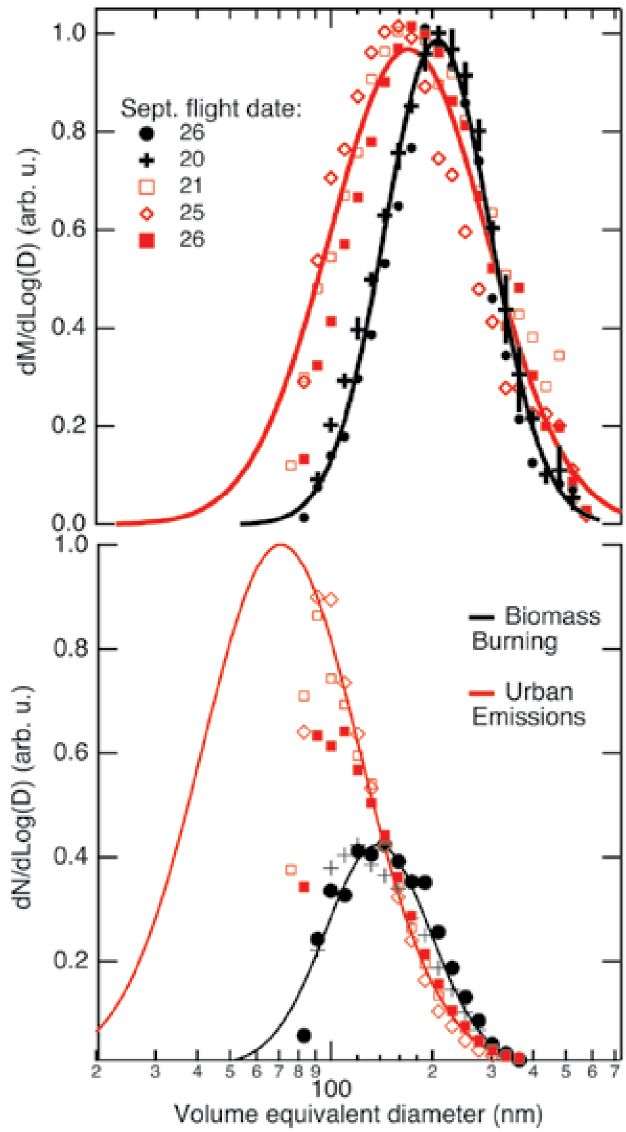
The Houston metropolitan area is characterized by large urban and industrial emissions. In vertical profiles, average BC mass decreased by more than two orders of magnitude from the polluted boundary layer to the clean middle troposphere (about 6 km). Simultaneous measurements of BC and CO in the boundary layer were positively correlated during the entire mission, and can be described by a compact linear relationship (figure previous page). The derived BC/CO slope (5.8 ng kg^{-1} ppb^{-1}) is representative of the urban and industrial regions of east Texas. The industrial emissions from the Houston ship channel region added variability to the BC/CO correlations. In a biomass-burning plume, BC varied linearly with CO with a higher slope than outside the plume (BC/CO emission ratio of 9 ng kg^{-1} ppb^{-1}). The BC/CO empirical relationships derived from the TexAQS data may be of value in estimating BC mass loadings from the more widely available measurements of CO in urban regions with a similar type and blend of mobile and industrial emissions. These results were published in *Geophysical Research Letters* (Spackman et al. 2008).

Product: Spackman, JR et al. (2008), Empirical correlations between BC aerosol and carbon monoxide in the lower and middle troposphere, *Geophys. Res. Lett.*, doi: 10.1029/2008GL035237.

Milestone 6. Use data from TexAQS to examine the mass, mixing state, and optical size of individual BC particles in fresh emissions from urban and biomass burning sources.

A single particle soot photometer, which flew on the NOAA WP-3D research aircraft during TexAQS, recorded the thermal and scattered light signals associated with individual BC particles heated to vaporization by an intense laser. Interpretation of these signals provided a measure of the size distribution of BC cores and the coatings associated with them. Mie theory was used to calculate the influence of the coatings on light absorption by the black carbon. This approach was applied to two very different sources: the Houston and Dallas urban areas, and some biomass burning sources around Houston. The quantitative results were surprisingly consistent: urban-generated BC tends to smaller sizes, fewer coated particles, thinner coatings, and less absorption per unit mass than biomass-burning BC (figure at right). This suggests that urban BC may have a longer lifetime in the atmosphere than biomass-burning BC, and possibly interacts with cloud and ice particles differently. Broadly speaking, our results provide direct measurements of the size distribution and coating state of fine-mode BC for use in constraining climate and aerosol models. The observed contrasts in BC's microphysical state from two different sources also highlights the need for the modeling community to use reasonable (not ad hoc) estimates of BC parameters in explorations of the evolution and climate impact of BC emissions.

Product: Schwarz, JP et al. (2008), Measurement of the mixing state, mass, and optical size of individual black carbon particles in urban and biomass burning emissions, *Geophys. Res. Lett.*, doi: 10.1029/2008GL033968.



Mass and number distributions of refractory BC cores vs. volume equivalent diameter observed in three fresh urban (red) and two fresh biomass burning (black) plumes. These data show the systematic difference in black carbon size distributions between urban and biomass-burning generated aerosol.

INTEGRATING ACTIVITIES

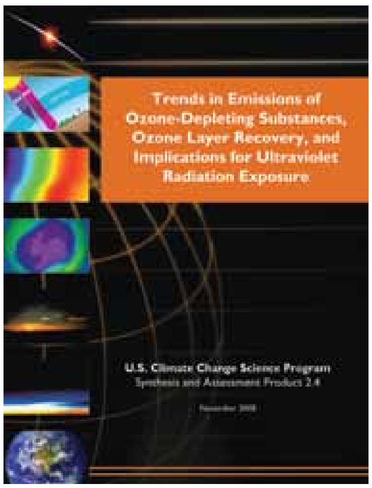
IA-01 Science and Society

- CSD-10 Scientific Assessments for Decision Makers
- Policy-01 Science Policy Lecture Series

CSD-10 Scientific Assessments for Decision Makers

Goal: Plan, lead, prepare, and disseminate assessments for the decision-making communities associated with ozone-layer depletion, greenhouse warming, and regional air quality.

Milestone 1. Contribute to the coordination and completion of the Synthesis and Assessment Product of the U.S. Climate Change Science Program (SAP 2.4, on chemistry related to the stratospheric ozone layer).



Synthesis and Assessment Product 2.4, Trends in Emissions of Ozone Depleting Substances, Ozone Layer Recovery, and Implications for Ultraviolet Radiation Exposure, was completed in 2008. This assessment product is one of 21 Synthesis and Assessment Products of the U.S. Climate Change Science Program. It provides a synthesis of the current knowledge of the stratospheric ozone layer, ozone-depleting substances, and ultraviolet radiation reaching the Earth's surface, with a particular emphasis on newly synthesized information regarding the role of the United States and the implications for the nation. This information is key to ensuring that international agreements to phase out production of ozone-depleting substances are having the expected outcome—recovery of the protective ozone layer. In addition, it provides information needed for U.S. decision makers in regards to any action by the Montreal Protocol parties and industry on the acceptability of substitutes.

Product: Ravishankara et al. 2008.

Policy-01 Science Policy Lecture Series

Goal: Provide useful information that will help improve the relationship between societal needs and science and technology policies.

Milestone 1. Continue the highly successful noontime seminar series held at the Center for Science and Technology Policy Research that brings in students, faculty, and researchers to discuss their science policy research and conduct additional outreach to departments that have not previously been involved to broaden the audience.

Prepare for publication, a book developed on the presidential science advisor lecture series. Plan a followup lecture series.

The noontime seminar series was continued, with talks on topics ranging from renewable energy policy to changes in the Arctic ice cover. A climate change discussion was organized to include people who participated in the March 2009 meeting in Copenhagen, and held in the CIRES building to encourage attendance by CIRES employees. A publishing contract was signed for a book based on the presidential science advisor lecture series, and publication is anticipated in 2010. With the CU-Boulder Energy Initiative, a lecture/panel discussion series during the fall was organized to address different aspects of the twin challenges of meeting rising global energy demand and reducing greenhouse gas emissions. The series was intended to foster discussion of these issues during the 2008 presidential campaign.

IA-02 Western Water Assessment

- WWA-01 Scientific Assessments
- WWA-02 Climate Products
- WWA-03 Climate and Water Affairs
- WWA-04 Management

WWA-01 Scientific Assessments

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

Milestone 1: Colorado meteorological station data long-term trends: In conjunction with the Colorado State Climatologist's office, evaluate all suitable stations in Colorado for long-term precipitation and temperature trends.

This project was completed in October 2008, and the information was an integral part of the WWA Report: *Climate Change in Colorado,* released at the Governor's Conference on Mitigating Risks of Drought and Climate Change. The Colorado Water Conservation Board, in support of Governor Ritter's Colorado Climate Action Plan, commissioned the report. The document is a synthesis intended to support water resources, management, and adaptation efforts throughout the state. WWA adapted an IPCC Working Group I approach to the process, including considerable stakeholder review and comment periods. As a consequence of our interactions with the water-management community about their decision processes and needs, there was significant participation by decision makers throughout Colorado.

The report was led by three WWA researchers, and more than 50 individuals contributed. The six chapters synthesize observation and projection data from diverse sources and connect climate science with the concerns of the water management and drought mitigation communities.

The *Climate Change in Colorado* report exemplifies the public service roles of NOAA and WWA, by making science, some of it funded by NOAA, available to the water-management community. It was also an opportunity to showcase WWA-sponsored research, including ongoing initiatives to identify good-quality observational datasets and interpret information in the context of the experimental climate divisions.

The report received significant attention in the media and was a finalist for the Governor's Research Impact Award. The document provided a springboard for several climate initiatives within the state (e.g., La Plata County Climate Action Plan), and WWA has been busy addressing the demand for public outreach about climate in Colorado. The authors have given more than 30 public presentations about the report, and have presented scientific findings at several major convenings. Currently, at least two manuscripts are being drafted about the process used by WWA to develop the document.

As a follow-up, WWA is now developing a Colorado Climate Roadshow. In collaboration with the Southern Climate Impacts Planning Program, WWA is busy adapting the NOAA-funded Climate 101 training workshop, first tested in Oklahoma, to Colorado. The intention is to add a Colorado-specific module to the training that is based on the Climate Change in Colorado report, test the workshop in a few locations, and then bring the information to stakeholders across the state.

Product: Ray, AJ et al. (2008), *Climate Change in Colorado: A Synthesis to Support Water Resources Management and Adaptation.*

Milestone 2: Colorado River climate change analysis: Utilize the U.S. Bureau of Reclamation's Colorado River Seasonal Forecasting (CRSS) model to investigate the vulnerability of the Upper Colorado River Basin to changes in inflows based on stochastically-generated streamflows that preserve spectral characteristics identified in historic and paleo records. The CRSS operations model will be used to analyze how current operating policies perform under differing streamflow regimes. In addition, the operations model will be run in optimization mode to identify how different operating policies would perform under modified streamflows.

The adaptive nature of the WWA interactions with stakeholders often results in evolving project objectives. In this case, this milestone evolved into greater emphasis on the work highlighted in Milestone 3, an assessment of the effect of climate on levels in Lake Mead.

Milestone 3: Colorado River seasonal forecasting: Investigate and identify historical relationships between seasonal streamflows in the basin and large scale climate variables such as PDO, ENSO, and AMO to develop a set of predictors for the Upper Colorado River Basin streamflow. Predictors will be used to project upcoming year streamflows and the streamflows will be used in an operations model for the next 24 months. The operations model will be run in two modes: one using current reservoir rules and one using modified rules to identify beneficial policy changes.

In a detailed assessment of the effect of climate on levels in Lake Mead, WWA scientists and colleagues found the following: Under current practices and in the absence of climate change, there is a relatively low risk of reservoir depletion—5 percent through 2026 increasing to 9 percent by 2057—demonstrating some level of resilience to demand growth and natural climate variability. A 20 percent reduction in Colorado River average flow due to climate change by 2057 increases risk through 2026 to about 12 percent, and greatly increases risk to 52 percent in 2057. However, management can greatly reduce risk. Under aggressive management, the risk reduces to 32 percent. A lower rate of climate change-induced flow reduction, demand adaptation, and aggressive management can further reduce the risk to around 10 percent, suggesting substantial flexibility in existing management could mitigate the increased risk.

Product: Rajagopalan, B et al. (2009), Water Supply Risk on the Colorado River: Can Management Mitigate?, *Water Resources Research*.

Barsugli, J et al. (2009), Comment on "When Will Lake Mead Go Dry?,' *Water Resources Research*, in review.

Milestone 4: Colorado snowcourse analysis: In conjunction with the local U.S. Department of Agriculture's Natural Resources Conservation Service (NRCS) office, the full data record of snowcourses, dating back to 1936, and SNOTEL, dating back to 1978, will be surveyed in order to develop basin-wide normals based on the longest and most reliable records. The existing 'normals' utilize all records, despite known problems with certain sites that can lead to erroneous analysis of runoff by water managers.

Due to staff availability, progress was not made on this milestone.

Milestone 5: Dust on snow studies: Investigate variability and impacts of dust storms on Southwest Colorado snowpack. Preliminary analyses indicates that runoff can occur up to one month earlier with significant impacts on water management.

In February 2008, WWA scientists co-organized a meeting with water managers and stakeholders in Montrose, CO. This meeting was followed by a meeting with the Colorado Basin River Forecast Center. In spring 2008, scientists performed multiple sampling missions across the state of Colorado to establish a framework for distributed monitoring of dust deposition and presence in the snowpack, now known as the Colorado Dust on Snow program (CODOS). These missions involved collection of samples for analysis of optical properties and provenance. Regular sampling of dust concentrations, bulk samples, and dust loadings during depositional events continue, in collaboration with the Center for Snow and Avalanche Studies (CSAS) in the Senator Beck Basin, San Juan Mountains. Alpine and subalpine energy balance towers were maintained and data were collected and quality checked and assured. This research was presented at diverse meetings, from the American Geophysical Union to the Ecological Society of America. Outreach has been extensive, from international media high school classrooms in southwest Colorado.

Toward the end of the year, a modeling effort was initiated to determine the impact of dust deposition on water yield in the Colorado River Basin. This effort with the Variable Infiltration Capacity model has provided compelling evidence that dust has affected flows, and a paper is in preparation. In addition, a biweekly dust advisory has been circulated to participating districts and stakeholders that assesses and summarizes our observations of dust loading, stratigraphy in the snowpack, and implications for melt acceleration.

Milestone 6: Lead authors on the U.S. Climate Change Science Program (CCSP) Unified Synthesis Product: Provide

input into water chapter of new CCSP "National Assessment" through lead authorship.

The unified synthesis product was released in 2009, with a WWA lead author.

Product: Unified Synthesis Product Team (2008), *Global Climate Change Impacts in the United States*, isbn: 978-0-521-14407-0.

WWA-02 Climate Products

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

Milestone 1. Monthly Intermountain West Climate Summary (IWCS): Climate information is widely scattered on the web and other locations. Water managers and other climate-sensitive sectors have requested a single-monthly summary of climate information including precipitation, temperature, snow water equivalent, long-lead temperature and precipitation outlooks, reservoir levels, and streamflow forecasts.

The IWCS continues to be WWA's most prominent outreach and education product. WWA distributes the IWCS to more than 400 decision makers, scientists, and climate information providers; and based on WWA tracking, the January 2009 IWCS page was viewed by about 800 individuals. The IWCS provides the latest climate information in a simple compact document aimed at managers, planners, and policy makers with water-related interests. By improving awareness and understanding about forecasts and climate phenomena, the climate summary helps WWA facilitate a dialog among potential users, researchers, and operational providers of climate information, with the goal of providing enhanced climate services.

Since January 2005, the IWCS has been released eight times each year, but in 2009, the distribution mechanism and process will change. The changes are in response to a 2008 survey, which evaluated whether the IWCS was providing stakeholders with the most relevant and useful information, and whether WWA was fulfilling the educational goal of enhancing climate literacy through the IWCS. Results confirmed that the IWCS is helping WWA achieve its goals of increasing climate awareness and literacy, facilitating a dialog between climate scientists and stakeholders, and providing enhanced climate services. WWA's stakeholders reported that IWCS is valuable, by interpreting and translating climate information and forecasts. The technical level of writing in IWCS is on target, and readers value the annotation of the maps and graphics. Most readers use the information in the IWCS to increase their knowledge of climate and hydrologic conditions, and to present this information to their colleagues and governing boards.

From the survey results, WWA was able to make significant improvements to the IWCS, which decreased production time without compromising the quality or utility of the product. The new production schedule will include a full IWCS disseminated five times each year, with two additional mini-summaries during critical water management decision times (spring and summer). Also, the IWCS has been transformed to a web format, reducing production time.

The results of the user survey, continued hits on the IWCS web site, and the ever-increasing number of people asking to be added to the distribution list all confirm that the IWCS is valued by WWA's stakeholders and is a WWA success story. Stakeholders want the IWCS to continue, and WWA hopes that it can, with some help from operational counterparts. Because of IWCS's operational component—presenting current conditions and forecasts for regional decision makers—WWA plans to apply for a NOAA grant (Transition of Research Applications to Climate Services) to help transfer the operational component of the IWCS to the Western Regional Climate Center.

If transitioned, WWA would continue to develop and write Feature Articles (which summarize current climate and water-related research) and Focus Pages (which describes a climate service) in a WWA newsletter that would also highlight WWA research and products. WWA has collaborated, and will continue to collaborate, with other climate information providers and university researchers to write these articles. Such collaboration is of great benefit to both WWA and relevant organizations. WWA is able to present the most recent climate research and services to stakeholders, and the scientists and climate information providers receive a summary of their research or climate service that can serve as a simple explanatory document for use on their web site. These documents are produced as pdfs that can easily be transferred to NOAA and other climate service providers as guidance for users.

Product: wwa.colorado.edu/IWCS/index.html

Milestone 2. Web-based seasonal guidance for water managers, Climate Prediction Center (CPC): Improve ability of federal, state, and local water managers to plan water operations during drought. Provide input to CPC seasonal outlooks.

Depending on drought conditions, WWA supports a CIRES scientist who generates monthly-to-seasonal briefings to the Colorado Water Availability Task Force and other stakeholders, experimental climate outlooks, and other climate forecast products. These briefings are based on a monthly updated web page (http://www.cdc.noaa.gov/people/klaus.wolter/SWcasts/) that covers the recent and projected evolution of El Niño-Southern Oscillation (ENSO), discusses the most recent CPC climate forecasts, and examines in detail experimental forecast guidance for the full interior southwestern United States, with special emphasis on Colorado. On the national scale, these climate forecasts are used by wildfire managers in the western United States (the 10th annual fire assessment workshop took place at NOAA ESRL in April 2009), and by CPC, both for seasonal climate forecasts and for the U.S. Drought Monitor Outlook. The WWA-supported scientist also contributes to CPC's monthly ENSO Diagnostic Discussion (http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/enso_advisory/) by briefing all interested parties on the monthly updated Multivariate ENSO Index ahead of CPC's release date.

Product: www.cdc.noaa.gov/people/klaus.wolter/SWcasts/

Milestone 3. National Integrated Drought Information System (NIDIS): As necessary, the Western Water Assessment (WWA) will provide support activities for NIDIS implementation efforts. This may include providing support for conferences, performing research, and providing input to NIDIS pilot projects, including the anticipated Colorado River pilot.

WWA has collaborated with NIDIS on several activities throughout the year, including the Upper Colorado River Basin pilot project. This collaboration is moving forward, with other projects in development.

Milestone 4: Lead authors on *Citizen's Guide to Climate Change*. Provide overall guidance and author several chapters for a citizen's guide currently being developed by a local foundation.

The Citizen's Guide was completed in late 2008, with several chapters written by WWA researchers. It is available online (www.noaa.gov/climateliteracy.html) and in print.

Milestone 5. WWA web site: Provide a portal into all Western Water activities for researchers, water providers and the public. The web site provides extensive documentation on Colorado River climate, various forecasts, and results of past research.

WWA worked closely with a consultant to redesign the web site, and to address html programming needs. New web content and presentation are centered around topic headings that appeal to a wide range of user groups with corresponding knowledge bases. Topic headings include: Colorado River, Front Range, Western Hydrology, Water Management and Drought, Climate Variability and Change, and Forecasts and Outlooks. The new web site went live in August 2008.

Product: wwa.colorado.edu.

WWA-03 Climate and Water Affairs

Goal: Increase decision makers' knowledge about climate science so they can become better consumers and demanders of climate products and assessments, which will assist WWA in setting its research agenda.

Milestone 1. Dendrohydrological workshops: Increasing interest by water managers in tree-ring reconstructions of streamflow has led to a demand for a hands-on workshop on how the reconstructions are generated and assessed. The goal is to provide water managers with the necessary tools to better interpret the reconstructions and apply them to water planning.

WWA led four technical workshops in 2008, in Salt Lake City, UT; Albuquerque, NM., Durango, CO, and Boulder City, NV. WWA staff and colleagues provided more than 100 water managers and stakeholders with information about how tree-ring data are gathered and reconstructions of streamflow are generated, the characteristics of these data, and how water entities are successfully incorporating the data into modeling and planning. In lieu of a separate workshop in California, a WWA-affiliated researcher presented at the Southern California Workshop on Water Conditions and Drought Preparedness in October 2008.

New web pages in the TreeFlow web resource were created for all four workshops held in 2008, with summary reports and access to the presentations and new data and products.

Based on feedback from the Durango, CO workshop, WWA staff also developed a two-page, trifold brochure on tree-ring reconstructions for Animas River stakeholders, in cooperation with the Mountain Studies Institute (http://www.mountainstudies.org/Education/pdfs/Animas_treering_brochure_RevC.pdf).

A WWA-affiliated researcher presented at the 2008 American Geophysical Union annual meeting about the workshops and the iterative evaluation process used to improve them.

JEFF LUKAS/CIRES

Jonathan Overpeck (University of Arizona) extracts a tree-ring sample from an ancient bristlecone pine in the South San Juan Mountains, in south-central Colorado, during collaborative USGS/NOAA/CIRES/WWA research in July 2008. Data from this site will be used, in part, to reconstruct past climate and streamflow for the WWA-funded TreeFlow project.

Milestone 2. Water Availability Task Force (WATF): Provide technical support for the Governor's drought task force, as needed, including issuing experimental regional seasonal forecasts.

WWA continues its ongoing relationship with the State of Colorado and the WATF. This year, the WATF has engaged WWA researchers in discussions focused on identifying the lessons learned from the drought in the 2000s, and in how the Surface Water Supply Index may be improved in the state.

Milestone 3. Speakers for interested organizations and public events: WWA is often invited to speak on the interaction of climate and water at public events and to various organizations, and will continue to perform this service.

WWA continued its long-standing reputation with stakeholders and decision makers as a trusted source of climate information. Collectively, WWA researchers gave more than 60 public talks and seminars, were cited or quoted by the media over 75 times, and served as members of many committees and organizations. A sampling of talks from 2008 follows:

June: The long view of the Rio: What tree rings tell us about the past variability of the Rio Grande River, and what it means for the future, New Mexico chapter meeting, American Water Resources Association, Albuquerque, NM.

June: Western water and climate change: What the science tells us, Gates Family Foundation, A Bar A Ranch, WY.

June: A tree-ring reconstruction of Animas River streamflow and its use in water management, Fort Lewis College, Durango, CO.

June: Climate change on the Colorado River: The state of the science, Continuing Legal Education, Reno, NV.

BUREAU OF LAND MANAGEMENT

Water Water Assessment consultants are helping to build and calibrate hydrology models for the Arkansas River Basin, among others.

June 2008: Managing Water in the West, Western Governors' Association Annual Meeting, Park City, UT.

July: Climate change and the Colorado River: Is time running out?, Continuing Legal Education Colorado River Superconference, Denver, CO.

July: Climate Predictions for 2018, CLIVAR Science Symposium, Irvine, CA.

July: Allocating water among competing uses: The potential for water markets in New Zealand, Institute for the Study of Competition and Regulation, Wellington, New Zealand.

August: Water, the West,and climate change in the 21st Century, Center for the American West, French Embassy and Consulates Briefing, Boulder, CO.

September: Water-cycle changes as the primary delivery mechanism for climate change impacts, Third Interagency Conference on Research in Watersheds, Estes Park, CO.

September: Urban water-management plans and reconstructed hydrology, Western States Water Council/Western Governors' Association, Climate Change Adaptation Policy Workshop, Irvine, CA.

September: Placing recent droughts in a long-term context with tree-ring reconstructions of precipitation, Southern California Workshop on Water Conditions and Drought Preparedness, Ontario, CA.

October: Climate and Colorado: Implications for wildlife, Colorado Conservation Summit, Keystone, CO.

October: Paleohydrology: From tree rings and applications to water-resource management, Climate Change Institute and Environmental and Water Resources Engineering seminar, University of Maine, Orono, ME.

October: Climate and Colorado, La Plata County League of Women Voters and Fort Lewis College, Durango, CO.

November: Climate change on the Colorado River: A quick review, Reconciling Colorado River Flows, Las Vegas, NV.

November: Effects of interannual variability and climate change on the Colorado River: A perspective, Colorado River Basin Science and Resource Management Symposium, Scottsdale, AZ.

November: Water-energy-climate: Exploring the connections for the Western United States, University of Colorado Energy Initiative, Boulder, CO.

December: Climate Change and Water, U.S. Environmental Protection Agency Sustainable Infrastructure Forum, Denver, CO.

December: Colorado River streamflow from tree rings: Lessons from the past, applications to the future?, Adjusting to less water: Climate change and the Colorado River, Glen Canyon Institute, Salt Lake City, UT.

Milestone 4. Provide technical analysis and education for Front Range water providers: A consortium of Front Range Water providers has been awarded an AWWA Research Foundation grant to investigate the changes in runoff that may occur in response to climate change. WWA will provide technical support and educational services for this effort.

In the past year, the participants in this project spent time learning about climate change projections, downscaling methods, and hydrology models, and chose consultants with whom to work on the future modeling component. WWA contributed the education component, and continues to fill that role. WWA researchers have attended all of the meetings, and contributed presentations and scientific guidance when requested. WWA experts helped stakeholders choose climate scenarios and downscaling methods for the project. Currently the consultants are building and calibrating hydrology models of the Upper Colorado, South Platte, and Arkansas River basins.

WWA-04 Management

Goal: Provide overall guidance to project as well as day-to-day management.

Milestone 1. General management activities: Hold biweekly team meetings. Prepare annual budget. Interact with Regional Integrated Sciences and Assessments (RISA) Program managers. Interact with CIRES and NOAA administrative staff. Establish strategic activities.

Beginning in 2009, WWA refocused its research and decision support products; all WWA projects now fall within three major thematic categories: 1) Decision Support for the Colorado River Basin and Headwaters; 2) Climate Adaptation and the Adaptation-Mitigation Nexus; and 3) Ecological Vulnerabilities, Impacts, and Adaptation. This involves an expansion of our stakeholder base beyond the water-resource community. Consistent with this effort, WWA broadened its mission statement: The mission of the WWA is to identify and characterize regional vulnerabilities to and impacts of climate variability and change, and to develop information, products, and processes to assist decision makers throughout the Intermountain West.

To facilitate this expansion into a broader cross-section of stakeholders, a new management structure has been adopted. The central WWA office is now comprised of a Director, Deputy Director, and two research assistants who start 1 July 2009. In addition to managing the day-to-day activities of WWA, the Director, Deputy, and the senior research assistant are responsible for leading and coordinating projects and outreach within the three research themes outlined above. This team works to ensure that projects continue to cross-cut sectors and disciplines, and that information about the impact of climate on water resources is communicated to other sectors.

IA-03 Resource Development for Educators and Decision Makers

- Policy-02 Outreach to Decision Makers through the Internet
- Policy-03 Outreach to Decision Makers through Newsletters

Policy-02 Outreach to Decision Makers through the Internet

Goal: Provide useful information that will help improve the relationship between societal needs and science and technology policies.

Milestone 1: Continue to maintain and upgrade the Center for Science and Technology Policy's web site and increase its usefulness to users. Increase its reliability and stability through hardware and software upgrades as necessary.

Our popular and highly regarded science policy blog, Prometheus, was completely revamped in August 2008, to improve reliability, stability, and appearance.

Policy-03 Outreach to Decision Makers through Newsletters

Goal: Provide useful information that will help improve the relationship between societal needs and science and technology policies.

Milestone 1: Add new section to newsletter, 'Ask a Science Policy Expert.' Continue to seek ways to expand readership.

The newsletter featured an exchange between climate experts Tom Chase, Kevin Trenberth, Mike Hulme, and Roger Pielke, Jr. about the usefulness of climate models. A revised newsletter format, more appropriate for a wider audience, is now under discussion and planning.

Measures of Achievement

CIRES scientists and faculty published 594 peer-reviewed papers in 2008, commanding attention from the scientific community and the news media. International awards and a strong record of service reflect institutional excellence.

KONRAD STEFFEN

A fishing boat is pulled over sea ice to open water near Qaanaaq in northwestern Greenland.

Publications by the Numbers

CIRES scientists and faculty published 594 peer-reviewed papers during calendar year 2008. The table below tabulates publications by affiliation of first author. CIRES scientists and faculty published an additional 185 non-refereed publications in 2008. These publication counts are only one measure of CIRES' impact. Additional information on how CIRES research is pushing the boundaries of scientific knowledge is summarized in the Executive Summary, and detailed throughout this report.

Refereed Publications

	2002	2003	2004	2005	2006	2007*	2008
CIRES Lead Author	112	177	165	188	141	130	110
NOAA Lead Author	60	31	56	20	81	73	99
Other Lead Author	110	183	134	145	289	264	385
Total	**282**	**391**	**355**	**353**	**511**	**467**	**594**

*The 2007 publication numbers are slightly revised from last year. Due to a database error, the 2007 refereed publications did not include several peer-reviewed review articles.

Refereed Publications, 2008

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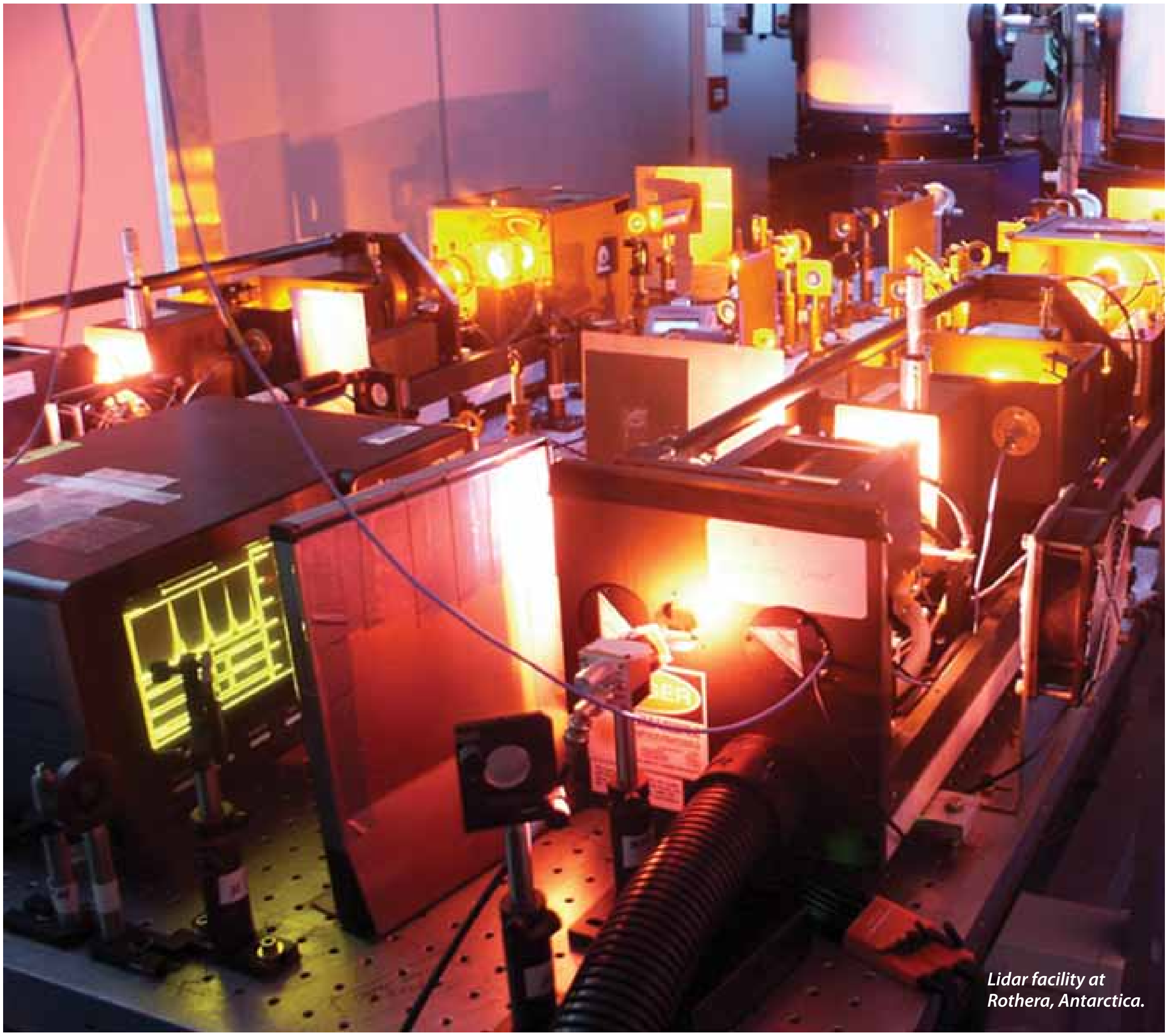
Journal of Geophysical Research-Solid Earth
Journal of Geophysical Research-Space Physics
Journal of Glaciology
Journal of Hydrometeorology
Journal of International Geophysics
Journal of Photochemistry and Photobiology A: Chemistry
Journal of Physical Chemistry A
Journal of Physical Chemistry B
Journal of Physical Oceanography
Journal of Physics B: Atomic, Molecular, and Optical Physics
Journal of the Acoustical Society of America
Journal of the American Water Resources Association
Journal of the Meteorological Society of Japan
Lake and Reservoir Management
Lithos
Mathematical Geosciences
Measurement Science and Technology
Monthly Weather Review
National Weather Digest
Natural Hazards and Earth System Sciences
Natural Hazards Review
Natural History
Natural Resources Research
Nature
Nature Geosciences



Lidar facility at Rothera, Antarctica.

Nonlinear Processes in Geophysics
Ocean Modeling
Ocean Science
Optical Engineering
Optics Express
Paleoceanography
Pharmaceutical Research
Philosophical Transactions of the Royal Society A: Mathematical, Physical, and Engineering Sciences
Physical Chemistry Chemical Physics
Physical Geography
Physics Today
Polar Geography
Polar Science
Proceedings of the National Academy of Sciences
Professional Geographer
Progress in Geomathematics
Progress in Physical Geography
Pure and Applied Geophysics
Quarterly Journal of the Royal Meteorological Society
Radio Science
Remote Sensing of Environment
Review of Scientific Instruments
Russian Meteorology and Hydrology
Science
Science in China Series D: Earth Sciences
Science in China Series E: Technological Sciences
Scientia Silvae Sinica
SEG Expanded Abstracts
Seismological Research Letters
Sensing Our Planet
Sensors
Soil Biology and Biochemistry
Southwest Hydrology
Space Science Review
Space Weather
Surveys in Geophysics
Tectonics
Tellus
Tellus Series B: Chemistry, Physics, and Meteorology
Theoretical and Applied Climatology
Verhandlungen Internationale Vereinigung für Limnologie
Water Resources Research
Weather Forecasting

Honors and Awards, 2008

Barry, Roger
Honored by the National Snow and Ice Data Center, which named a library the Roger G. Barry Resource Office for Cryospheric Studies (ROCS); Recognized in the Colorado Senate Joint Resolution 08-035, for participation in the Intergovernmental Panel on Climate Change (IPCC); Humboldt Research Fellowship in Geophysics, Bavarian Academy of Sciences, Commission on Glaciology

Bates, Gary
Norbert Gerbier-MUMM International Award, World Meteorological Organization

Chu, Xinzhao
Director, Consortium Technology Center for the Consortium of Resonance and Rayleigh Lidars, NSF

Diaz, Henry
Fellow of the American Meteorological Society

Dutton, Geoffrey
NASA Group Achievement Award for Tropical Composition, Cloud, and Climate Coupling (TC4) campaign

Ennis, Christine
CIRES Outstanding Performance Award for Service; CIRES Bronze Medal

Ervens, Barbara
Paper selected as an American Geophysical Union Editor's Highlight

Froyd, Karl
NASA Group Achievement Award for Tropical Composition, Cloud, and Climate Coupling (TC4) campaign

Ghosh, Tilottama
Outstanding Woman Scientist Award, Association for Women Geoscientists, Laramide Chapter

Godin, Oleg
CIRES Outstanding Performance Award for Science and Engineering

Gupta, Vijay
Robert E. Horton medal, American Geophysical Union; Nominated for the Stockholm Water Prize, known as the "Nobel Prize for water"

Heller, Molly
ESRL Global Monitoring Division Director's Award

Hirsch, Adam
NOAA/OAR Outstanding Scientific Paper co-author

Hodges, Gary
CIRES Outstanding Performance Award for Science and Engineering; Letter of Commendation, U.S. Department of Energy

Hofmann, David
U.S. Department of Commerce Silver Medal

Hurst, Dale
NASA Group Achievement Award for Tropical Composition, Cloud, and Climate Coupling (TC4) campaign

Jacobson, Andrew
NOAA/OAR Outstanding Scientific Paper co-author

Jing, Xiangbao
ESRL Global Systems Division Team Member of the Month

Jimenez, Jose-Luis
Kenneth T. Whitby Award, American Association for Aerosol Research

Jones, Craig
Exceptional Reviewer for GSA Today, Geological Society of America

Klein, Roberta
Buff Energy Star Award, University of Colorado

Lack, Daniel
Paper selected as an American Geophysical Union editor's highlight; Recognition by Rear Admiral Jonathon Bailey, NOAA Office of Marine and Aviation Operations

Loughe, Andrew
Global Systems Division Team Member of the Month

Maus, Heinrich
NOAA Team Member of the Month, June

McCaffrey, Mark
CIRES Outstanding Performance Award for Service

McComiskey, Allison
CIRES Outstanding Performance Award for Science and Engineering

Miller, John
ESRL Global Monitoring Division Director's Award; NOAA/OAR Outstanding Scientific Paper co-author

Moore, Fred
NASA Group Achievement Award for Tropical Composition, Cloud, and Climate Coupling (TC4) campaign

Nerem, Steven
Fellow of the American Geophysical Union

Peters, Wouter
ESRL Global Monitoring Division Director's Award; NOAA/OAR Outstanding Scientific Paper co-author

Petron, Gabrielle
NOAA/OAR Outstanding Scientific Paper co-author

Petropavlovskikh, Irina
NASA Group Achievement Award for Tropical Composition, Cloud, and Climate Coupling (TC4) campaign

Pettegrew, Brian
Aviation Meteorology Award, National Weather Association

Pielke Jr., Roger
Bruno Kreisky Forum for International Dialogue Lectureship, Vienna, Austria

Rajagopalan, Balaji
Norbert Gerbier-MUMM International Award World Meteorological Organization

Schwarz, Joshua
NASA Group Achievement Award for Tropical Composition, Cloud, and Climate Coupling (TC4) campaign

Senff, Christoph
Certificate of recognition for outstanding performance, International Coordination-Group on Laser Atmospheric Studies

Sievers, Robert
Governor's Award for Research Impact; Astellas Foundation Prize, American Chemical Society

Spackman, J. Ryan
NASA Group Achievement Award for Tropical Composition, Cloud, and Climate Coupling (TC4) campaign

Sun, Dezheng
Tengfei Guest Professor (an honorary appointment), Xian Jiaotung University, Xi'an, China

Sweeney, Colm
NOAA/OAR Outstanding Scientific Paper co-author

Tierney, Craig
ESRL Global Systems Division Director's Certificate of Appreciation

Tolbert, Margaret
2009 National Award for Creative Advances in Environmental Science, American Chemical Society; Frontiers in Science Lecturer, University of Iowa

Tuttle, Benjamin
NASA Earth and Space Science Fellowship

Udall, Bradley
Partners in Conservation Award, U.S. Department of the Interior

Wang, Hailong
Best Research Poster, Department of Commerce Boulder Laboratories Postdoctoral Poster Symposium

Warneke, Carsten
Paper selected as a *Geophysical Research Letters* editor's highlight; paper selected as a *Nature Geoscience* research highlight

Washenfelder, Rebecca
Best Presentation in the Department of Commerce Boulder Laboratories Postdoctoral Poster Symposium, in the NOAA and CIRES Chemical Sciences category

Watts, Laurel
NASA Group Achievement Award for Tropical Composition, Cloud, and Climate Coupling (TC4) campaign

Zhang, Tingjun
Elected a CIRES Fellow; Reviewers Award from Elsevier, Cold Regions Science & Technology

Selected Service and Outreach by CIRES Employees

Science Advisory Boards and Editorial Service

24th International Laser Radar Conference
Acoustical Society of America, Technical Committee on Acoustical Oceanography
Advances in Atmospheric Sciences
AGU Geodesy Section Executive Committee
AGU Geodesy Section Fellows Selection Committee
American Meteorological Society Scientific and Technological Activities Commission (STAC)
American Society of Civil Engineers
AMS Air-Sea Interaction Conference Committee
AMS Applied Climatology Conference Committee
AMS Atmospheric Chemistry
AMS Board on Women and Minorities
AMS Coastal Environment Committee
AMS committee on Boundary Layers and Turbulence
AMS Haurwitz Memorial Lecture Selection Committee
AMS Joint Conference on Middle Atmosphere and Atmospheric and Oceanic Fluid Dynamics
AMS/EPA Regulatory Model Improvement Committee
Annals of Glaciology
Antarctic Science
Arctic CHAMP Scientific Steering Committee
Arctic Council, Cryosphere Project
Arctic Council, Snow, Water, Ice, and Permafrost in the Arctic Assessment
Arctic Research Commission
Arctic System Model Implement Plan
ASCE Journal of Hydrologic Engineering
Asian CliC Beijing Data Working Group
Atmosphere
Atmospheric Chemistry and Physics
Atmospheric Environment
Atmospheric Research
Bioorganic Chemistry
Boulder Creek Critical Zone Observatory
Centre National de la Recherche Scientifique France
Chinese Academy of Sciences
Climate Change Science Program (CCSP) Synthesis and Assessment Products
Climate Research
CLIVAR Decadal Prediction Working Group
Colorado Department of Public Health and Environment
Community Climate System Model Polar Climate Working Group
Community Surface Dynamics Modeling System
Continental Deformation Thematic Working Group
CReSIS advising board chair, NSF
Cryosphere
Current Opinion in Microbiology
Darwin
EGU
Encyclopedia of Inland Waters
Environmental Hazards
Environmental Science and Policy
French National Research Agency (ANR)
Geophysical Research Letters
Geoscience and Remote Sensing Society Technical Committee
GeoSphere
GEOSS
GEWEX Cloud System Study
Global Environmental Change
Goldschmidt Award Committee for the Geochemical Society
High Precision Isotope Ratio Mass Spectrometry Consortium
IEEE Committee on Earth Observations
International Association for Mathematical Geosciences
International Glaciological Society, council
International Laser Radar Conference
International Permafrost Association
International Union of Geodesy and Geophysics, Commission on Cryospheric Sciences
International Union of Radio Science
Irish Research Council for Science, Engineering and Technology (Ireland)
Journal of Earth System Science
Journal of Earthquake Engineering
Journal of Geophysical Research
Journal of Geophysical Research-Earth Surface
Journal of Geophysical Research-Solid Earth
Journal of the Acoustical Society of America
Mountain Research and Development
NASA Earth Science Subcommittee
NASA ICESat-II Science Definition Team
NASA ECHO
National Academies of Science, America's Climate Choices
National Academies of Science, Polar Research Board
National Center for Ecological Analysis and Synthesis
National Centers for Environmental Prediction
National Research Council
National Science Foundation
National Sciences Research Council of Canada
National Solar Observatory User Committee
Natural Environment Research Council (UK)
Natural Hazards Review
Ninth International Conference on Permafrost
NOAA Earth System Research Laboratory Teaching and Instructional Endeavors
NOAA Professional Women's Group
Nonlinear Geophysics Group, AGU
North American Carbon Program
NSIDC User Working Group
Oak Ridge National Laboratory
Ocean Sciences Education Committee (OSEC)
Paleoclimate Modelling Intercomparison Project

Permafrost Young Researchers Network
Platte River Recovery Implementation Program
Polar Geography
Policy Sciences
Potomac Institute
Rocky Mountain Hydrologic Research Center
Significant Opportunities in Atmospheric Research and Sciences
Smithsonian
Task Force on Hemispheric Transport of Air Pollutants Geneva
U.S. Department of Agriculture
U.S. Permafrost Association
University of Denver Library School
U.S. Carbon Cycle Science Program
Water Resources Research
World Climate Research Programme-Climate and Cryosphere Project, WMO
World Data Center for Glaciology
Zeitschrift fuer Gletscherkunde und Glazialgeologie

Paper and Proposal Review

Aerosol Particles
Aerosol Science and Technology
African Journal of Agricultural Research
Agriculture and Forest Meteorology
AMS Journal of Climate
AMS Journal of the Atmospheric Sciences
Annales Geophysicae
Annals of Glaciology
Antarctic Science
Applied Optics
ASCE Journal of Hydraulic Engineering
Atmospheric Chemistry and Physics
Atmospheric Environment
Atmospheric Physics and Chemistry
Austrian Science Fund
BioScience
Boundary-Layer Meteorology
Bulletin of the American Meteorological Society
Chemical Physics
Chemical Physics Letters
Chemical Reviews
Climate Dynamics
Climate Research
Cold Regions Science and Technology
Computer and Geoscience
Cryosphere
Department of Energy Pacific Northwest National Laboratory
Department of Energy Atmospheric Radiation Measurement Program Aerosol Working Group
Earth and Planetary Science Letters
Earth Science Informatics
Ecological Applications
Ecology
Ecosystems
Encyclopedia of Inland Waters
Environmental Chemistry
Environmental Modeling and Software
Environmental Research Letters
Environmental Science and Technology
European Environment Agency Report
Freshwater Biology
Geophysical Journal International
Geophysical Research Letters
Georgian National Science Foundation
Global and Planetary Change
Global Biogeochemical Cycles
HESSD
Hydrological Processes
IGARSS
IGRS
Indoor Air Pollution
International Journal of Mass Spectrometry
International Journal of Remote Sensing
International Laser Radar Conference
Ion Emitter Development Program, U.S. Department of Energy
Israel Science Foundation
Journal of Aerosol Science
Journal of Applied Meteorology and Climatology
Journal of Atmospheric and Oceanic Technology 2008
Journal of Atmospheric and Solar-Terrestrial Physics
Journal of Climate
Journal of Computational Acoustics
Journal of Environmental Analytical Chemistry
Journal of Geology
Journal of Geophysical Research
Journal of Geophysical Research-Atmosphere
Journal of Geophysical Research-Biogeosciences
Journal of Geoscience Education
Journal of Glaciology
Journal of Hydrology
Journal of Hydrometeorology
Journal of Marine Geodesy
Journal of Physical Chemistry
Journal of Sound and Vibration
Journal of the Acoustical Society of America
Journal of the Atmospheric Sciences
Journal of Zoology
Kearney Foundation
Limnology and Oceanography
Limnology and Oceanography Methods
Marine Ecological Research
Marine Ecology Progress Series
Mathematical Geosciences
Meteorologische Zeitschrift
Monthly Weather Review
Murdock Charitable Trust
NARSTO Assessment
NASA MAP ROSES
NASA Satellite mission proposal reviews
National Geographic Society research proposal
National Science Foundation
Nature

Netherlands Organisation for Scientific Research
NOAA
NOAA Climate Change Detection program
NSF CEDAR proposal
NSF ANS
NSF Antarctic Research
NSF Atmospheric Sciences
NSF Climate and Large-Scale Dynamics Program
NSF Ecology
NSF Geomorphology and Land-Use Dynamics
NSF Hydrology program
NSF Innovative Technology Experiences for Students and Teachers
NSF Microbial Observatories
NSF Physical Oceanography Program
NSF Polar Programs
NSF Research Experiences for Undergraduates
NSF Tectonics panel
Open Atmospheric Science
Optical Engineering
Paleoceanography
Physical Chemistry
Physical Geography
Plant Journal
Polar Geography
Proceedings of the National Academy of Sciences
Quarterly Journal of the Royal Meteorological Society
Quaternary Research
Quaternary Science Reviews
Remote Sensing of Environment
Science
Science of the Total Environment
Tectonics
Tellus
U.S. Army Research Office, Earth Surface Processes and Landforms
U.S. Bureau of Reclamation Science and Technology
U.S. Department of Energy Small Business Innovation Research
U.S. Department of Energy Small Business Technology Transfer
U.S. Geological Survey National Earthquake Hazards Reduction Program
University of Arizona Ion Detector Development Program
Water Resources Research
Wave Motion
Weather and Forecasting

Professional Membership

Acoustical Society of America
AGU Education and Human Resources
AGU Education Awards Committee
AGU Spring and Fall Meeting Planning committees
Alaska Sea Ice Working Group
Alexander von Humboldt Association of America
American Association for the Advancement of Science
American Association of Pharmaceutical Scientists
American Association of State Climatologists
American Geophysical Union (AGU)
American Indian Science and Engineering Society
American Institute of Aeronautics and Astronautics
American Libraries Association
American Meteorological Society (AMS)
American Quaternary Association
American Society for Limnology and Oceanography, Education Committee
American Society for Mass Spectrometry
American Society for Photogrammetry and Remote Sensing
American Society of Engineering Education
American Water Resources Association, Colorado
American Water Works Association Research Foundation
AMS Middle Atmosphere Committee
AMS Polar Meteorology and Oceanography Committee
Arctic-CHAMP (Community-wide Hydrologic Analysis and Monitoring Program)
Association of American Geographers
Bureau Central de Magnétisme Terrestre
Chinese Society of Glaciology and Geocryology
Colorado Alliance for Environmental Education
Deutsche Gesellschaft fuer Polarforschung
Deutscher Alpenverein (German Alpine Club)
European Geophysical Union
European Space Agency Noordwijk
Geological Society of America
Global Climate Observing System
IEEE
Integrated Ocean Observing System
International Association for Geomagnetism and Aeronomy
International Association for Mathematical Geosciences
International Association for Mathematical Physics
International Glaciological Society
International Ice Charting Working Group
International Permafrost Association
International Society on General Relativity and Gravitation
International Union of Radio Science
Mountain Plains Library Association
National Association of Geoscience Teachers
Oceanography Society
Polar Libraries Colloquy
Sigma Xi Scientific Research Society
Society of American Archivists
Society of Rocky Mountain Archivists
Special Libraries Association
U.S. Permafrost Association
WMO Global Atmosphere Watch

Sunset near Whistler, British Columbia, Canada.

Appendices

Governance and Management

CIRES Leadership

Konrad Steffen, Director

William Lewis, Jr., Associate Director

Jon Rush, Associate Director for Administration

Suzanne van Drunick, Associate Director for Science

CIRES Divisions

■ Cryospheric and Polar Processes: Richard Armstrong, Director

■ Ecosystem Science: Carol Wessman, Director

■ Environmental Chemistry: Fred Fehsenfeld and Margaret Tolbert, co-Directors

■ Environmental Observations, Modeling and Forecasting: Michael Hardesty, Director

■ Solid Earth Sciences: Roger Bilham, Director

■ Weather and Climate Dynamics: Randall Dole, Director

Fellows Committees

The Council of Fellows constitutes the "Board of Directors" and chief governing body of CIRES. It is comprised of individuals with an outstanding record of achievement and ability in diverse areas of environmental sciences. They are university faculty, senior research scientists, or government scientists who form the core leadership of the Institute.

Their responsibilities are to 1) provide leadership at all levels in environmental science; 2) maintain an active scientific research/education program; 3) support the CIRES infrastructure through indirect cost recovery and in-kind contributions; 4) participate in CIRES management; and 5) contribute interdisciplinary expertise and participate in collaborative work. As a group, they personify the concept of collaboration that is the founding principle of the NOAA Cooperative Institutes Program. Ex-officio individuals include representatives of the Members' Council and CIRES administration. Fellows meetings are held monthly during the academic year.

The Council of Fellows met seven times during FY08: August 28, October 16, and November 13, 2008; and January 22, February 19, March 19, and April 16, 2009.

Council of Fellows

■ **Waleed Abdalati** Associate Professor of Geography, Director of Earth Science and Observation Center

■ **Richard Armstrong** CIRES Senior Research Scientist in the National Snow and Ice Data Center, Director of CIRES' Cryospheric and polar processes division

■ **Susan Avery** Former CIRES Director; Former Professor of Electrical and Computer Engineering—*on leave*.

■ **Ben Balsley** Research Professor and CIRES Senior Research Scientist

■ **Roger Barry** Distinguished Professor of Geography; Director, World Data Center for Glaciology

■ **Roger Bilham** Professor of Geological Sciences; Director of CIRES' Solid Earth sciences division

■ **John Cassano** Assistant Professor of Atmospheric and Oceanic Sciences

■ **Thomas Chase** Associate Professor of Civil, Environmental, and Architectural Engineering

■ **Xinzhao Chu** Associate Professor of Aerospace Engineering

■ **Shelley Copley** Professor of Molecular, Cellular, and Developmental Biology

■ **Joost de Gouw** CIRES Senior Research Scientist, ESRL CSD

■ **Lisa Dilling** Assistant Professor of Environmental Studies

■ **Randall Dole** Deputy Director for Research, ESRL PSD; Director of CIRES' Weather and climate dynamics division

■ **David Fahey** NOAA Research Physicist and Program Lead, Atmospheric Composition and Chemical Processes, ESRL CSD

■ **Christopher Fairall** Chief, Weather and Climate Physics Branch, ESRL PSD

■ **Lang Farmer** Professor of Geological Sciences

■ **Fred Fehsenfeld** CIRES Senior Research Scientist, ESRL CSD; Co-director of CIRES' Environmental chemistry division

■ **Graham Feingold** Research Scientist, ESRL CSD

■ **Noah Fierer** Assistant Professor of Ecology and Evolutionary Biology

■ **Baylor Fox-Kemper** Assistant Professor of Atmospheric and Oceanic Sciences

■ **Timothy Fuller-Rowell** CIRES Senior Research Scientist, NOAA Space Weather Prediction Center

■ **Vijay Gupta** Professor of Civil, Environmental, and Architectural Engineering

■ **Michael Hardesty** Senior Scientist and Program Lead, Atmospheric Remote Sensing, ESRL CSD; Director of CIRES' Environmental observations, modeling, and forecasting division

■ **José-Luis Jiménez** Associate Professor of Chemistry and Biochemistry

Executive Committee

The Executive Committee assists and advises the Director in matters regarding day-to-day management of the Institute, and makes important decisions and policies affecting CIRES. Members of the Executive Committee include the Associate Directors of the CIRES' six divisions, two Fellows elected at-large for two-year terms (renewable for one term), and two voting members representing the Members' Council. The Associate Director for Administration, Associate Director for Science, and the Director's Administrator 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.

Distinguished Lectureship Series Committee

This lecture series was created to bring in outstanding scientists and innovative thinkers who have given thoughtful consideration to environmental and Earth system science issues. Coordinators put together the program and host scientists' visits.

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 materials submitted by the Fellow, which includes a cover letter outlining reasons for continuing as a Fellow, and a curriculum vitae. The committee prepares its recommendations, which are submitted to the full Council of Fellows for consideration and final vote. This committee is also charged with considering the identification and nomination packages of possible new Fellows within the community of scientists at the University of Colorado at Boulder and NOAA. Nominations for new Fellows are considered once yearly.

Graduate Student Research Fellowship Committees

These groups serve as the review and selection committees for the CIRES Graduate Student Research Fellowships and the ESRL-CIRES Fellowships. The fellowships are competitively awarded to new or existing CIRES-affiliated graduate students each year.

Innovative Research Program Committee

This program is designed to stimulate a creative research environment within CIRES and encourage synergy between disciplines and research colleagues. The intent is to provide an uncomplicated mechanism for supporting small research efforts that can quickly provide concept viability. The committee reviews all the research proposals and recommends to the CIRES Director for funding those that are the most inventive and bridge boundaries between traditional disciplines. The number of awards each year depends upon the funds available and funds requested, but averages about six.

■ **Craig Jones** Associate Professor of Geological Sciences

■ **William Lewis, Jr.** Professor of Ecology and Evolutionary Biology; Director, Center for Limnology; Associate Director, CIRES

■ **Peter Molnar** Professor of Geological Sciences

■ **Russell Monson** Professor of Ecology and Evolutionary Biology

■ **William Neff** Senior Scientist and Director, ESRL PSD

■ **Steven Nerem** Professor of Aerospace Engineering

■ **David Noone** Assistant Professor of Atmospheric and Oceanic Sciences

■ **Roger Pielke, Jr.** Professor of Environmental Studies

■ **Balaji Rajagopalan** Associate Professor of Civil, Environmental, and Architectural Engineering

■ **Prashant Sardeshmukh** CIRES Senior Research Scientist, ESRL PSD; Director, Climate Diagnostics Center

■ **Mark Serreze** Professor of Geography; Director, National Snow and Ice Data Center

■ **Anne Sheehan** Professor of Geological Sciences

■ **Robert Sievers** Professor of Chemistry and Biochemistry; Director, CU-Boulder Environmental Program

■ **Susan Solomon** Senior Scientist and Program Lead, Chemistry and Climate Processes, ESRL CSD

■ **Konrad Steffen** Professor of Geography; Director, CIRES

■ **Margaret Tolbert** Professor of Chemistry and Biochemistry; Co-director of CIRES' Environmental chemistry division

■ **William Travis** Associate Professor of Geography; Director, Center for Science and Technology Policy Research

■ **Greg Tucker** Associate Professor of Geological Sciences

■ **Veronica Vaida** Professor of Chemistry and Biochemistry

■ **Rainer Volkamer** Assistant Professor of Chemistry and Biochemistry

■ **John Wahr** Professor of Physics

■ **Carol Wessman** Professor of Ecology and Evolutionary Biology, Director of CIRES' Ecosystem science division

■ **Tingjun Zhang** CIRES Senior Research Scientist, National Snow and Ice Data Center

Emeritus Fellows

■ **George Reid** CIRES Senior Scientist Emeritus, ESRL CSD

■ **Doug Robertson** Retired NOAA National Ocean Service, National Geodetic Survey

■ **Hartmut Spetzler** Professor Emeritus of Geological Sciences

Fellow Affiliate

■ **Ray Fall** Professor of Chemistry and Biochemistry

New Fellows Committee

This committee is charged with considering the identification and nomination packages of possible new Fellows within the community of scientists at the University of Colorado at Boulder and NOAA. Nominations for new Fellows are considered once yearly.

Visiting Fellows Committee

This committee is responsible for the review of all applications for CIRES Visiting Fellowships. The committee chooses those best qualified for a fellowship in any given year, and submits that slate to the Fellows Council for final discussion and selection.

Special Committees

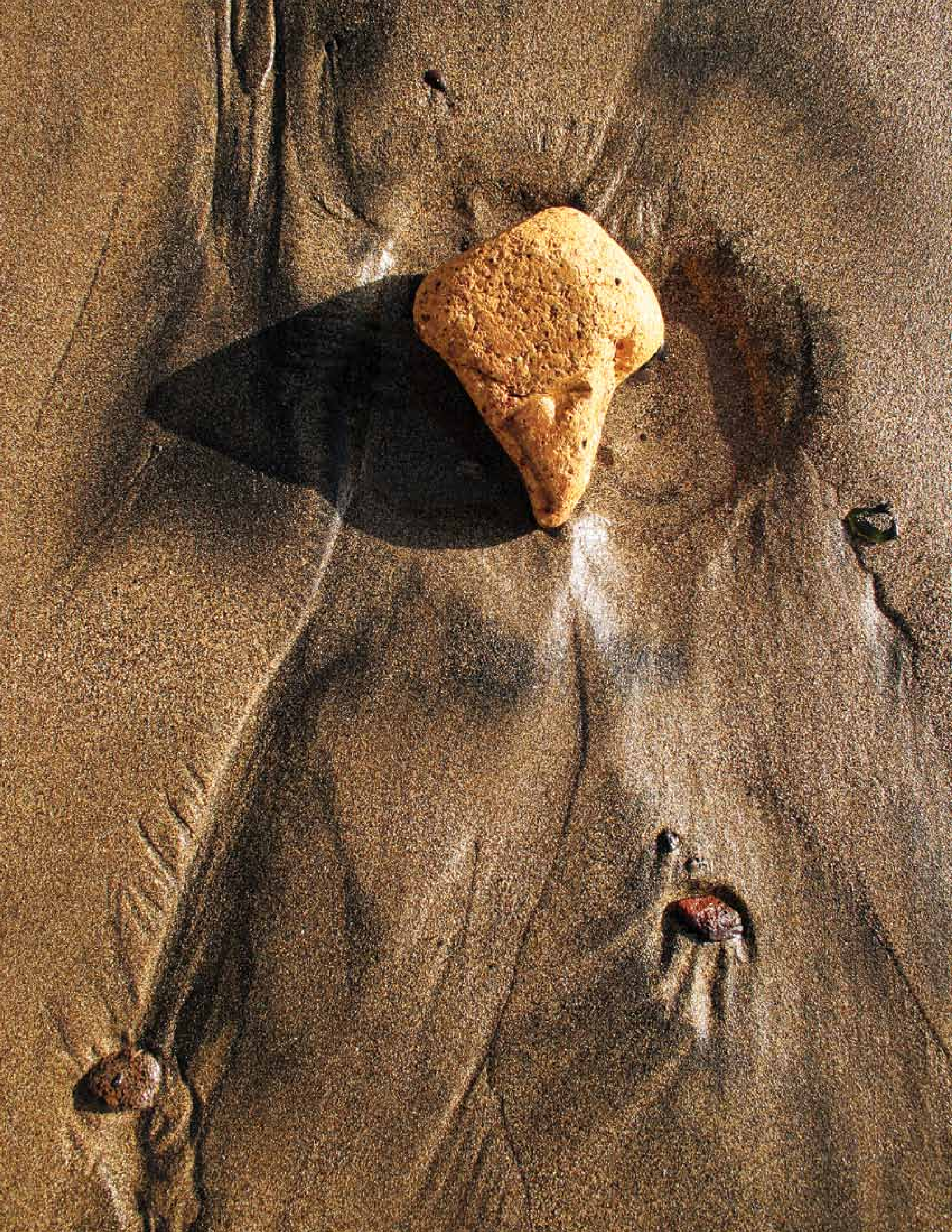
Additional special committees are appointed as needed by the Director. These include Faculty Search committees, the university Program Review Committee, award committees, and others. They are created as a need arises, exist to accomplish a specific task, and are then disbanded.

Professional Masters in Remote Sensing Committee

The Earth Science and Observation Center (ESOC) acts as a focus for campus-wide research in the use of remote sensing for global geosciences studies. So far, master's and Ph.D. candidates from the following departments have carried out thesis research in ESOC: Anthropology, Geography, Geological Sciences, Electrical Engineering, Ecology and Evolutionary Biology, and the interdepartmental Geophysics Program. In fiscal year 2008, ESOC began development of a Professional Masters Degree Program in Remote Sensing. This formal program will organize and strengthen the remote sensing curriculum at the university.

Members' Council

The CIRES 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 Council of Fellows and Executive Committee are elected. The two representatives to the Fellows' Council/Executive Committee serve as the liaison between the Council of Fellows/Executive Committee and the Members' Council. The Members' Council, which meets monthly, then serves as a direct line of communication to the Member population at large.



Personnel Demographics

CIRES Personnel Breakdown 2008-2009

Category	Total CIRES Personnel	NOAA-supported CIRES Personnel	Highest Degree Earned by NOAA-supported Personnel B.S.	M.S.	Ph.D.
Faculty	20	0	0	0	0
Research Scientist	182	107	0	0	107
Visiting Scientist	30	0	0	0	0
Postdoctorate Researcher	16	6	0	0	6
Associate Scientist	199	111	47	61	3
Administrative	36	25	21	2	2
Total > 50% NOAA support		**249**	**68**	**63**	**118**
Undergraduate Students	73	16	0	0	0
Graduate Students	95	24	24	—	0
Received < 50% NOAA Support		61	8	8	45
Total < 50% NOAA Support		**101**	**32**	**8**	**45**
Total CIRES personnel	**651**				

CIRES Personnel in NOAA Boulder Laboratories	
OAR	217
Chemical Sciences Division	70
Global Monitoring Division	47
Global Systems Division	27
Physical Sciences Division	73
NESDIS/NGDC	36
NWS/SWPC	27
Obtained NOAA Employment in Last Year	3
Total NOAA	**280**

Attendees pore over research posters at CIRES' 2009 Rendezvous! science symposium on the University of Colorado at Boulder campus.

CIRES

Acronyms

AGDC	Antarctic Glaciological Data Center
AGL	Above Ground Level
AIRS	Atmospheric Infrared Sounder
AMIE	Assimilative Mapping of Ionospheric Electrodynamics
AMISA	Arctic Mechanisms of Interaction between the Surface and the Atmosphere
AMMA	African Monsoon Multidisciplinary Analysis
AMO	Atlantic Multidecadal Oscillation
AMOS	Advanced Modeling and Observing Systems
AOML	Atlantic Oceanographic Meteorological Laboratory
AR4	Fourth Assessment Report
AR5	Fifth Assessment Report
ARCPAC	Aerosol, Radiation, and Cloud Processes affecting Arctic Climate
ARCTAS	Arctic Research for the Composition of the Troposphere from Aircraft and Satellites
ARM	Atmospheric Radiation Measurement
ASCOS	Arctic Summer Cloud Ocean Study
ASPTC	Aspirated Thermocouple
ASTER	Aerosol Scattering To Extinction Ratio
ATI	Applied Technologies, Inc.
BAO	Boulder Atmospheric Observatory
BC	Black Carbon
CADIS	Cooperative Arctic Data and Information Center
CAPS	Center for Analysis and Prediction of Storms
CaRDS	Cavity Ring-Down System
CCSM	Community Climate System Model
CCSP	Climate Change Science Program
CDC	Climate Diagnostics Center
CDMP	Climate Database Modernization Program
CET	Center for Environmental Technology, CU-Boulder
CHAMP	Challenging Minisatellite Payload
CIMS	Chemical Ionization Mass Spectrometry
CIRES	Cooperative Institute for Research in Environmental Sciences
CME	Coronal Mass Ejection
CODOS	Colorado Dust on Snow
CPC	Climate Prediction Center
CRM	Costal Relief Model
CRSS	Colorado River Seasonal Forecasting
CSAS	Center for Snow and Avalanche Studies

CSD	Chemical Sciences Division (NOAA ESRL)
CSES	Center for the Study of Earth from Space
CSV	Climate System Variability
CU	University of Colorado
CUDA	Language used by GPUs
DAAC	Distributed Active Archive Center
DEMs	Digital Elevation Models
DMSP	Defense Meteorological Satellite Program
DOE	U.S. Department of Energy
DPI	Dry Powder Inhalers
D-RAP	D-Region Absorption Prediction
DSL	Domain Specific Languages
DTC	Developmental Testbed Center
ECMWF	European Centre for Medium-Range Weather Forecasts
ECS	Extended continental shelf
EIT	Extreme Ultraviolet Imaging Telescope
EMC	Environmental Modeling Center
ENSO	El Niño-Southern Oscillation
EO	Education and Outreach
EPA	Environmental Protection Agency
EPCS	Essential Principles of Climate Sciences
ESOC	Earth Science Observation Center (a CIRES center)
ESRL	Earth System Research Laboratory (NOAA)
ETH	Eldgenössische Technische Hochshule
FAA	Federal Aviation Administration
FDA	Food and Drug Administration
FGDC	Federal Geographic Data Committee
FIM	Flow-Following Finite-Volume Icosahedral Model
GAIM	Global Assimilation of Ionospheric Measurements
GASEX	Southern Ocean Gas Exchange Experiment
GCM	General Circulation Model
GC-MS	Gas chromatography-mass spectrometry
GDS	Ground Data System
GEO	Geodynamics
GFS	Global Forecast System
GIP	Global Ionosphere Plasmasphere
GIS	Geographic Information System
GLDAS	Global Land Data Assimilation System
GLIMS	Global Land Ice Measurements from Space

GMD	Global Monitoring Division (NOAA ESRL)
GOES	Geostationary Operational Environmental Satellite
GoMACCS	Gulf of Mexico Atmospheric Composition and Climate
GPS	Global Positioning System
GPU	Graphics Processor Unit
GRACE	Gravity Recovery and Climate Experiment
GSD	Global Systems Division (NOAA ESRL)
GSI	Gridpoint Statistical Interpolation
GTG3	Graphical Turbulence Guidance
HCFCs	Hydrochlorofluorocarbons
HF	High Frequency
HIPPO	HIAPER Pole-to-Pole Observations
hJ	Wind maximum
HMT	Hydrometeorology Testbed
HPCS	High Performance Computing Systems
HRDL	High Resolution Doppler Lidar
HWRF	Hurricane Weather Research and Forecasting model
HYSPLIT4	Hybrid Single-Particle Lagrangian-Integrated Trajectory
IA	Integrating Activities
ICEALOT	International Chemistry Experiment in the Arctic Lower Troposphere
IDEA	Integrated Dynamics through Earth's Atmosphere
IGY	International Geophysical Year
IHY	International Heliophysical Year
IOCM	Integrated Ocean and Costal Mapping
IPPC	Intergovernmental Panel on Climate Change (United Nations)
IPY	International Polar Year
IR	Infrared
IRD	Ice-rafted Sedimentary Detritus
ISO	International Standards Organization
IWCS	Intermountain West Climate Summary
LEO	Low Earth Orbit
LLJ	Low-level Jet
LPAS	Laser photo-Acoustic Spectroscopy
LS	Lower Stratosphere
MABL	Marine Atmospheric Boundary Layer
MAF	Million Acre Feet
MAX-DOAS	University of Colorado Ship Multi Axis Differential Optical Absorption Spectrometer
MBL	Marine Boundary Layer
MFRSR	Multi-Filter Rotating Shadow-Band Radiometer

MOS	Monin-Obukhov Similarity
MTM	Midnight Temperature Maximum
Na-DEMOF	Sodium Double-Edged Magneto-Optic Filter Technique
NARR	North American Region Reanalysis
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
NCDC	National Climatic Data Center
NCEP	National Centers for Environmental Predication
NEUBrew	NOAA-EPA Brewer Spectrophotometer UV and Ozone Network
NEVS	Network-Enabled Verification Service
NGDC	National Geophysical Data Center
NIDIS	National Integrated Drought Information System
NIM	Non-hydrostatic Icosahedral Model
NOAA	National Oceanic and Atmospheric Administration
NRCS	Natural Resources Conservation Service
NSF	National Science Foundation
NSIDC	National Snow and Ice Data Center
NTAS	Northwest Tropical Atlantic Station
NTAS	North Atlantic
NWS	U.S. National Weather Service
OA	Organic Aerosol
ODS	Ozone-Depleting Substances
OMI/AURA	Ozone Monitoring Instrument (on the satellite Aura)
OMPS	Ozone Mapping and Profiler Suite
OS	Open Source
PANTHER	Peroxyl Acetyl Nitrate and other Trace Hydrocarbon Experiment
PBL	Planetary Boundary Layer
PDO	Pacific Decadal Oscillation
PIRATA	Prediction and Research Moored Array in the Atlantic
PM	Planetary Metabolism
PMEL	Pacific Marine Environment Laboratory
PNE	PIRATA Northeast Extension
POES	Polar Operational Environmental Satellite
PRF	Pulse-Repetition Frequency
PSD	Physical Sciences Division (NOAA ESRL)
PZT	Piezoelectric
QNX	Linux operating system
RH/Ts	Relative Humidity and Temperature
RMNP	Rocky Mountain National Park

ROCS	Roger G. Barry Resource Office for Cryospheric Studies
RP	Regional Processes
RTVS	Real-Time Verification System
RUC	RUC Rapid Update Cycle
SAP	Synthesis and Assessment Product
SAPHIR	Simulation of Atmospheric PHotochemistry In a large Reaction chamber
SBL	Stable Boundary Layer
SCIPP	Southern Climate Impacts Planning Program
SEARCH	Study of Environmental Arctic Change
SIMM	Simulation of the Inner Magnetosphere
SLR	Sea-Level Rise
SNOTEL	Snow Telemetry
SOA	Secondary Organic Aerosol
SOF	Solar Occultation Flux
SST	Sea-Surface Temperature
START-08	Stratosphere-Troposphere Analyses of Regional Transport, 2008
STEREO	Solar Terrestrial Relations Observatory
SWA	Southwest Australia
SWPC	Space Weather Prediction Center
TAF	Terminal Aerodrome Forecast
TC	Tropical Cyclones
TexAQS	Texas Air Quality Study
TM5	Test Model 5
TOPEX	Topography Ocean Experiment, NASA
UAS	Unmanned Aircraft Systems
UCATS	Chromatograph for Atmospheric Trace Species
UCESat-2	Ice Cloud and Land Elevation Satellite-2
uDig	User-friendly Desktop Internet GIS
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
UT	Upper Troposphere
VOCALS	VAMOS Ocean-Cloud-Atmosphere-Land Study
VOCs	Volatile Organic Compounds
WAM	Whole Atmosphere Model
WATF	Water Availability Task Force
WGMS	World Glacier Monitoring Service
WHOTs	Woods Hole Oceanographic Institute Hawaii Ocean Time-series Station
WRF	Weather Research and Forecasting model
WWA	Western Water Assessment