Cooperative Institute for Research In Environmental Sciences

2011 CIRES ANNUAL REPORT

COOPERATIVE INSTITUTE FOR RESEARCH IN ENVIRONMENTAL SCIENCES

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Table of Contents

From the Director

"We strive to explore all aspects of the Earth system to better understand all processes of our dynamic planet, which will help guide its management and conservation for future generations."

Researchers from NOAA and the Cooperative Institute for Research in Environmental Sciences (CIRES) were among the first responders to measure the black smoke that rose from the water's surface during the Deepwater Horizon Oil Spill in the Gulf of Mexico. The earthquake this spring that moved Japan 12 feet closer to the United States was studied by CIRES geophysicists and featured on national television. The Arctic sea ice has melted to its second-lowest level on record (since 1979) as reported this fall by the CIRES National Snow and Ice Data Center. The U.S. Supreme Court is presiding over a case related to water-quality issues in the Florida Everglades and will consider CIRES water-quality research on Grand Lake, Colo., in its decision. The U.S. Department of the Interior announced in October that CIRES and the University of Colorado Boulder would play important roles in two new regional Climate Science Centers that will conduct climate-change research, with a focus on wildlife and ecosystems. Dark-colored dust that settles on snow in the Upper Colorado River Basin makes the snow melt early and robs the Colorado River of about 5 percent of its water each year, reveals a new study from CIRES scientists at the University of Colorado Boulder and NOAA. These are just a few highlights that make my life as CIRES Director so interesting and rewarding. We strive to explore all aspects of the Earth system to better understand all processes of our dynamic planet, which will help guide its management and conservation for future generations.

This coming year will be another milestone in the history of CIRES as we celebrate our 45th anniversary as a cooperative institute, the oldest such unit collaboration with NOAA. We also will submit a proposal to NOAA based on an open competition to continue this legacy for many more years. CIRES continues to engage in cross-disciplinary research in cryosphere, biosphere, atmosphere, geosphere and hydrosphere sciences; therefore, we organized and facilitated six mini-retreats on topics including remote sensing in geosciences, organic molecules in the environment, decision making under uncertainty and paleo-perspectives in climate change and two retreats on energy and the environment. The latter led to a new CIRES initiative to study the environmental effects of future energy solutions, in particular biomass and natural gas production.

CIRES had another exceptional year and showed healthy growth both in funding and research personnel. Again, we had a remarkable increase of 10 percent in research funding in FY11, with about half of our funding from the cooperative research with NOAA and the remaining funding from the National Science Foundation, NASA, other federal agencies and the University of Colorado, totaling more than $64 million. Our research productivity remains very strong with 512 peer-reviewed publications in all the major research journals of our disciplines. The strong research funding and stellar publication record are the fruits of truly dedicated researchers (500), which include our 22 faculty lines, and excellent administrative staff (32) working with 96 graduate students and 86 undergraduate students as one team to advance our knowledge and understanding in environmental sciences. CIRES has grown to a 714-person institute, and we continue to remain a world leader in interdisciplinary research.

CIRES researchers and staff received a total of 35 awards, ranging from Distinguished Professor at the University of Colorado (Dr. Margaret Tolbert); Career Achievement Service to America Medal (Dr. Susan Solomon) for her research on the ozone hole; Honorary Doctor of Science, Oberlin College (Dr. Peter Molnar); Rosenstiel Award in

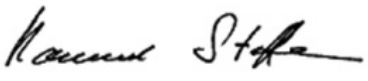
Marine and Atmospheric Science, Univesity of Miami (Dr. Jose-Luis Jimenez); Baldi Memorial Lecture Award, International Society of Limnology (Dr. William Lewis); and the two-year appointment as Chief Scientist at NASA (Dr. Waleed Abdalati), to name a few.

CIRES welcomes three new Fellows to the Council of Fellows: Dr. Stanley Benjamin, ESRL/Global Systems Division, Dr. Steve Montzka, ESRL/Global Monitoring Division, and Dr. Judith Perlwitz, ESRL/Physical Sciences Division. The Graduate School has authorized the search for a new senior faculty in experimental atmospheric chemistry in support of the new CIRES Center for Atmospheric Chemistry, increasing our tenure track faculty lines in the graduate school to 23 in nine different departments and programs in the colleges of Arts and Sciences and Engineering and Applied Science.

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 38 CIRES Fellows, the research activities of CIRES' five scientific centers, education and outreach and the Western Water Assessment. Our research is broad, deep and innovative, and I am very proud to present you this report.

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

Enjoy your reading!



Dr. Konrad Steffen

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 Boulder was established in 1967 as NOAA's first cooperative institute. CIRES continues to be a world leader in interdisciplinary research and teaching across a diverse range of Earth system science topics. CIRES researchers use established and innovative approaches to study the cryosphere, ecosystems, weather and climate, solid earth and environmental chemistry, observations, modeling and forecasting. This summary highlights many of the past year's research accomplishments and activities, demonstrating how CIRES supports NOAA in meeting its strategic goals. In service to society, CIRES continues to communicate its research findings to help inform decision makers and the public about how to best ensure a sustainable environment.

On a broader scale, fiscal year 2011 (FY11, July 1, 2010 to June 30, 2011) was marked by natural disasters worldwide, including the 2011 Great East Japan Earthquake, the 2010 Russian Heat Wave and the aftermath of the 2010 Deepwater Horizon Oil Spill in the Gulf of Mexico, along with record droughts, tornados and temperature extremes in the United States, making CIRES' mission of forecasting and responding to severe weather and climate more critical than ever. CIRES leads the way in this capacity, extrapolating data gleaned from the Japan megaquake to the United States, where seismologists expect a 9.0 earthquake to shake the Oregon-Washington Coast sometime in the next 200 years. The lessons learned from Japan are serving as an important template for forecast and disaster mitigation in the United States and elsewhere.

CIRES researchers met their forecasting goal by upgrading and extensively testing the Hurricane Weather Research and Forecasting (HWRF) model; developing advanced DART (Deep-ocean Assessment and Reporting of Tsunamis) programs for the early detection and warning of tsunamis; and creating 22 new digital elevation models of the U.S. coast. These representations of Earth's solid surface are fundamental for modeling and planning for tsunamis, hurricane storm-surges and sea-level rise.

Among CIRES' many other accomplishments, our scientists released a state-of-the-art product, MASIE–NH (Multisensor Analyzed Sea Ice Extent–Northern Hemisphere), which allows anyone to view current Arctic sea-ice coverage by region—information vital for transportation, commerce, ecosystem protection and climate understanding. Additionally, CIRES researchers spearheaded the writing, reviewing and editing of the 2010 international scientific state-of-understanding assessment report on the ozone layer and delivered it to the United Nations Environment Programme (UNEP), where it will inform policy decisions to protect the ozone layer. Advances were also made toward the deployment of an aerosol forecast system (similar to the national ozone forecast system), which will give early warning of high levels of these tiny, airborne particles harmful to human health.

In response to natural hazards, CIRES quickly mobilized around the Deepwater Horizon Oil Spill by diverting a cutting-edge research aircraft (the NOAA WP-3D) to the region to evaluate air-quality concerns, oil leakage rates and the risks posed to human health and wildlife. The researchers, who worked in collaboration with the U.S. Environmental Protection Agency and the Occupational Safety and Health Administration, discovered that approximately one-third of the oil evaporated into the atmosphere. After the deadly Russian Heat Wave in summer 2010, CIRES scientists statistically analyzed observations and ran climate models to conclude the event was due to natural variability and not climate change. The researchers cautioned, however, that extreme weather events could become more likely in the future as greenhouse gases continue to increase. Following the April 2010 eruptions of Eyjafjallajokull in Iceland, CIRES researchers ran real-time volcanic ash forecasts using the NOAA/CIRES FIM (Finite-volume Icosahedral Model) and used this data to refine the model in the event of future such eruptions.

CIRES had another exceptional year of research support during FY11, with total extramural research expenses of $60,421,835 (increasing again by 10 percent or nearly $5.7 million more than the previous year). The outlook for CIRES science remains strong, as CIRES' total budget, including university faculty support, was $64,522,969. NOAA support through the Cooperative Agreement accounted for $30,867,036 (48 percent); external research awards accounted for $29,554,799 (46 percent); and university faculty support accounted for $4,101,134 (6 percent).

CIRES supported 193 research scientists, 228 associate scientists, 29 visiting scientists, 28 postdoctoral researchers, 32 administrative staff, 96 graduate students and 86 undergraduate students. In total, CIRES supported 714 scientists, staff and students. In FY11, CIRES had 22 faculty lines. In total, CIRES researchers published 512 peer-reviewed publications during calendar year 2010.

The CIRES Council of Fellows welcomed Dr. Stanley Benjamin, Dr. Steve Montzka and Dr. Judith Perlwitz. Benjamin is a NOAA meteorologist working at the Earth System Research Laboratory (ESRL) Global Systems Division. His research focuses on numerical weather prediction, data assimilation and aviation meteorology. Montzka is a NOAA scientist at the ESRL Global Monitoring Division where he tracks trace atmospheric chemicals, including ozone and substitutes for ozone-depleting substances. Perlwitz is a CIRES atmospheric scientist working at the ESRL Physical Sciences Division exploring the two-way interactions between the troposphere and stratosphere, and mechanisms by which the stratosphere influences climate.

CIRES researchers who received awards and honors in FY11 are too numerous to list in this summary, but a sample of recognized expertise and service includes the selection of four CIRES Fellows to be lead authors for the Intergovernmental Panel on Climate Change (IPCC) 5th Assessment Report. They include Konrad Steffen and Tingjun Zhang (cryosphere), Judith Perlwitz (global to regional detection and attribution of climate change) and Steve Nerem (sea-level change). Other notable recognitions of CIRES Fellows include the selection of Waleed Abdalati, Director of CIRES Earth Science and Observation Center and Associate Profes-

KONRAD STEFFEN/CIRES

The NSF research facility on top of the Greenland Ice Sheet (Summit Station), with a satellite dish for data transmission and communication.

sor of Geography, to serve as NASA's Chief Scientist for a two-year appointment beginning in January 2011. Professor William Lewis Jr., Director of the CIRES Center for Limnology, was the invited speaker for the Baldi Lecture at the triennial congress of the International Society for Limnology. Margaret Tolbert was named CU Distinguished Professor—the University's highest faculty honor. David Noone, Associate Professor in the Department of Atmospheric and Oceanic Sciences, and Noah Fierer, Associate Professor in the Department of Ecology and Evolutionary Biology, received the prestigious National Science Foundation (NSF) CAREER Award.

CIRES facilities are also making news. The National Science Foundation awarded $525,000 to the CIRES National Snow and Ice Data Center, to reduce the data center's carbon footprint and become one of the most energy-efficient data centers in the United States. The completion of the new "Green Data Center" is expected in late 2011. The new Center for Atmospheric Chemistry—a collaboration between CIRES and the Department of Chemistry and Biochemistry—will enable researchers to investigate the impact of aerosols on the environment by helping to resolve the differences between the observed and modeled particle-related cooling influence on Earth's surface. The new laboratory likely will become one of the top three in the United States and will support two new faculty lines. CIRES also became part of two new Department of Interior Climate Science Centers in the Southwest and North Central regions that were created to conduct and coordinate research on climate change and ecosystems.

The Western Water Assessment (WWA)—a NOAA Regional Integrated Sciences and Assessments program created in 1999 as a joint program with CIRES—completed the Colorado Climate Preparedness report and database to facilitate adaptation-planning strategies for the state. Related research by WWA includes the recent findings that dark-colored dust settling on high-elevation snowpack in the Colorado River headwaters causes earlier snowmelt and evaporative losses of nearly 5 percent of the average total annual flow in the river.

CIRES Education and Outreach group serves the community through its science education projects that provide professional development for science educators and scientifically robust climate and energy materials for teachers and students. This group also leads a K-12 program placing graduate students in socioeconomically diverse local schools to enhance science, technology, engineering and math skills. CIRES is involved in other important efforts to improve diversity in Earth system research. We have been a longtime supporter of the Significant Opportunities in Atmospheric Research and Science (SOARS) program,

which is a learning community and mentoring program for promoting ethnic and gender equity in the atmospheric and related sciences. New this year, CIRES established a Diversity Committee for staff and scientists to identify opportunities for underrepresented ethnic groups and women to pursue advanced degrees in science.

Communication of CIRES' research and activities reached a broad audience through 23 press releases that generated wide media coverage; a dynamic website featuring expanded multimedia that includes 16 new videos and several podcasts; and new editions of our popular periodic magazine, *Spheres*.

CIRES proudly continued support of its established competitive programs that provide research and education opportunities to visiting scientists, innovative CIRES scientists and graduate students. This past year, the CIRES Visiting Fellow Program supported seven sabbatical and five postdoctoral scientists conducting diverse research on the role of erosion in mountain building, Arctic coastal communities, three-dimensional ice-sheet models, climate change impacts on water resources at Shasta Lake, interdecadal variability in Sierra Nevada aquatic ecosystems, novel microbial degradation of pentachlorophenol, spectroscopic studies of Titan particles and other topics.

The Innovative Research Program is designed to stimulate a creative and interdisciplinary research environment within CIRES by supporting novel, unconventional or fundamental pilot or exploratory studies. Six inventive proposals were funded on diverse topics that include: secondary organic aerosol formation from evaporated crude oil; nitrogen fixation by blue-green algae to better understand the global nitrogen cycle and nutrient limitation in aquatic ecosystems; novel lidar technology to extend measurements of wind, temperature and possibly aerosols to the stratosphere and troposphere; development of a lower boundary layer radar for wind energy research; development of an instrument for laboratory experiments of contact nucleation to investigate this ice formation mechanism that occurs at temperatures much warmer than other mechanisms; and development of a novel air sampling technology to improve the study of the sources and sinks of greenhouse gases and ozone-depleting substances.

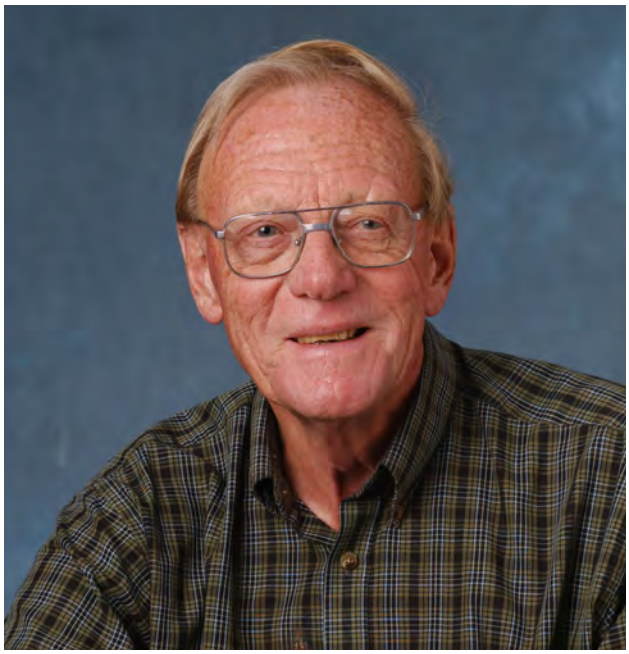
The CIRES Distinguished Lecture Series featured five prominent speakers: David Goldston, U.S. Natural Resources Defense Council, "Loving science to death: Problems at the intersection of science and policy"; Mike Hulme, University of East Anglia, "Why we disagree about climate change"; Daniel Jacob, Harvard University, "Mercury in the environment: Where does it come from, where does it go?"; Andrew Revkin, Pace University, "Are we stuck with 'blah, blah, blah bang'?"; and Peter Rhines, University of Washington, "Exploring the cold oceans of the North."

CIRES continues to support strongly its expanding graduate student enrollment through fellowships and sponsorship of its Graduate Student Association. CIRES offers two graduate student fellowships. The CIRES Graduate Student Research Fellowship was awarded to nine doctoral students, who are advised by CIRES Fellows, with dissertation topics that include determining emissions and chemistry of atmospheric trace species in the laboratory and field; atmospheric processing of methylglyoxal in aqueous environments; acquisition of atmospheric data such as wind vectors and air density; formation and evolution of supra-glacial lakes on glaciers in the Himalaya and Karakoram; electromagnetic study of crust and mantle electrical conductivity beneath the Rio Grande Rift; forecasting and uncertainty treatment in hydrologic modeling; scaling and parameterization of oceanic mesoscale eddies; and decision makers' demand for climate change adaptation information. The ESRL-CIRES Fellowship will be awarded in 2011-12 and funded by participating divisions at ESRL.

CIRES participated in, organized and sponsored numerous events in FY11. Highlights include a special seminar on "Arctic seasons: An Inuit perspective"; a panel on Japan's recent disaster; and workshops on "Deepwater Horizon Data," "Energy and the Environment," the "Colorado River Basin" and "Mountain Pine Beetle and Water." In December 2010, we wished a fond retirement to Distinguished Professor and longtime CIRES Fellow Roger G. Barry, who directed the World Data Center for Glaciology (WDC) since 1976. Under Barry's leadership, the WDC/National Snow and Ice Data Center grew from a staff of two in 1977 to about 90 in 2008, when he stepped down as Director. A leader in the cryospheric science community, Barry shares a legacy of discovery about Arctic and mountain climates and cryospheric processes, climate change and collaborations incorporating indigenous environmental knowledge into scientific weather analysis. He published four textbooks and more than 200 scientific papers and chapters, and he inspired nearly 60 graduate students.

This annual report is an accounting of collaborative research goals described in the CIRES–NOAA July 1, 2010, to Sept. 30, 2012, Scientific Workplan, year one. The report is organized by NOAA's six scientific themes identified in the Cooperative Agreement—advanced modeling and observing systems, climate variability, geodynamics, planetary metabolism, regional processes and integrating activities.

We dedicate this report to Dr. George Colvin Reid who passed away on May 6, 2011, at age 81. Reid was a founding fellow of CIRES, a NOAA physicist who helped pioneer climate research since the 1970s, recipient of the Gold Medal for Distinguished Achievement in the Federal Service presented by President Jimmy Carter and a Nobel Laureate for his contribution as an IPCC author.



CIRES founding Fellow George Colvin Reid

ISTOCK

During the Deepwater Horizon Oil Spill, CIRES and NOAA researchers developed new methods for determining the fate of leaking gases and oil that could pose a threat to fish and wildlife.

Contributions to NOAA's Vision

CIRES' fundamental research priority—to enhance the understanding and prediction of Earth's environment—complements 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 implementing new approaches to monitoring biotic and abiotic conditions in remote ocean and coastal areas; by improving forecasts for extreme weather events that impact coastal areas; and by developing and archiving new data sets and other information products that can help assess coastal hazards and support seafloor research.

During the 2010 BP Deepwater Horizon Oil Spill, CIRES scientists were at the front lines of research investigating the dynamics, chemistry and impacts of the spill. Several important results emerged, including the discovery of a new set of oil-vapor chemicals that form organic aerosols (a harmful air pollutant) as well as estimates of the exposure risks of marine species to potentially toxic compounds such as benzene.

In other work, CIRES researchers developed 17 community and five regional seamless, integrated, bathymetric-topographic Digital Elevation Models (DEMs) of U.S. coasts, including Alaska, Hawaii and the Virgin Islands. The DEMs are instrumental in the modeling of coastal processes, such as storms, sediment transport, ocean currents and sea-level rise; ecosystem management and habitat research; coastal and marine spatial planning;

and community preparedness and disaster mitigation for hazards such as tsunamis and hurricanes.

CIRES researchers also played a key role in education and outreach, producing a "Coastal DEM Best Practices" handout; interactive online magazines; and a Gulf of Mexico DEM that *National Geographic Magazine* used as the source of bathymetry for its October 2010 award-winning map "Gulf of Mexico: A Geography of Offshore Oil."

Related highlights include the addition of 230 multibeam swath sonar surveys (covering 904,199 nautical miles) and 26 trackline surveys (67,462 nautical miles), throughout all of the world's oceans, to the National Geophysical Data Center's (NGDC) global marine geophysical archives. This data, used by numerous national and international organizations, also support two U.S. mapping efforts: the Extended Continental Shelf (ECS) project and the Integrated Ocean Coastal Mapping (IOCM) program.

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, and in FY11 contributed 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. Some highlights are described below, but CIRES accomplishments in this goal are extensive, and a full accounting can be found in the Themes section (page 82).

One major advance toward these goals is the completion and publication of the Twentieth Century Reanalysis (20CR) project, an international effort led by CIRES and NOAA researchers to produce a comprehensive global atmospheric circulation data set spanning the period 1871 to the present. The 20CR data set is widely available through a web interface and serves as a valuable resource for climate research and model validation.

In other timely research, CIRES scientists presented an analysis of the 2010 Russian Heat Wave, incorporating an interactive map and plots of climate-model simulations. Additionally, in support of NOAA's goal to serve society with climate products, CIRES and the U.S. National Ice Center created an important new sea-ice analysis product: the Multisensor Analyzed Sea Ice Extent–Northern Hemisphere (MASIE-NH), which allows anyone to view and download sea-ice coverage by region for latest day and the last four weeks. Closer to home, the CIRES-NOAA Western Water Assessment published the final report of the Colorado Climate Preparedness Project, outlining climate impacts and adaption strategies for the state.

Triple-digit temperatures scorched western Russia during summer 2010. CIRES climate models and observations indicate such heat waves will become more common in coming decades.

CIRES scientists also played a pivotal leadership role in coordinating, authoring, reviewing and editing the 2010 international scientific state-of-understanding assessment report on the ozone layer, which was delivered to the United Nations Environment Programme (UNEP). Updated every four years, this key assessment informs decisions made under the Montreal Protocol to prevent ozone-layer depletion.

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

Weather. CIRES researchers support NOAA's mission to provide essential information on weather by advancing numerical weather model forecasting through model improvements and assimilation of data collected in observational field campaigns, ongoing monitoring and from satellite missions. In FY11, CIRES continued its leadership in weather forecast through the release of the Weather Research and Forecasting with Chemistry model (WRF-Chem) version 3.3, which features many performance-enhancing additions, such as greater coupling between chemistry and physics modules and the incorporation of new chemical mechanisms. The community Hurricane Weather Research and Forecasting (HWRF) model also was upgraded and extensively tested, a process that employed 1,190 cases from 53 storms in the North Atlantic and Eastern North Pacific basins for the 2008, 2009 and 2010 seasons. CIRES scientists made state-of-the-art improvements to the Flow-following finite-volume Icosahedral Model (FIM)—used in weather-research modeling—including incorporating volcanic ash from eruptions such as the major volcanic eruption of Iceland's Eyjafjallajökull in April 2010.

To address health concerns about particulate matter aerosols, NOAA and the National Weather Service have made it a priority to deploy an operational national PM2.5 aerosol forecast system, similar to the national ozone forecast system currently in place. Toward that end, CIRES researchers have made advances to develop reliable aerosol forecast capabilities, particularly in respect to the model accuracy of secondary organic aerosols. Another milestone made in measuring aerosol absorption is the completion of a new 3-wavelength, 5-channel photo-acoustic aerosol absorption spectrometer. This high-sensitivity instrument was deployed onboard the NOAA P-3 research aircraft during the 2010 CalNex field campaign, a major multi-agency mission exploring the intersection of climate change and air quality in California.

Water. In the wake of recent events such as the Deepwater Horizon Oil Spill and political debate over climate change, Congress, reporters, bloggers and the general public continue to rely heavily upon NOAA data sets and ask questions about how they were collected. In response, NOAA and CIRES scientists are spearheading the initiative to provide high-quality metadata for hundreds of data sets across NOAA using the ISO (International Standards Organization) 19115-2 and related standards. They also are developing a collection of metadata authoring, archiving and access tools known as the Enterprise Metadata System (EMS).

Iceland's Eyjafjallajökull volcano spews ash into the air in April 2010. ISTOCK

CIRES researchers are leading the way in the early detection and warning of tsunamis by developing a set of programs for the control, validation, processing and visualization of Deep-ocean Assessment and Reporting of Tsunamis (DART) data. The NOAA Tsunami Warning Centers, along with hazard managers, researchers and other parties, use DART to improve forecasting and understanding of tsunamis. CIRES scientists also processed and presented real-time DART data from the Chilean Feb. 27, 2010, and Tohoku March 11, 2011, earthquakes and tsunamis.

In related work, the NGDC's Natural Hazards database can now be explored using a powerful new interactive map interface that integrates historical tsunami events, significant earthquakes, volcanic eruptions and water-level data from open-ocean buoys and coastal tide gauges.

As record drought and heat beset the U.S., CIRES researchers continued pioneering development of a diagnostic/forecast tool for probabilistic forecast of seasonal drought and pluvial conditions. Work also continues, in collaboration with Bureau of Reclamation researchers, on reservoir-operations models, and with The Nature Conservancy and University of Washington on the modeling of water flows relevant to ecological applications. Additionally, CIRES staff briefed water managers throughout the country, including Colorado, the Southeast and California, on critical water issues such as runoff prospects, drought situations and river-basin predictions.

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

The Space Physics Interactive Data Resource (SPIDR) is an online system that allows customers to access space weather data sets, including geomagnetic, ionospheric and cosmic-ray data, along with Defense Meteorological Satellite Program (DMSP) satellite images (which display such features as aurora, city lights, fires and cloud coverage). CIRES scientists contributed to several new features—including a downloadable desktop graphical application for creating and executing workflows, as well as a new web-service interface that allows easier access to the web-service middle ware. These advances bring SPIDR's web services to a much larger community of science-data customers. In recognition of these accomplishments, the SPIDR team received a NGDC customer-service award and a NASA software award.

In support of NOAA's project goal to provide spatial and temporal depictions of human activities, CIRES and NOAA researchers developed a radiance-calibrated nighttime-lights product using data collected by DMSP satellite F16. This system overcomes the problem of saturation and allows bright urban cores to be resolvable. The product already has been used in studies of economics, stocks of metals and carbon emissions.

To aid in year-round transportation capabilities in the Arctic Ocean, NOAA researchers at the National Snow and Ice Data Center published a new data set as part of a multi-year program sponsored by the U.S. Maritime Administration: Arctic Marine Transportation Program 1979–1986. The data set will advance the program's goal to define environmental conditions in the Bering, Chukchi and Beaufort Seas; obtain data to improve design criteria for ice-worthy ships and offshore structures; and demonstrate the operational feasibility of commercial icebreaking ships along possible future Arctic marine routes.

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 the University of Colorado Boulder to NOAA.

University of Colorado Boulder

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

CIRES Divisions

Cryospheric and Polar Processes

Ecosystem Science

Environmental Chemistry

Environmental Observations, Modeling, and Forecasting

Solid Earth Sciences

Weather and Climate Dynamics

Interdisciplinary Research Centers

Climate Diagnostics Center

Center for Limnology

Center for Science and Technology Policy Research

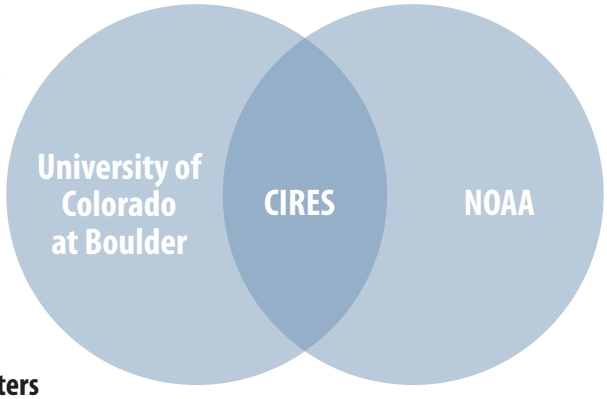
National Snow and Ice Data Center

Earth Science and Observation Center

Programs

Education & Outreach

Western Water Assessment



NOAA at Boulder 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

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, Associate Director
- Ecosystem Science: Carol Wessman, Associate Director
- Environmental Chemistry: Fred Fehsenfeld and Margaret Tolbert, Co-Associate Directors
- Environmental Observations, Modeling and Forecasting: Michael Hardesty, Associate Director
- Solid Earth Sciences: Anne Sheehan, Associate Director
- Weather and Climate Dynamics: Randall Dole, Associate Director

Fellows Committees

The Council of Fellows constitutes the "Board of Directors" and chief governing body of CIRES. It is comprised of individuals with an outstanding record of achievement and ability in diverse areas of environmental sciences. They are 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 FY11: Sept. 23, Oct. 21 and Nov. 18, 2010; and Jan. 20, Feb. 24, March 31 and April 21, 2011.

Council of Fellows

■ **Waleed Abdalati** Associate Professor of Geography; Director of the Earth Science and Observation Center

■ **Richard Armstrong** CIRES Senior Research Scientist in the National Snow and Ice Data Center; Associate Director of CIRES' Cryospheric and Polar Processes Division

■ **Ben Balsley** Research Professor and CIRES Senior Research Scientist

■ **Stan Benjamin** Chief of Assimilation and Modeling Branch, NOAA/ESRL GSD

■ **Roger Bilham** Professor of Geological Sciences

■ **Maxwell Boykoff** Assistant Professor of Environmental Studies

■ **John Cassano** Associate 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; Associate Director of CIRES' Weather and Climate Dynamics Division

■ **David Fahey** 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, and Dept. Chair of Geological Sciences

■ **Fred Fehsenfeld** CIRES Senior Research Scientist, ESRL CSD; Co-Associate 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; Associate Director of CIRES' Environmental Observations, Modeling, and Forecasting Division

■ **José-Luis Jiménez** Associate Professor of Chemistry and Biochemistry

■ **Craig Jones** Associate Professor of Geological Sciences

■ **William Lewis, Jr.** Professor of Ecology and Evolutionary Biology; Director of the Center for Limnology; Associate Director of CIRES

■ **Peter Molnar** Professor of Geological Sciences

■ **Steve Montzka** Research Chemist, NOAA/ESRL GMD

Executive Committee

The Executive Committee assists and advises the Director in matters regarding day-to-day management of the Institute. Members of the Executive Committee include the Associate Directors of CIRES' six divisions, two Fellows elected at-large for two-year terms (renewable for one term) and two Members' Council members. 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 Lecture 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. The committee and CIRES administrative staff schedule the guest lecturers and host them during their visit.

Fellows Appointment Committee

Fellows of CIRES are selected by two-thirds vote of the Council of Fellows and are appointed or reappointed by the Director of CIRES with the concurrence of the Vice Chancellor for Research and the Dean of the Graduate School. New Fellow nominations are considered by the Council of Fellows once yearly, drawing from the community of scientists at the University of Colorado at Boulder and NOAA. Cases for appointment of new Fellows are presented to the Council of Fellows by a committee of three or more Fellows. The initial appointment of any new CIRES Fellow is for two years, and continuing-term reappointments are for five years. Qualifications for reappointment are the same as for the initial appointment, except that the established record of the appointee must show evidence of commitment to the affairs of CIRES.

Innovative Research Program Committee

This program is designed to stimulate a creative research environment within CIRES and our NOAA partner organizations, 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.

■ **William Neff** Senior Scientist and Director, ESRL PSD

■ **Steven Nerem** Professor of Aerospace Engineering

■ **David Noone** Associate Professor of Atmospheric and Oceanic Sciences

■ **Judith Perlwitz** CIRES Research Scientist III, NOAA/ESRL PSD

■ **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 of the Climate Diagnostics Center

■ **Mark Serreze** Professor of Geography; Director of the National Snow and Ice Data Center

■ **Anne Sheehan** Professor of Geological Sciences; Associate Director of CIRES' Solid Earth Sciences Division

■ **Robert Sievers** Professor of Chemistry and Biochemistry; Director of the CU-Boulder Environmental Program

■ **Susan Solomon** Senior Scientist and Program Lead, Chemistry and Climate Processes, ESRL CSD

■ **Konrad Steffen** Professor of Geography; Director of CIRES

■ **Margaret Tolbert** Distinguished Professor of Chemistry and Biochemistry; Co-Associate Director of CIRES' Environmental Chemistry Division

■ **William Travis** Associate Professor of Geography; Director of the 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; Associate Director of CIRES' Ecosystem Science Division

■ **Tingjun Zhang** CIRES Senior Research Scientist in the National Snow and Ice Data Center

Emeritus Fellows

■ **Susan Avery** Former CIRES Director; Former Professor of Electrical and Computer Engineering

■ **Roger Barry** Distinguished Professor of Geography; Director, World Data Center for Glaciology

■ **John Birks** Professor of Chemistry and Biochemistry.

■ **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

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.

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 sabbatical or postdoctoral fellowship, 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 Academic Review and Planning Advisory Committee, award committees, tenure-consideration committees, and others. They are created as a need arises, exist to accomplish a specific task, and are then disbanded.

Diversity Committee

Recent studies highlight that fewer underrepresented minorities are pursuing careers in science, especially in higher education. To increase diversity is a major challenge we face today as scientists and educators, and CIRES has made it a priority to extend our knowledge and our community to include more of the diverse ethnic groups that make up society, and with a better gender balance. Toward that end, the Diversity Committee was created in 2010 to help achieve this goal. This initiative is headed by Eduardo Araujo-Pradere of the Space Weather Prediction Center along with Executive Assistant Yvonne Garcia and Associate Director for Administration Jon Rush. They work with CIRES Education and Outreach, the Communications Group, and scientists and staff to help identify opportunities for CIRES to make a difference in this vital work to enrich our science and enhance our mission.

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. These two representatives 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.

Organization

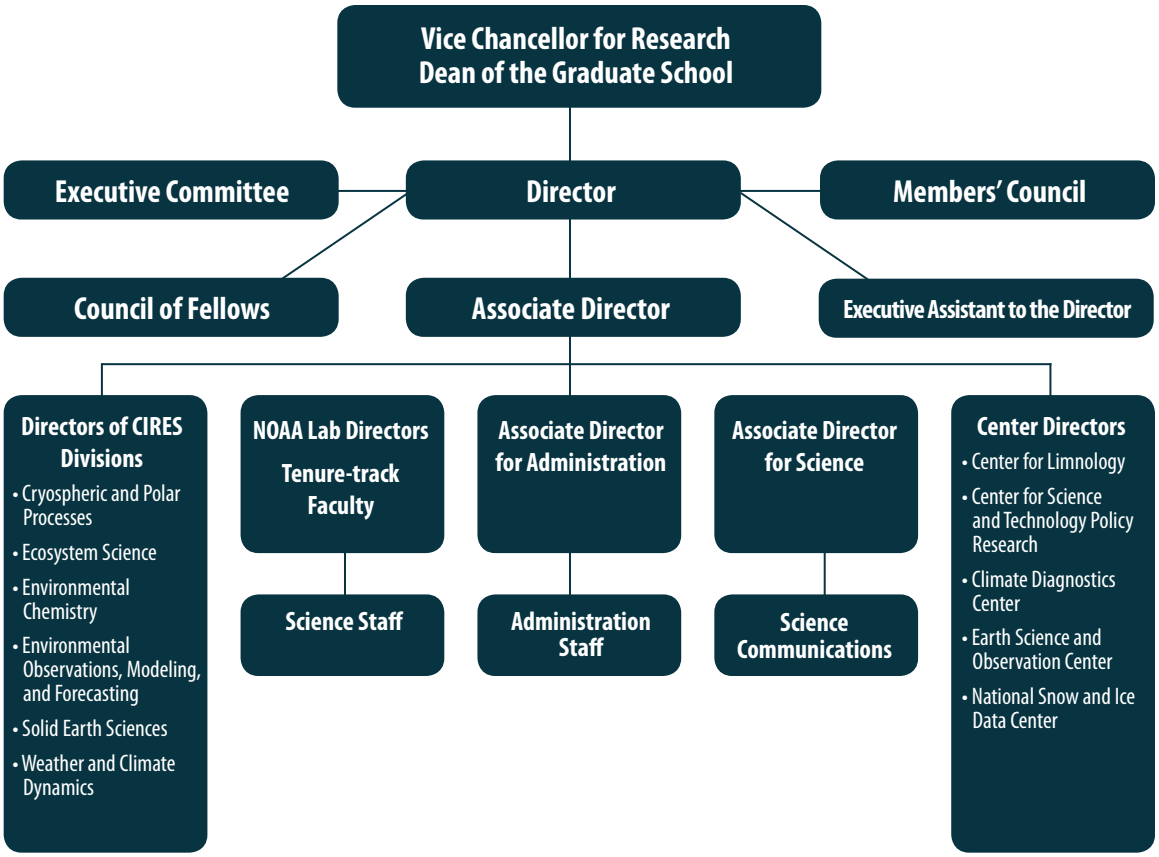
The Cooperative Institute for Research in Environmental Sciences (CIRES) is a scientific research institute established in 1967 between the University of Colorado Boulder and the National Oceanic and Atmospheric Administration (NOAA). CIRES maintains an interdisciplinary environment for research on the 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 allows 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 and an advisory Executive Committee. 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 11 university departments (see page 11). 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.

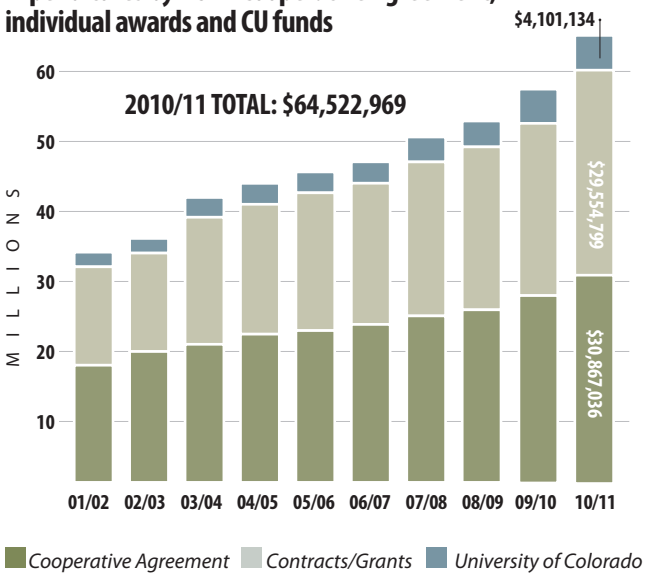
Vision and Mission

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.



Funding

Expenditures by NOAA Cooperative Agreement, individual awards and CU funds



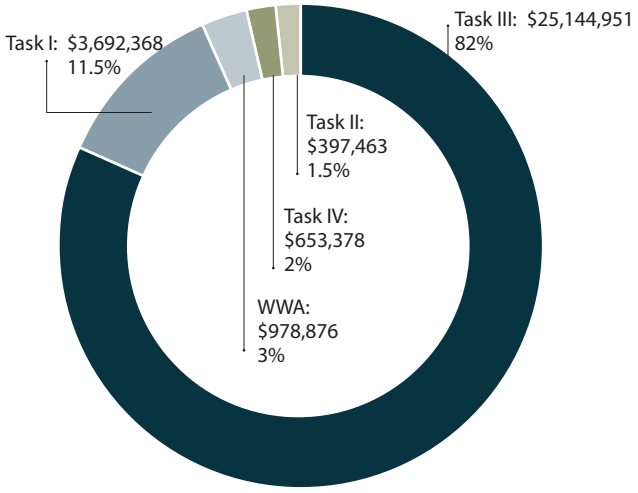
In recent years, CIRES has maintained steady growth, including a remarkable increase in FY11 of nearly 10 percent. (bar graph above). The largest portion of CIRES' funding (48 percent) is provided by the Cooperative Agreement with NOAA, and expenditures in this category have increased every year for the last decade. CIRES researchers also have 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 fluctuations in the CIRES-affiliated University faculty appointments.

Agreement expenditures by task for FY11 are shown in the top figure at right. Task I expenditures include CIRES administration and internal scientific programs, such as the Visiting Fellows and Graduate Student Fellowship programs. 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 mechanism for the administration of NOAA research grants and awards, which would otherwise be stand-alone projects outside the Agreement, to CIRES researchers in fields aligned with CIRES' mission. Two Task IV projects have been awarded through our NOAA "shadow" award, NA08OAR4320914.

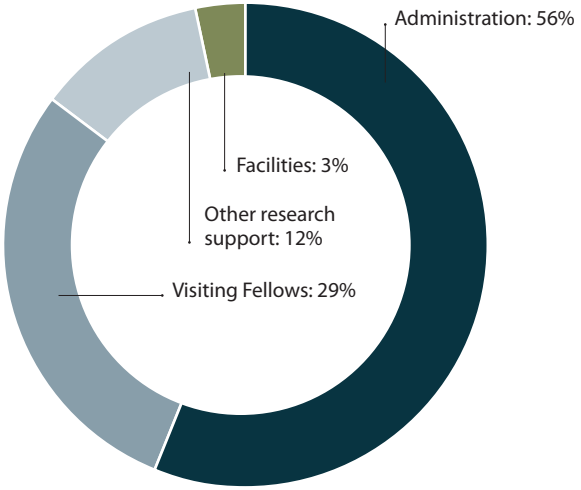
The largest share (56 percent) of Task I base funds support CIRES administration, primarily salaries and benefits for the administrative staff (middle figure at right). The Visiting Fellows program receives the second-largest share (29 percent) of Task I base fund support and is subsidized by other funding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

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

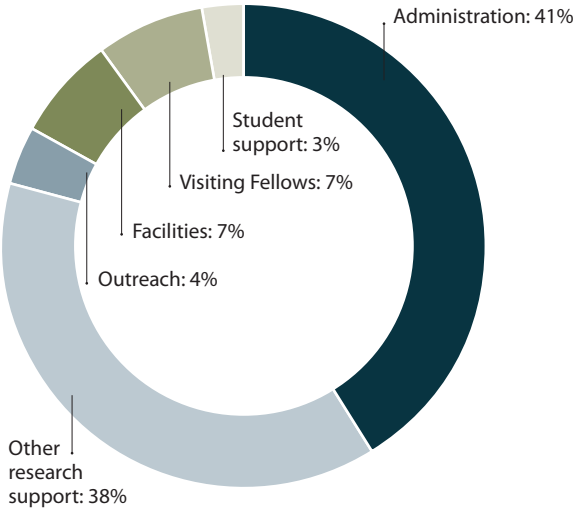
Cooperative Agreement expenditures by Task



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, hydrology, ecology, law and policy to work with decision makers across the Intermountain West to produce policy-relevant information about 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 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; CU-Boulder's Natural Resources Law Center, Institute for Behavioral Studies, Environmental Studies Program and Center for Advanced Decision Support for Water and Environmental Systems; and other researchers based at Utah State University and the University of Wyoming. WWA's mission 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. 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**

Using multidisciplinary teams of experts in climate, water, law and economics, the Western Water Assessment team works with decision makers across the Intermountain West to produce policy-relevant information about climate variability and change. ***Page 70***

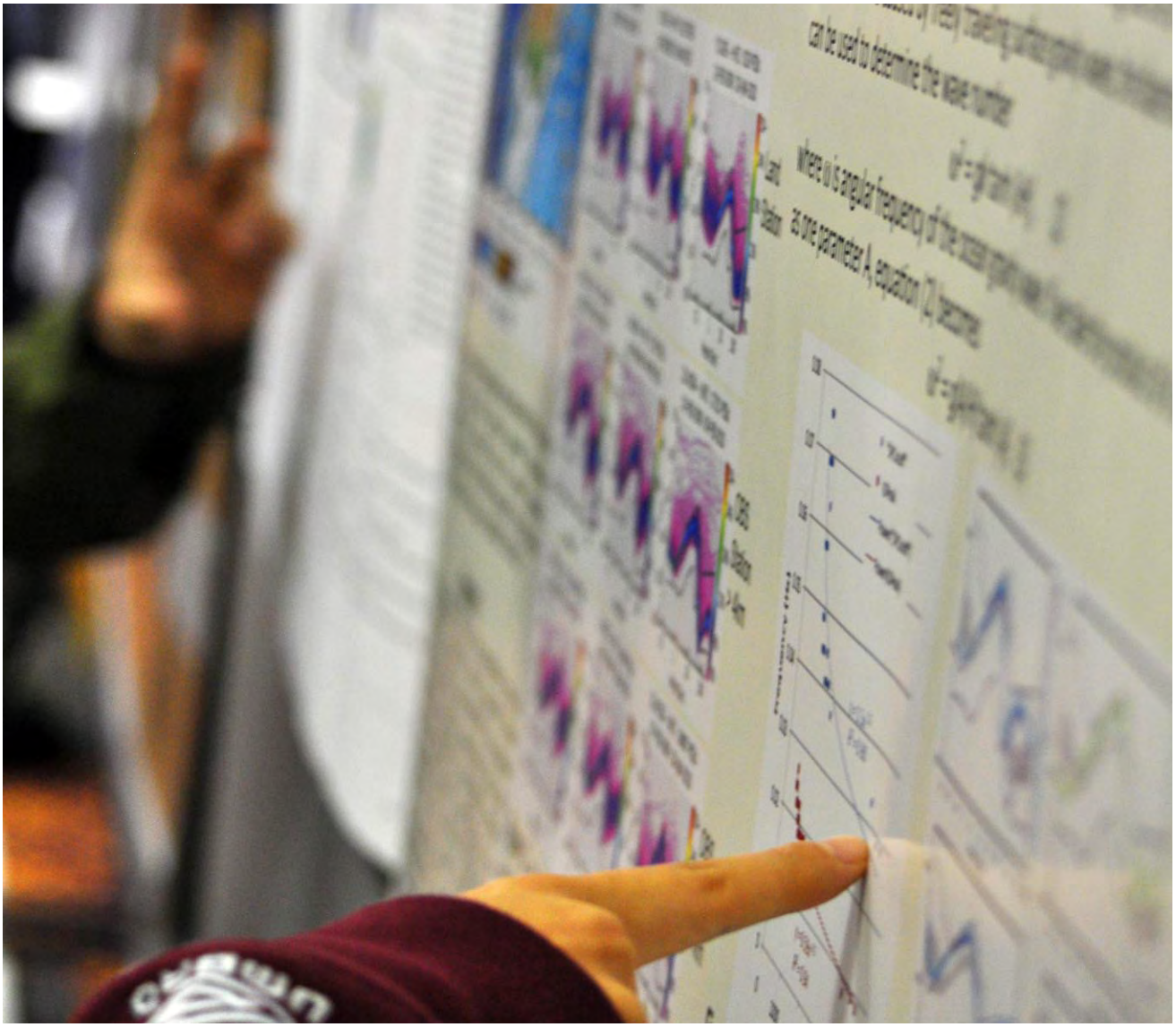
Education and Outreach

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 Inspiring Climate Education Excellence, the Climate Literacy Energy Awareness Network and the Colorado Collaborative of the Center for Ocean Science Education Excellence. Student programs include the National Ocean Sciences Bowl, after-school activities for students underrepresented in science and fellowships for graduate students participating in a K-12 education project. Climate communications workshops, support for education activities, and research-proposal preparation assistance support scientists.

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

The CIRES Education and Outreach (EO) group is active across the spectrum of geosciences education, including teacher and scientist professional development, digital learning resources and courses, graduate student fellowships and more. ***Page 72***



DAVID OONK/CIRES

The CIRES Members' Council Rendezvous! science symposium featured poster presentations and a state-of-the-institute address by Director Konrad Steffen.

Visiting Fellows Program

CIRES annually conducts a competitive Visiting Fellows program that promotes collaborative research at the forefront of scientific knowledge. Fellowships of up to one year are awarded to Ph.D. scholars (Postdoctoral Fellowships) and faculty planning sabbatical leave (Sabbatical Fellowships). Visiting Fellows conduct interdisciplinary research in areas such as atmosphere and ocean processes, cryospheric processes, ecology and ecosystems, regional/global environmental variability and change, global water cycle, advanced observing systems, geophysics, global health, science and technology policy research, and space weather. Selections for the Visiting Fellows program are based in part on the likelihood of interactions between the Visiting Fellows and the scientists at CIRES and the degree to which both parties will benefit from the exchange of new ideas. To further this goal, priority is given to candidates with research experience at institutions outside the Boulder scientific community. Since 1967, CIRES has awarded over 265 Visiting Fellowships. Recipients have included previous CIRES Director Susan Avery and current Director Konrad Steffen.

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

Rendezvous!

More than 400 people attended the CIRES Members' Council's fifth annual Rendezvous research symposium on April 22, 2011. This half-day, institute-wide symposium featured 100-plus posters showcasing the depth, breadth and quality of the science being conducted at CIRES. Director Konrad Steffen spoke about the "State of the Institute," and presented awards for outstanding performance, years in service and other scientific achievement.

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

DAVID OONK/CIRES

CIRES Director Konrad Steffen presents an Outstanding Performance Award to a team from the ESRL Chemical Sciences Division for their support of NOAA P-3 science flights over the Gulf of Mexico to study air-quality risks caused by the Deepwater Horizon Oil Spill.

Individual Performance Awards

The CIRES Awards Committee, comprised of CIRES Members' Council representatives, annually reviews nominations and recommends awards for outstanding professional achievement. Three Outstanding Performance Awards are given for science and engineering and two for service. Each award is for $2,000, and each recipient also receives a desktop trophy. Winners of the CIRES Outstanding Performance Awards for Science and Engineering in 2010 were Dave Carter, Dave Costa and Paul Johnson of ESRL Physical Sciences Division for their work to design, prototype, build and deploy a new network of snow-level radars for California; Paul Loto'aniu and Juan Rodriguez of the Space Weather Prediction Center for their investigation of the failure of the Galaxy-15 geostationary communications satellite; and a team consisting of Ken Aikin, Roya Bahreini, John Holloway, Gerhard Hübler, Dan Lack, Justin Langridge, Andy Neuman, John Nowak, Jeff Peischl, Anne Perring, Ilana Pollack, Harald Stark and Carsten Warneke of the ESRL Chemical Sciences Division for their support of the NOAA P-3 science flights in June 2010 over the Gulf of Mexico to assess the potential air-quality risks posed by the BP Deepwater Horizon Oil Spill crisis to workers/citizens in the Gulf and surrounding areas. Awards for Outstanding Performance for Service went to Craig Tierney of ESRL Global Systems Division for his work as a leader of the High Performance Computing (HPC) team that has led to significant improvements that have served CIRES and other NOAA centers and the HPC community as a whole; and Katherine Leitzell of the National Snow and Ice Data Center for her leadership and initiative as science writer and editor for NSIDC's hugely visible Arctic Sea Ice News and Analysis (ASINA) product, which provides a monthly scientific sea-ice analysis that is picked up by news media worldwide, and for her work for the Antarctic Glaciological Data Center. Leslie Hartten (Physical Sciences Division-PSD) received the 2011 Director's Award for Diversity.

DAVID OONK/CIRES

Three CIRES Outstanding Performance Awards are given annually for science and engineering and two are given for service.

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 committee selects the award recipients, and the results of their research are presented the following year at a poster reception. The 13th annual Innovative Research Program in 2011 funded six projects, including research into the formation of secondary organic aerosols from evaporated crude oil, developing radar for renewable energy research and the development of novel lidar technologies for profiling the whole atmosphere.

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

Graduate Research Fellowships

CIRES supports two prestigious student fellowship programs: the long-established CIRES Graduate Student Research Fellowship (GSRF) and the ESRL-CIRES Fellowship, awarded to prospective masters and doctoral students every other year with the support of NOAA's Earth System Research Laboratory.

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

Conferences, Workshops, Events, Presentations

CIRES hosts conferences, workshops, events, lecture series and presentations throughout the year. See page 173 for a complete list of FY11 events.

BRIAN CLARK/CIRES

Bruce Strickrott, captain of the Deep Submergence Vehicle Alvin, was the keynote speaker at the National Ocean Sciences Bowl Trout Bowl.

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.

OCTOBER 8, 2010

Daniel J. Jacob

Harvard University

Mercury in the environment: Where does it come from, where does it go?

NOVEMBER 5, 2010

Mike Hulme

University of East Anglia, Norwich, UK

Why we disagree about climate change

NOVEMBER 19, 2010

Andrew Revkin

Science Reporter, *The New York Times*

Are we stuck with 'blah, blah, blah bang'?

FEBRUARY 4, 2011

David Goldston

Director of Government Affairs,
U.S. Natural Resources Defense Council

Loving science to death: Problems at the intersection of science and policy

APRIL 29, 2011

Peter Rhines

University of Washington

Exploring the cold oceans of the North

CIRES Communications

It has long been a part of CIRES' mission to communicate world-class research in ways that help inform decision makers and the public about how we can best ensure a sustainable future environment. Our communications work involves close collaborations with NOAA, CU-Boulder, our centers and international colleagues in academic and government institutions. In FY11, communication efforts included: Press releases and media relations, tweets, *Spheres* magazines, web features and multimedia presentations, many of which are listed below. CIRES research was discussed widely in the media, receiving coverage in, for example: *USA Today, Time, The New York Times, Scientific American,* CBS, *Discovery, Discovery News, National Geographic,* Nature News BBC, *Business Week,* MSNBC, Fox News, *Science NOW, Science News, Nature News* and the *Los Angeles Times.*

Press releases

■ Ambient ocean noise helps scientists monitor ocean physics and quantify and predict climate change. (07/10)
■ Sea levels rising in parts of the Indian Ocean. (07/10)
■ Texas petrochemical emissions down, but industry still underestimates its contribution to air pollution. (08/10)
■ Aerosols control rainfall in the rainforest and originate from forest ecosystem as biological particles. (09/10)
■ Desert dust reduces river flow in the Colorado River. (09/10)
■ Arctic sea-ice extent falls to third-lowest extent, continuing a downward trend. (10/10)
■ Water flowing through ice sheets accelerates ice warming and could speed up ice flow. (11/10)
■ Study shows discrepancies between modeled and data-based estimates of stratospheric air circulation. (11/10)
■ Extent of corruption in countries around the world tied to earthquake fatalities. (01/11)
■ The 20th Century Reanalysis Project: A time machine for climate scientists. (01/11)
■ Large dams can affect local climates, says new study. (02/11)
■ Thawing permafrost will accelerate warming in decades to come. (02/11)
■ Alternative theory on the formation of the Colorado Rockies. (02/11)
■ CIRES Fellow Robert Sievers develops new inhalable measles vaccine. (02/11)
■ CIRES scientists use Erie Tower to study wintertime air chemistry. (03/11)
■ New network of snow-level radars deployed in California. (03/11)
■ Natural variability main culprit of deadly Russian Heat Wave, which killed thousands. (03/11)
■ Insights from Gulf Oil Spill air-pollution study identify previously unknown sources of air pollution in urban environments. (03/11)
■ Scientists use airborne chemistry measurements for the first time to assess flow rate, fate of spilled gases and oil during Gulf Oil Spill. (03/11)
■ CIRES Fellow Roger Bilham investigates Japanese quake. (03/11)
■ Measurements of winter Arctic sea ice show continuing ice loss. (03/11)
■ Scientists investigate wind turbine wakes with a view to improving the productivity of wind farms. (04/11)
■ Newly detected chemical in smoke may have serious health implications. (05/11)
■ Ice loss in Greenland and Antarctica changing the Earth's shape. (06/11)

Spheres magazines

This periodic publication highlights the diversity of CIRES research in particular topics.
■ Snow and Ice (28 pp, 12/10)

@theCIREswire | youtube.com/user/CIRESvideos

Multimedia

■ Clearing the Air (08/10, podcast). Texas petrochemical emissions are down but still underestimated.

■ Robbing the West (09/10, video). Study shows the dark-colored dust on snow makes the snow melt early and robs the Colorado River of about 5 percent of its water each year.

■ CIRES—Science in Motion (12/10). An overview of CIRES: CIRES researchers explore all aspects of the Earth system and search for ways to better understand how natural and human-made disturbances impact our dynamic planet.

■ CIRES Expertise on Loan to DIY "Disaster House" (03/11, video). A behind-the-scenes look as CIRES researcher Christopher Williams provides his scientific expertise for two episodes of the DIY Network program "Disaster House."

■ Insights from Gulf Oil Spill (03/11, podcast). Air pollution study assesses impacts of the Gulf Oil Spill.

■ Climate change and the water cycle (04/11, video). Western Water Assessment Director Brad Udall discusses the relationship between climate change and the water cycle.

■ Discovery of isocyanic acid in smoke (05/11, video). CIRES Fellow and NOAA Research Physicst Joost de Gouw discusses the discovery of a chemical in smoke that may have serious health implications.

■ A CIRES Division Video: Cryospheric and Polar Processes (05/11, video) Mark Serezze, director of CIRES' Cryospheric and Polar Processes Division and the National Snow and Ice Data Center, discusses the importance of understanding the world's frozen resources.

■ CIRES Division: Ecosystem Science (05/11, video). Carol Wessman of CIRES' Ecosystem Science Division discusses the study of life in the Earth system.

■ CIRES Division: Solid Earth Sciences (05/11, video). Anne Sheehan discusses the areas of study within CIRES' Solid Earth Sciences division.

■ Remote Sensing: What and Why? (06/11, video). CIRES Fellow Waleed Abdalati discusses the use of remote sensing to study the Earth's environment.

■ Measurements in the Sky: CU Micro Autonomous Vehicles (06/11, video). CIRES Fellow Ben Balsley and Aerospace Engineering Sciences Professor Dale Lawrence team up for an interdisciplinary effort to study the environment.

■ Urban Greenspace (06/11, video). CIRES Fellow Carol Wessman discusses her work in the area of urban greenspace.

■ Wind and Wake (06/11, video). CIRES and NOAA scientists studying the wake effect of wind turbines.

■ CIRES Division: Center for Science and Technology Policy Research (06/11, video). Roger Pielke, Jr., discusses the work of CIRES' Center for Science and Technology Policy Research.

■ CIRES Division: Education and Outreach (06/11, video). Susan Buhr discusses the work of CIRES' Education and Outreach group.

■ Using Lidar to Study the Atmosphere (06/11, video). CIRES graduate student Ryan Neely talks about his use of lidar to study the atmosphere.

■ City Lights Exacerbate Air Pollution (06/11, video). CIRES scientist Harald Stark discusses how bright city lights can affect daytime air pollution.

People&Projects

NOAA Scientists

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

CU-Boulder Teaching Faculty

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

CIRES Scientists

Richard Armstrong
Joost de Gouw
Judith Perlwitz
Prashant Sardeshmukh
Tingjun Zhang

CIRES starts with people. Researchers here all seek to better understand the planet, and they do so from different perspectives that reflect diverse areas of expertise. Fellows, 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 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 Theme Reports (page 82).

Waleed Abdalati

Studying Ice Sheets from Orbit

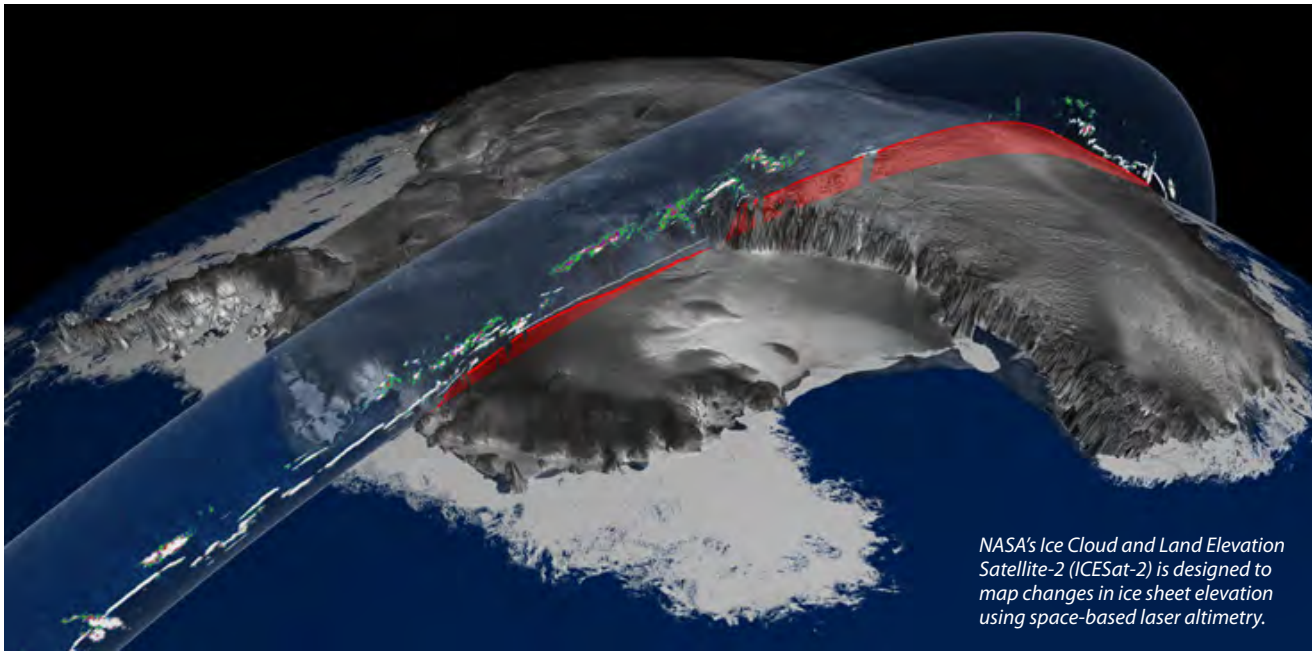
FUNDING: NASA

Satellite observations of recent dramatic changes in the Earth's polar ice cover have transformed our thinking about polar ice in recent years. A key space-based capability for understanding this critical part of the Earth system is NASA's Ice Cloud and Land Elevation Satellite-2 (ICESat-2). ICESat-2 is designed to significantly improve upon measurements begun by its predecessor, ICESat, to map changes in ice sheet elevation using space-based laser altimetry. Through Dec. 31, 2010, I served as lead of the ICESat-2 Science Definition Team, which has been carrying out extensive analyses to define and optimize the science capabilities of the ICESat-2 mission.

I have also been working with data from the Gravity Recovery and Climate Experiment (GRACE), airborne laser altimetry, ice-penetrating radar and various other satellite observations. GRACE measures changes in the Earth's gravity field, which are used to infer ice-sheet mass changes and evolution with time. The airborne laser altimetry provides high-resolution measurements of ice sheet changes to complement those made by satellites to better understand outlet glacier changes. Ice-penetrating radar observations provide information on the geometry of the bedrock over which these glaciers flow, enabling better understanding of the controls on glacier discharge. The other satellite observations provide insights into the ice flow, ice melt and ice deformation processes.

Using these tools, I seek to understand the behavior of glaciers and ice sheets and the mechanisms that control them. My primary focus is on Greenland; however, my research interests are also on the Canadian ice caps and the Antarctic Ice Sheet. My ultimate research objectives are to determine how and why the Earth's glaciers and ice sheets are changing, and what the implications are for sea-level rise.

Beginning Jan. 2, 2011, I began an assignment as Chief Scientist of the National Air and Space Administration. I am currently on a two-year leave of absence from the University of Colorado Boulder (CU) to fulfill my responsibilities as NASA Chief Scientist, which include: serving as primary advisor to the NASA administrator on scientific matters related to NASA; interfacing with Congress, the Executive Office of the President and other federal agencies to ensure alignment among NASA, White House and Congressional Science priorities; representing NASA's science programs to the public and the scientific community; and serving as a voice for science within the Agency. This continues to be a challenging and fascinating experience, and I look forward to returning to the University and using what I learn in this position to better serve the University community. In the meantime, I keep a hand in the research, working with my graduate students and other colleagues at CU to carry this research forward.



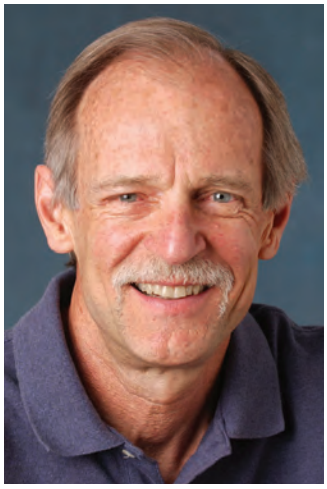
NASA's Ice Cloud and Land Elevation Satellite-2 (ICESat-2) is designed to map changes in ice sheet elevation using space-based laser altimetry.

NASA IMAGES

Richard Armstrong

The Glaciers and Seasonal Snow Cover of the Himalaya-Karakoram-Hindu Kush Region

FUNDING: NASA EARTH SCIENCE, WORLD BANK, USAID

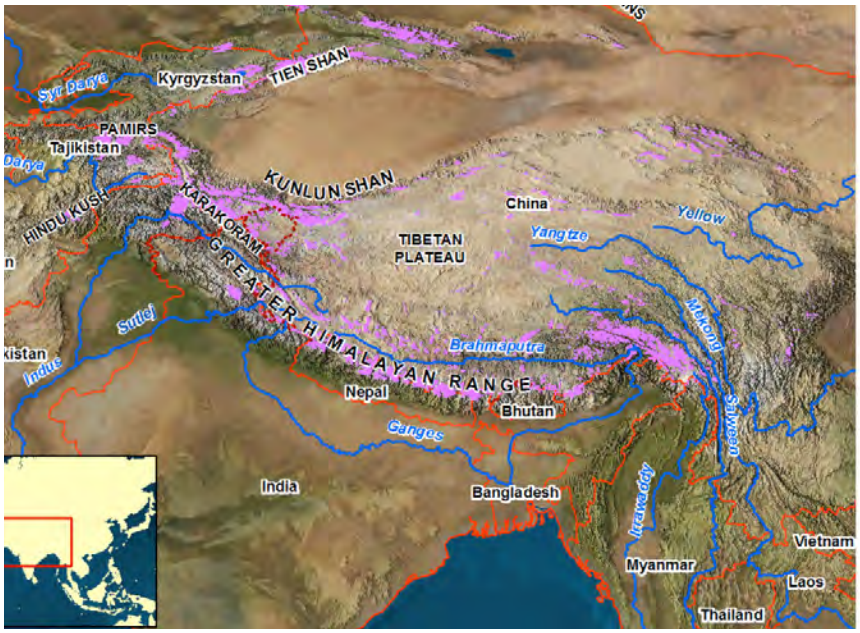


Snow and ice constitute a significant component of the hydrologic regime of the high alpine catchments of the world such as the Himalaya-Karakoram-Hindu Kush (HKH) region. The timing and spatial patterns of snow- and ice-melt play key roles in providing water sources for irrigation, hydropower generation and general consumption. Hydrologic processes in the high-altitude regions of the world are particularly sensitive to climate change because of the predominant role of snow and glaciers.

The overall objective of this study is to develop an accurate, comprehensive assessment of the snow and glacier contribution to the water resources originating across the greater HKH region. Approximately one-third of the world's human population depends to some degree on fresh water availability within the HKH hydrologic system, and planning for future changes is a high priority. However, realistic, accurate and comprehensive assessments of the current and future availability and vulnerability of the water resources in these regions are not possible until the existing hydrologic regime of these mountains is better defined; the relationship between snow, glaciers and streamflow is evaluated in quantitative terms; and the contribution from other sources of streamflow is examined. To date, this comprehensive goal has not been addressed in a coordinated and systematic manner, and conclusions reached by other investigations have often been based on anecdotal evidence that is typically not spatially representative. Specifically, our project objectives are being accomplished through the application of a comprehensive suite of satellite remote sensing and ground-based data as input to appropriate snow- and ice-melt models. A series of distributed process models, in conjunction with area-altitude relationships for snow, ice and temperature data, is being used to assess the general hydrometeorological environment of these mountain-catchment basins

Although often considered as a single region, the HKH represents a wide range of climate conditions where precipitation and basin runoff decrease considerably from the east to west as a direct result of the weakening influence of the summer monsoon. The glacier accumulation and ablation patterns are distinctly different, seasonally and spatially, across the region. In the east, the summer season combines both accumulation at the highest elevations with melt below, while in the west, there is a clear pattern of summer melt and winter accumulation, similar to North America and Europe. Earlier results have indicated that only about 5 percent or less of the river flow in the eastern Himalaya is the result of glacier melt (Alford et al., 2010). Outside the monsoon-dominated eastern Himalaya, the contribution from melting glacier ice has been estimated to be as much as 30 percent or more, but no accurate quantitative assessments have been undertaken. Therefore, the current phase of our project focuses on quantifying the contribution of melting glacier ice, melting seasonal snow, rainfall and groundwater to total streamflow in the western Himalaya, and extending into the Pamir mountain range of Central Asia, based on melt models and stream geochemistry.

Graduate student Adina Racoviteanu using a GPS to establish ground control points in support of accurate glacier mapping from satellite data, Khumbu region, Nepal.



Mountain ranges, river systems and glaciers of the Himalayan-Karakoram-Hindu Kush region.

Ben Balsley

Fine-Scale In Situ Measurements to Study Atmospheric Dynamics (0-10 km)

We are currently involved in examining the fine-scale details of atmospheric dynamic processes from the surface to upper-tropospheric heights. Understanding these processes, which occur on scales of meters and seconds, is turning out to be critical for gaining a better understanding of energy-cascading processes throughout this region.

The vehicle used in these measurements, called the CUMAV (University of Colorado Micro Autonomous Vehicle), was developed by Professor Dale Lawrence of CU's Aerospace Engineering Department. The CUMAV is a small, low-cost, programmable, reusable, autonomous, GPS-controlled, battery-powered aircraft. Total cost per unit is in the vicinity of $1,000. CIRES has equipped it with fast-response sensors to measure temperature, humidity, wind speed, wind direction and 'temperature' turbulence (CT2). Data are both telemetered to the ground as well as archived aboard for later downloading and analysis.

For upper-tropospheric measurements, the CUMAV will be carried aloft beneath a conventional meteorological balloon. After release, it will fly to a specific location, spiral downward and then land at a predetermined site. Typical spiral diameter is 100 to 200 m. Vertical resolution is in the range of 1 to 2 m.

An example of our initial measurements appears in Figure 1. This figure plots temperature (expressed here in volts) versus time. These data were obtained while the CUMAV was flying a series of 12 circles at a constant height of 56 m over central Kansas. Although the full range of temperatures shown here is very small (1.11–1.17°C), a clear indication of mean heating can be seen by the upward trend in the dotted line. The sharp 'spikes' on top of this mean curve appear to be manifestations of early convective activity that increases with time as the atmosphere warms. The horizontal width of the smaller spikes can be less than 15 m or so.

We anticipate that this technique will serve as an impetus for developing a unique, new and powerful technology for studying fine-scale dynamic processes throughout the first 10 km of the atmosphere.

PHOTOS BY DAVID OONK/CIRES

In one of three possible launch modes, the CUMAV is launched using a bungee cord. In this case, the actual release is triggered by a computer command.

Dale Lawrence, Professor Aerospace Engineering Sciences, prepares to launch the CUMAV by hand.

To launch from a higher altitude, the CUMAV is raised into the air via balloon, released and then controlled remotely. Landing the CUMAV in all situations is autonomous, with the landing site programmed prior to launch. Because of its relative ruggedness (Styrofoam fuselage, pusher propeller and embedded sensors), the aircraft can land safely virtually anywhere.

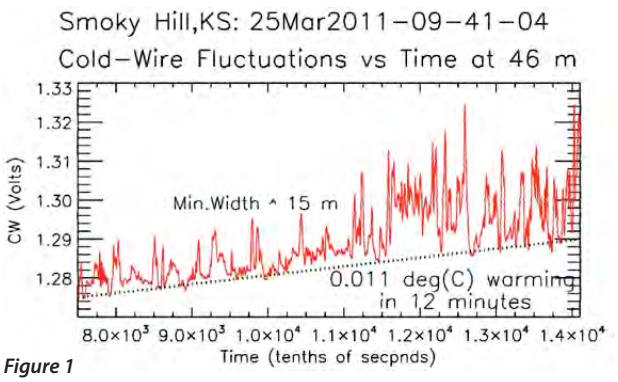


Figure 1

Roger Bilham

Block Bounding Bookshelf-Faulting in Baluchistan

FUNDING: NATIONAL SCIENCE FOUNDATION

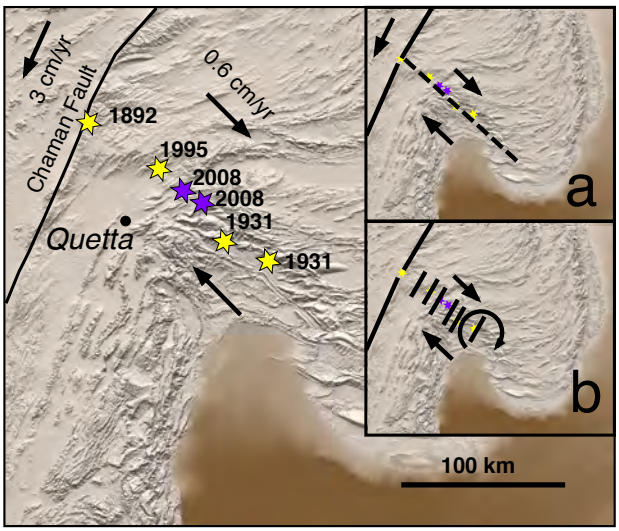
In 2008, a pair of earthquakes occurred northeast of Quetta, Pakistan, causing the collapse of several thousand buildings and the burial of others in landslides. As it happened, the earthquakes occurred within a line of collaborative GPS survey points installed by our colleague Din Mohammad of the University of Baluchistan expressly to monitor earthquake processes in the region. They revealed the existence of an interesting new phenomenon for earthquakes in the Indian plate: bookshelf-faulting.

The earthquakes were unusual in that two identical earthquakes occurred 11 hours apart—two mainshocks followed by a sprinkling of magnitude 5 and magnitude 4 aftershocks in the next few months. The initial mechanisms of the earthquakes indicated a sliding motion, and as is always the case with strike-slip earthquakes, additional information was needed to decide whether the far side of a northwest-striking fault slipped to the right, or the far side of a northeast-striking fault slipped to the left. In this case, the decision seemed easy enough, because the two mainshocks were aligned northwest. The earthquakes appeared to have occurred on two adjoining segments of a 50 km–long northwest fault. End of story? Not quite.

The GPS points installed before the earthquakes were shifted tens of centimeters when they were remeasured in the following weeks, but far from confirming the contiguous rupture theory, their motion equally satisfied the rupture of two parallel faults separated by 15 km, we found. We decided to investigate further.

We first gathered a few dozen seismograms from throughout the world that had recorded the earthquakes in detail, and to our surprise, we found that to emulate the seismic waves wiggle for wiggle, most of the energy had been released on northeast-trending planes parallel to each other. For further verification, we examined satellite images (from interferometric synthetic aperture radar, InSAR) of the earthquakes. These were severely distorted by widespread avalanches that had occurred throughout the region during the events, but enough of the deformation pattern anticipated from a pair of parallel quakes had been preserved to confirm the seismic solution.

The implication that two parallel faults had slipped in 2008 meant that perhaps other earthquakes in the region had slipped similarly in the past. A search revealed three more. The first was the largest aftershock of the 2008 sequence, indicating that this sequence had actually permitted three parallel faults to slip. The second was a moment-magnitude 5.5 earthquake in 1995 to the northwest; and the third was a 1931 moment-magnitude 7.1 earthquake to the southeast. We now believe that these parallel faults bound the edges of a series of contiguous blocks 15 km wide and 20 km long, all rotating slowly clockwise allowing northern Baluchistan to slide southeast relative to the ranges east of Quetta. The process is called bookshelf-faulting and has hitherto been found in Iceland, Afar and parts of California.



Moderate earthquakes north of Quetta (dates of occurrence are shown) appeared to fall along a line that suggested a large fault could slip (a). We now know that they occurred on shalt faults bounding blocks that are incrementing clockwise during earthquakes. Bookshelf-faulting means that the magnitudes of the earthquakes are limited to about Mw=6.0.

Din Mohammad, left, and Bilham.

Most of the edges of the rotating blocks have slipped at least once in the past century, and are likely to do so again in the next. That is, the zone of bookshelf-faulting can be defined as a source of persistent seismic hazard, an important contribution to the characterisation of future seismic risk in Baluchistan.

Din Mohammad was invited by the Seismological Society of America to present these findings at its annual meeting in Portland, Ore., this year, the first such honor ever to be extended to an international guest.

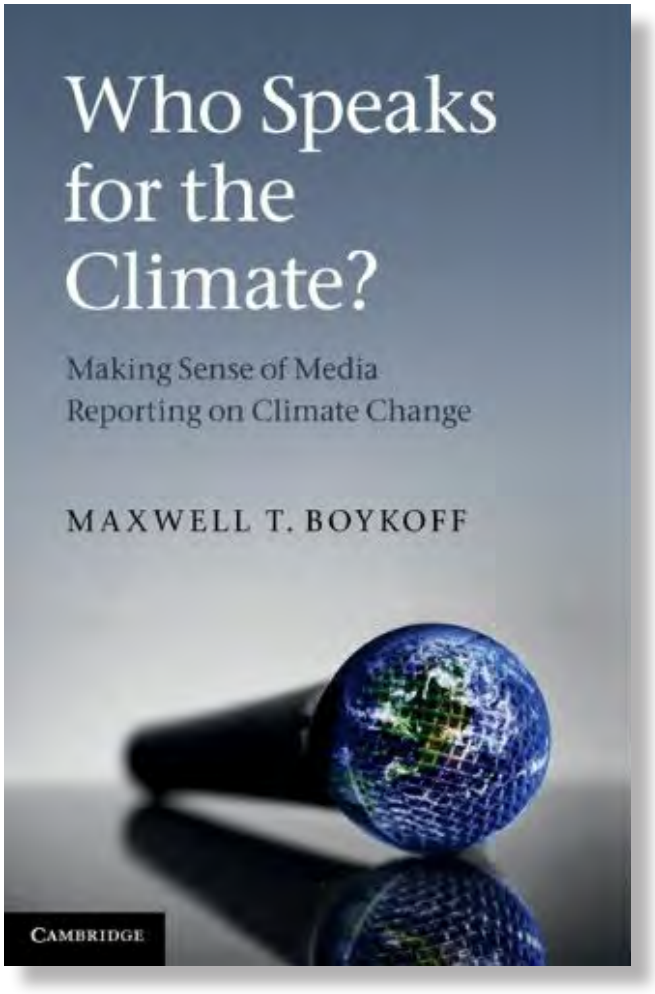
Maxwell Boykoff

Making Sense of Media Representations of Climate Change

Media representations—from news to entertainment—provide critical links between the everyday realities of how people experience climate change and the ways in which these are discussed between science and policy actors. Clearly, activities in climate science and politics have provided content and characters for the media to cover. But perhaps more subtly, media representations have, in turn, shaped ongoing scientific and political considerations, decisions and activities. In other words, mass media have influenced how issues are taken into account, who has a say and how. This research has analyzed how a burgeoning array of 'actors,' 'agents of definition' and 'claims makers' in these spaces have created, contested, negotiated and reconfigured climate science and policy discourses and actions over time.

Many dynamic, nonlinear and complex factors contribute to how media outlets portray various facets of climate change. Swirling contextual factors as well as competing journalistic pressures and norms contribute to how issues, events and information have often become climate 'news.' Such challenges have contributed to critical misperceptions, misleading debates and divergent understandings that are detrimental to efforts that seek to enlarge rather than constrict the spectrum of possibility for responses to climate challenges.

This research is situated in wider 'cultural politics of climate change,' where formal climate science and governance link with daily activities in the public sphere. It is important to examine 'how' media representations have been negotiated over time and space, through relations of power and inequalities of access and resources, thereby influencing climate action.



World newspaper coverage of climate change, as well as U.S., United Kingdom and India country-level monitoring of climate coverage, are updated each month here: http://sciencepolicy.colorado.edu/media_coverage/.

John Cassano

Polar Climate and Meteorology

FUNDING: NATIONAL SCIENCE FOUNDATION

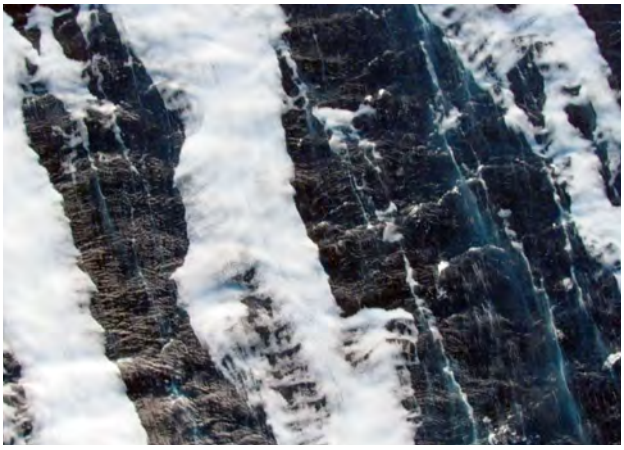
The Cassano Polar Climate and Meteorology research group is involved in both numerical modeling of polar climate and observational studies in polar regions. In September 2009 we used the Aerosonde unmanned aerial vehicle to make detailed observations of air-sea interactions in the Terra Nova Bay polynya, a region of open water surrounded by sea ice and land. During this campaign, the Aerosondes flew a total of 130 flight hours with air temperatures as cold as -40°C and wind speeds in excess of hurricane force. Observations from the Aerosondes provided the first in situ observations of the atmospheric state and air-sea interaction over this polynya during the late winter/early spring. Digital photographs from the Aerosondes provide detailed views of the polynya surface and assist us in interpreting the other data collected by the UAS.

Strong winds over the polynya result in large heat and moisture fluxes from the ocean to the atmosphere, leading to pronounced modification of both the ocean and atmosphere. Wind, temperature and humidity data collected by the Aerosonde UAS have allowed us to calculate the heat and moisture fluxes over the polynya—the first such in-situ estimates of these fluxes for wintertime conditions. These fluxes, along with other data from this field campaign, will provide insight into the formation of Antarctic bottom water, details on the atmospheric forcing for this polynya and validation data for high-resolution numerical simulations.

We are planning a repeat field mission in September 2012. We are also exploring the use of smaller and less expensive UAS for less-demanding missions. In January 2012 we will deploy a small unmanned aerial observer (SUMO) UAS in Antarctica to observe the details of the atmospheric boundary layer in the vicinity of the McMurdo Station.

J. REUDER, UNIVERSITY OF BERGEN

SUMO UAS in flight



Aerial photograph of the polynya surface showing bands of wind-accumulated frazil ice with open water and white cap waves, Sept. 24, 2009.

Aerosonde UAS being launched from the roof of a pickup truck at the Pegasus white ice runway, Antarctica.

Tom Chase

Land and Ocean Surface Impacts on Global Hydrology

We continue to examine the impact of surface hydrology on climate, particularly in the massively irrigated regions of Asia, and have found evidence of substantial impacts both in observational and model simulation studies. For example, irrigation in India seems to have reduced monsoon rainfall and slowed the East Asian Jet maximum, indicating that circulations around the globe could be affected by human disturbances to the land surface in remote areas.

We have continued examining minimum temperature regulation by convection at high latitudes and have updated our observational analysis of this phenomenon in the last year. This work documents that mid-tropospheric temperatures at high latitudes reach a minimum (about -40°C) early in the winter and then never get much colder, despite the lack of solar input for months. We hypothesize that this is due to convective heating driven by sea-surface temperature slightly below 0°C in cold air masses that migrate over the ocean. Surface air rises moist adiabatically to reach the observed minimum by 500 mb. We are proposing to extend this to maximum temperatures and lower latitudes in future work.

Finally, we also have been looking into low-level inversions in the Western United States, which we found to have substantially decreased in frequency—but increased in strength—over the period of record in six Western cities (Figures 1 and 2 show trends in inversion frequency and strength in Denver, Colo.). This is of interest because air quality in the West is a function of inversion frequency and strength and because climate models have predicted that inversions would be more frequent in a warming climate.

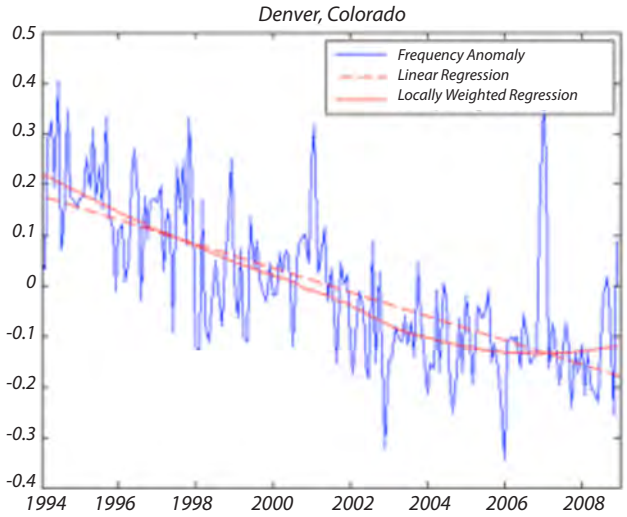


Figure 1: *Monthly anomalies in the occurrence of two or more consecutive days in Denver, Colo., during which low-level daytime inversions were present. Y-axis is fraction of days per month, and x-axis is calendar year. Locally weighted regressions smooth the original data using a 0.7 span.*

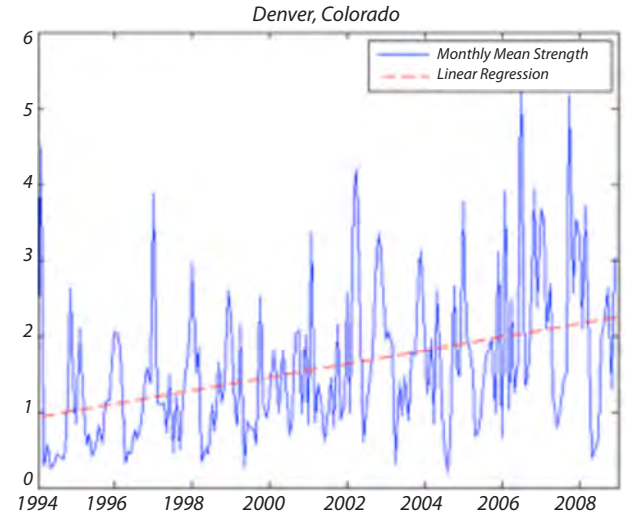
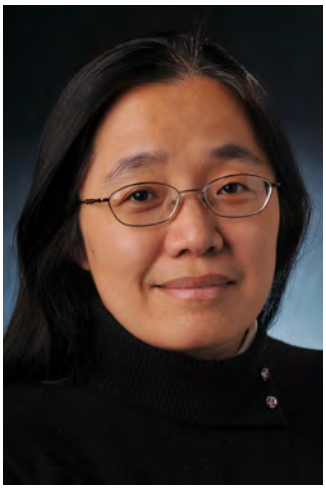


Figure 2: *Monthly anomalies in frequencies (fraction of days per month during which inversions were present) of low-level inversions. Y-axis is fraction of days per month, and x-axis is calendar year.*

Xinzhao Chu

LIDAR Research Campaign at McMurdo, Antarctica

FUNDING: NATIONAL SCIENCE FOUNDATION
(POLAR PROGRAMS; MAJOR RESEARCH INSTRUMENTATION; CAREER; AND AERONOMY)

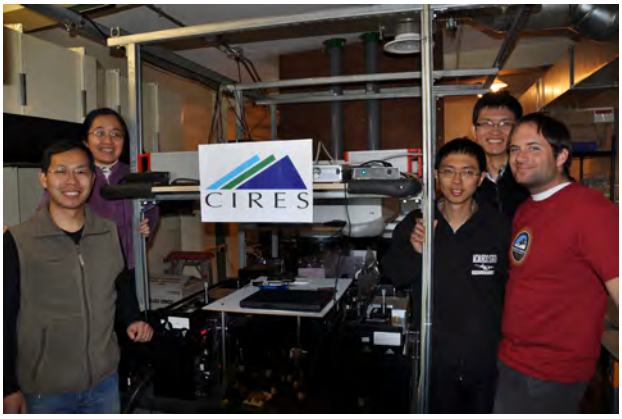


The FY11 has been a remarkable year for the Chu Research Group. We received the Best Poster Paper Award at the 25th International Laser Radar Conference (ILRC)—the highest-level lidar conference—in July 2010 in St. Petersburg, Russia; conducted a successful lidar campaign at McMurdo (78°S), Antarctica; and achieved significant scientific discoveries in the polar atmosphere study.

The lidar technology development we made for the Major Research Instrumentation (MRI) Fe Doppler lidar is truly innovative and will bring the resonance lidar and science research to the next generation. We also achieved great success in the lidar installation and research campaign at McMurdo Station in Antarctica, under the support of National Science Foundation (NSF) Office of Polar Programs funding. Research associate Wentao Huang and graduate students gained their first-ever experience in such a special and harsh environment as the Antarctic.

Overcoming many expected and unexpected difficulties and challenges, the lidar team finally achieved its first Fe signal on Dec. 16, 2010, and collected numerous valuable data in the austral summer and then continued into the winter. Papers on the results of our discoveries in progress.

It was also a year for graduate students to blossom. Ph.D. student Chihoko Yamashita won the Coupling, Energetics, and Dynamics of Atmospheric Regions (CEDAR) first-place prize in the student poster competition at an NSF workshop in Santa Fe, N.M., on June 30, 2011. In doing so, she made history at CEDAR by becoming the only student who has won three student prizes in three consecutive years (2009–2011). Ph.D. student Zhibin Yu bravely took the first winter-over scientist position for the Antarctic lidar campaign. He is the first grantee winter-over at McMurdo in the last 22 years. Zhibin has done a fantastic job in collecting a large amount of lidar data. Because of his work, the austral winter 2011 is the most successful winter that we have ever had in the last 12 years of lidar expedition in Antarctica. Ph.D. students Zhang Wang and Weichun Fong made significant contributions to the success of the McMurdo lidar project by leading the upgrade of the lidar at Boulder, Colo., and participating in the lidar installation and data collection at McMurdo. Weichun Fong also worked with Wentao Huang to improve the Student Atmospheric Resonance (STAR) Na lidar. Ph.D. student John A. Smith led master student Brendan Roberts and undergraduate Aaron Holt to significantly improve the Na signal levels of the STAR Na Doppler lidar from the original 70 counts per shot to an unbelievable level: 800 counts per shot. Ph.D. student Cao (Chris) Chen is making valuable contributions to the spectral analysis of McMurdo lidar data and science study. He is going to be the second courageous winter-over scientist for McMurdo.



A happy moment when the first Fe signals were achieved at McMurdo. From left: Wentao Huang, Xinzhao Chu, Weichun Fong, Zhibin Yu and John A. Smith.

PHOTO BY BY ZHIBIN YU

Two lidar beams shoot into the Antarctic sky from Arrival Heights, McMurdo, in May 2011.

MRI lidar won the Chu Group a Best Poster Award at ILRC.

Shelley Copley

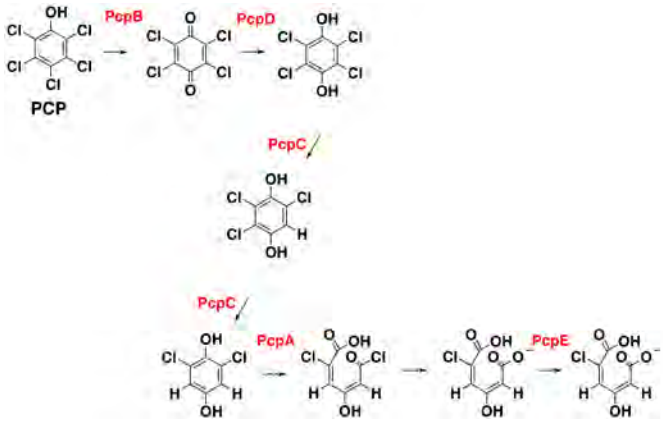
The Origin of the PCP-Degradation Genes in *Sphingobium chlorophenolicum* L-1

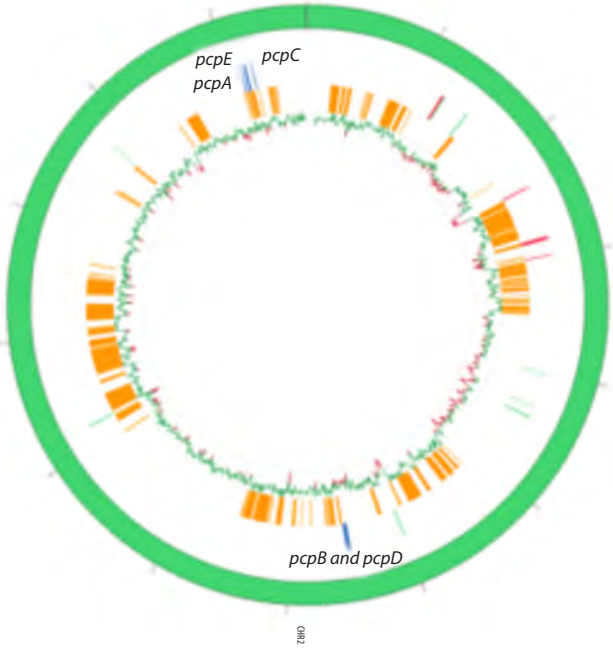
FUNDING: NATIONAL INSTITUTES OF HEALTH

The pesticide pentachlorophenol (PCP) is listed as a Priority Pollutant by the U.S. Environmental Protection Agency due to its toxicity and persistence in the environment. *Sphingobium chlorophenolicum*, a bacterium isolated from a PCP-contaminated site, has patched together a poorly functioning pathway (left figure) that allows mineralization of PCP, although degradation is slow and the bacterium cannot grow at high concentrations of PCP.

We recently sequenced the genome of *S. chlorophenolicum* L-1. Comparison of this sequence with that of the closely related *Sphingobium japonicum*, which degrades lindane, provides insights into the origins of the PCP degradation genes. The right figure shows a map of chromosome 2 of *S. chlorophenolicum*. The locations of the PCP degradation genes are shown in blue on the second circle. Orange bars in the third circle show the positions of genes in *S. chlorophenolicum* that are also found in *S. japonicum*. The inner circle shows guanine-cytosine (GC) content. Gene segments that are acquired by horizontal gene transfer often have significantly different GC content. The genes pcpB and pcpD on one side of the chromosome and pcpC on the other side have no homologs in *S. japonicum* and are located in regions with low GC content. In contrast, pcpA and pcpE have closely related homologs in *S. japonicum*.

Our analysis suggests that the first three enzymes in the pathway were acquired by *S. chlorophenolicum* by horizontal gene transfer in two separate events after it diverged from *S. japonicum*. In contrast, the last two enzymes in the pathway were present in the most recent common ancestor of *S. chlorophenolicum* and *S. japonicum*. None of the genes encoding the PCP degradation enzymes arose by duplication and divergence of ancestral genes within S. chlorophenolicum. The genes occur in two disparate parts of the genome and have not yet been integrated into a compact and consistently regulated operon.





Left, a map of chromosome 2 of S. chlorophenolicum. *Right, the PCP degradation pathway.*

Joost de Gouw

Sources and Chemistry of Organic Carbon in the Atmosphere

FUNDING: NOAA

Atmospheric aerosols play an important role in air quality and climate: They scatter and potentially absorb radiation, and are damaging to human health when present in the air we breathe. A significant portion of aerosol consists of organic material, but the sources of this material are poorly understood. In polluted conditions, the dominant fraction of organics is not directly emitted from combustion sources, but is formed from the oxidation of gas-phase organic compounds from both anthropogenic and biogenic sources. Determining the relative importance of anthropogenic and biogenic sources is an important component of our current research.

In 2010, we performed the CalNex (Research at the Nexus of Air Quality and Climate Change) study in California. One of the goals was to study how emissions in the Los Angeles basin, where anthropogenic emissions are large, react to form organic aerosol. Toward that goal, we made measurements by mass spectrometry and gas chromatography of gas-phase organic compounds 1) from a research ship to characterize inflow conditions into the basin, 2) from a surface site in Pasadena to characterize emissions and the initial stages of photochemical formation and 3) from the NOAA WP-3D research aircraft to follow the urban air masses downwind. Analysis of this large and detailed data set, in conjunction with numerous measurements of organic aerosol, is currently ongoing.

The Deepwater Horizon Oil Spill in the Gulf of Mexico occurred during CalNex, and the NOAA WP-3D aircraft made two flights over the spill to determine the atmospheric impact. It was found that a significant fraction of the oil evaporated and organic aerosol was formed efficiently from these vapors. Interestingly, the aerosol appeared to be primarily formed from less volatile compounds, as opposed to the more volatile compounds with fewer than 12 carbon atoms, which have traditionally been considered as precursors. Measurements in this extreme environment have, thus, given important insight into organic aerosol formation in other environments, such as urban atmospheres where these same less-volatile compounds are emitted.

DAN LACK/CIRES

Scientists used NOAA's WP-3D aircraft to measure the effect of the Deepwater Horizon Oil Spill on air quality.

Lisa Dilling

Climate Change, Decision Making and Managing Risks

FUNDING: NATIONAL SCIENCE FOUNDATION, NOAA

While much attention has been focused on estimating future impacts from climate change, much remains to be understood about the barriers to successful adaptation from a societal perspective (Adger et al., 2007).

My colleagues and I are working on several interrelated projects tackling the questions of what capacity is needed to respond to the risks posed by climate change and how policy processes can function as barriers or opportunities for incorporating risk into decision making. Capacity is understood broadly to include institutional flexibility in making decisions, the availability of usable knowledge, attitudes and perceptions, governance and legal frameworks, and financial and human resources.

I have chosen to focus on decision making in two important resource areas: public lands and water supply. Management of these resources involves several complex agencies, legal institutions and public interests at a wide variety of scales. Managers demonstrate an increasing awareness of the vulnerability of these resources to a variety of hazards stemming from natural climate variability, climate change and increasing (and often conflicting) demands.

Projects in my group include: 1) surveying how public lands managers are incorporating climate change in their decision making and identifying potential needs and barriers; 2) analyzing water management at the state level across five states to understand the capacity for adaptive behavior and the use of information; 3) examining how the response to short-term drought at the municipal level creates or diminishes vulnerability and adaptive capacity for future climate change; 4) identifying adaptive actions across a wide suite of municipalities across three states and illuminating the underlying factors that may explain why some communities respond to risk and others do not; and 5) creating a time-series analysis of stakeholder needs for climate information and other resources with respect to climate change and variability across three states.

ISTOCK

Water-pumping station near Los Banos, Calif.

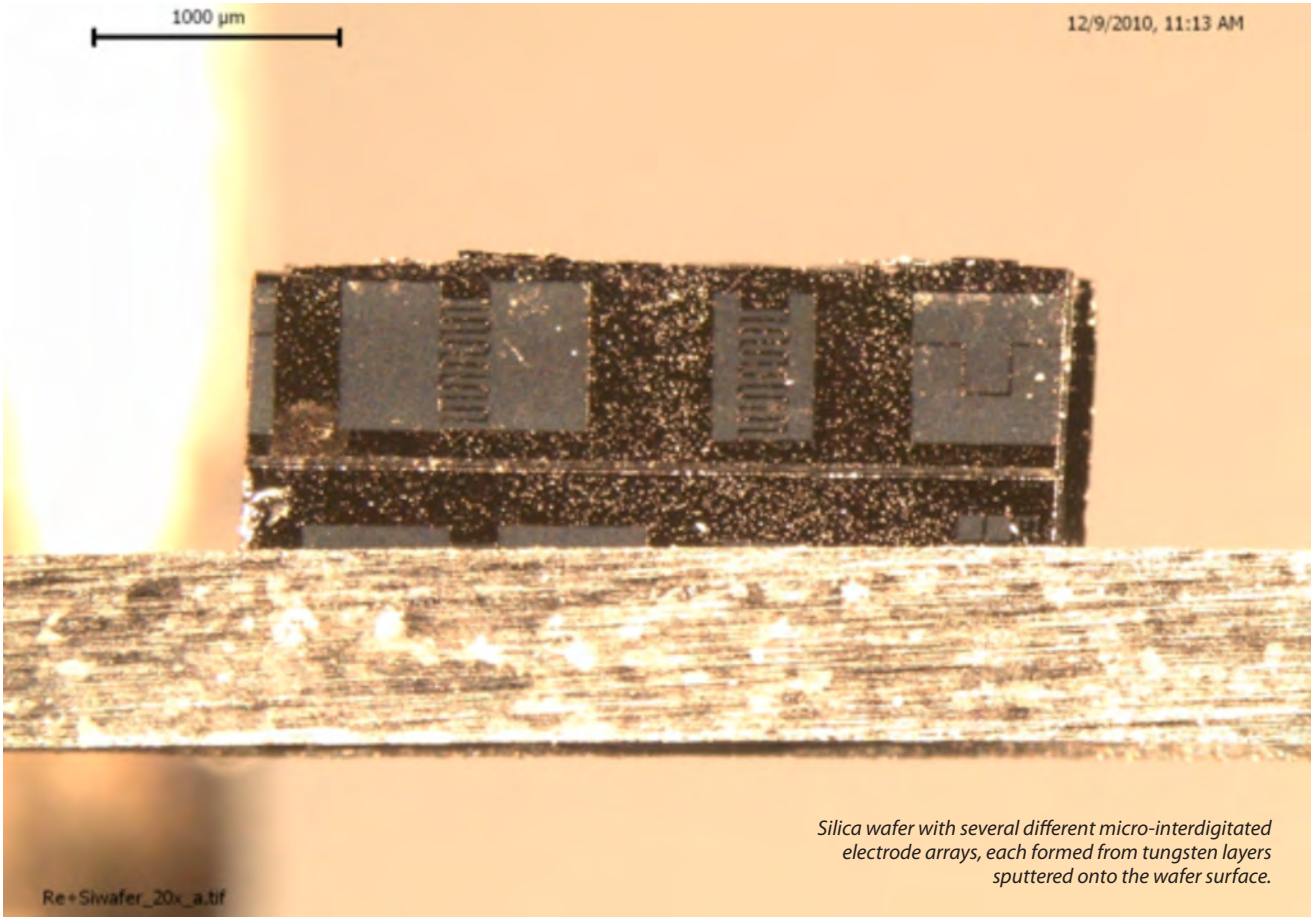
Lang Farmer

Development of a Microinterdigitated Electrode Array for Use in High-Precision TIMS-Based Isotope Ratio Determinations

FUNDING: NATIONAL SCIENCE FOUNDATION

Thermal ionization mass spectrometry (TIMS) remains the method of choice for high-precision lead (Pb) isotopic measurements, but "silica gel" techniques used to generate thermalized Pb ions have ionization efficiencies of only 10 percent at best. To improve Pb ionization efficiencies from liquid glass ion emitters and, ultimately, the precision of uranium-Pb age determinations, we are using electrochemical techniques to increase Pb ionization efficiencies in situ in liquid glasses. Our initial work demonstrated that Pb-doped high-temperature (about 1,300°C) liquid glass can serve as the electrolyte in an electrochemical cell and that Pb metal atoms prevalent in the glass under vacuum conditions can be oxidized to Pb+ by the application of about 1 V across platinum wire electrodes.

To take advantage of this ionization mechanism, we are developing a micro-interdigitated electrode array (IDA) for use as an "electrochemical" ion source. This array consists of a "comb" structure of interleaved tungsten electrode "fingers" sputtered onto a pure silicon wafer. The array fabrication process includes spinning photoresist on an oxidized 275 μm-thick silicon wafer and exposing the wafer to ultraviolet light through a photomask. The DC (direct current) sputter deposition system applies a 1-μm layer of tungsten to the wafer. A photoresist liftoff procedure removes most of the metal layer, leaving the IDA structures on the wafer. The electrode lengths and widths range from 100–200 μm and 10–200 μm, respectively. There are one to 14 pairs of these electrodes on each IDA, with gap widths of 10–15 μm. Our initial results reveal that a Pb-doped silica suspension can be dried and melted on the IDA surface by a metal ribbon resistive heater placed in contact with the electrically nonconducting silicon wafer substrate of the IDA. Our next step will be to install the IDA and heater ribbon in a Finnigan-MAT 261 TIMS, and to connect the assembly to a specially designed potentiostat that will allow the IDA to float at 10 kV while a differential voltage from 0.1 to 10 V is applied across the IDA electrodes. This work is currently in progress.



Silica wafer with several different micro-interdigitated electrode arrays, each formed from tungsten layers sputtered onto the wafer surface.

Noah Fierer

Microbial Life in the Atmosphere

NATIONAL SCIENCE FOUNDATION, U.S. DEPARTMENT OF AGRICULTURE, ENVIRONMENTAL PROTECTION AGENCY

Bacteria are abundant in the atmosphere, with the near-surface atmosphere containing more than 106 bacterial cells per cubic meter of air. Atmospheric transport is a key mode of microbial dispersal, and the transmission of airborne plant and animal pathogens can significantly affect ecosystems, agriculture and human health. For example, recent work implicates bacteria found in outdoor air—rather than pollen or fungi—as being one of the dominant triggers of allergies and asthmatic reactions in many locations. In addition, recent evidence suggests that airborne bacteria may be able to alter atmospheric dynamics by facilitating atmospheric ice nucleation and cloud condensation.

Our ongoing work addresses two fundamental questions regarding bacteria in the atmosphere:

1) What is the full extent of bacterial diversity in the near-surface atmosphere?, 2) How does the abundance, composition and diversity of airborne bacterial communities change seasonally and across the continental U.S.?

We have been addressing these questions with a series of studies conducted across a range of sites including: the Colorado Front Range, a mountaintop research facility in northern Colorado (Storm Peak Laboratory, Figure 2) and metropolitan areas across the Midwest. We used a range of molecular techniques, including high-throughput pyrosequencing and flow cytometry, to characterize bacterial diversity and cell abundances in the collected air samples. We have analyzed more than 400 individual air samples yielding the largest and most comprehensive survey of airborne bacterial diversity conducted to date. We have found that bacterial cells often represent an unexpectedly large portion (typically more than 20 percent) of total aerosol particles, with the average cubic meter of air harboring more than 100 unique bacterial species. We observe strong geographic and seasonal changes in airborne bacterial community composition that are largely driven by changes in land-surface characteristics.

We are currently expanding on this work to examine airborne bacterial diversity across broader spatial and temporal gradients in order to build predictive models of airborne bacterial abundances and diversity. We also have initiated a 'citizen-science' project, the MiASMA project (Mapping and Integrated AnalySis of Microbes in the Atmosphere; http://tinyurl.com/3tybvmt), to build an atlas of airborne microbial diversity across the continental U.S.

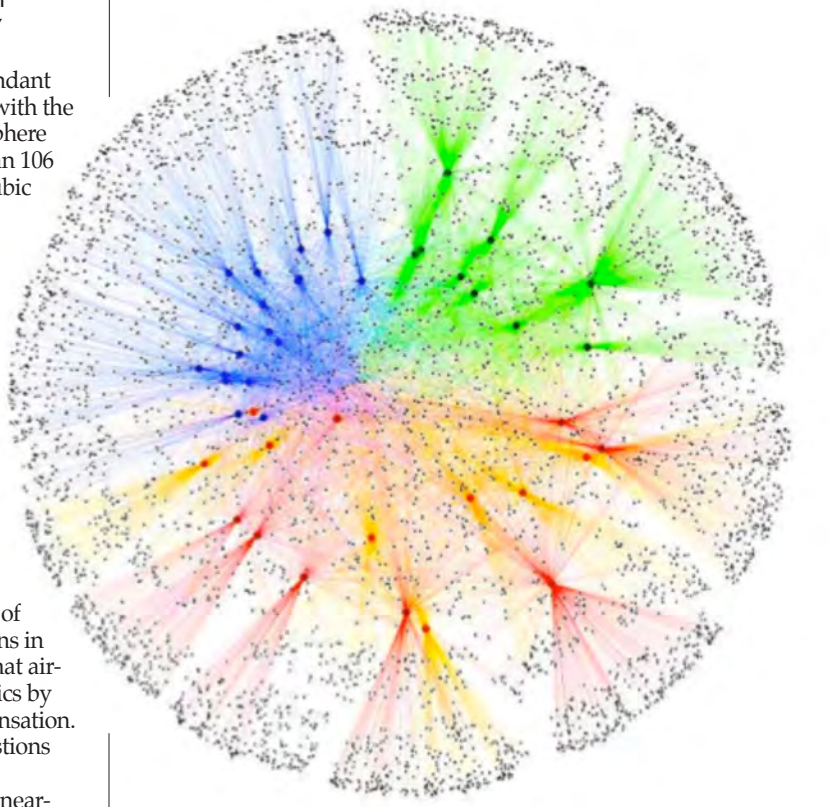


Figure 1: *Network analysis of the airborne bacterial communities collected from the Storm Peak Laboratory. Individual samples are denoted by the larger circles and color coded by season with the smaller black dots indicating individual bacterial species. Lines indicate species shared between samples. This plot not only shows the high levels of bacterial diversity found in the collected air samples, but it also indicates that the species composition changes seasonally.*

Figure 2: *Views of Storm Peak Laboratory (Steamboat, Colo., 3220 M.A.S.L.) during each of the air-sampling campaigns (photos taken by R. Bowers).*

Baylor Fox-Kemper

Improving Subgridscale Physics in Ocean Climate Models

FUNDING: NATIONAL SCIENCE FOUNDATION, NASA, NATIONAL CENTER FOR ATMOSPHERIC RESEARCH

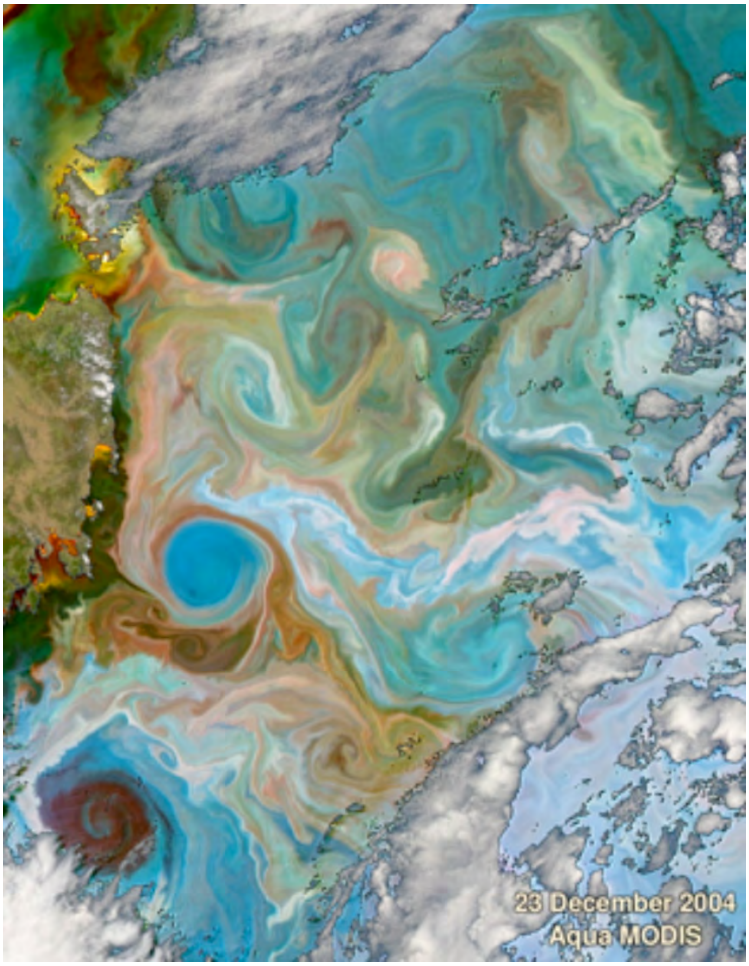
My research group focuses largely on the representation of mesoscale (100 km), submesoscale (1-10 km) and Langmuirscale (100 m) mixing processes in global climate models. The group is improving the representation of these processes in climate models and has demonstrated some impacts of properly representing them on global climate simulations.

On April 20, 2010, the explosion of the Deepwater Horizon oil platform and subsequent oil leakage have provided images of many near-surface mixing processes in action. The shape of the spilled oil as it spreads and is stirred by mesoscale and submesoscale eddies and the formation of windrows between the Langmuir cells are disturbing examples of oceanic stirring at different scales. Understanding where and why these Langmuir windrows occur has been a big part of my group's effort this year, with support from NASA and the National Science Foundation (NSF).

On larger scales, submesoscale eddies stir the upper ocean. These eddies form from thin currents called fronts that occur in the upper ocean. These fronts can result from flow around obstacles, uneven wind or cooling, or even stretching by larger eddies. The image at right shows a false-color satellite image showing some of the stirring by submesoscale features. The false colors accentuate the differences between slightly different colors of water due to biology or water properties.

The submesoscale parameterization developed by my group is being used in many of the models presently simulating future climate for the upcoming Intergovernmental Panel on Climate Change Fifth Assessment Report (IPCC AR5), due in 2013.

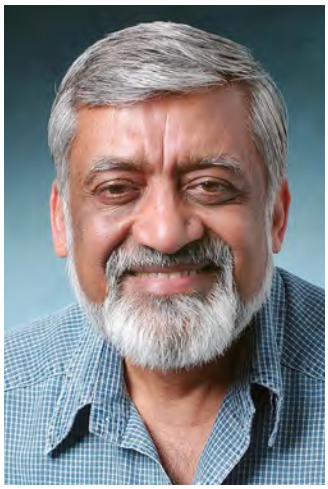
A new set of simulations has begun this year. It is a series of simulations designed to understand the interactions between Langmuirscale and submesoscale features. These simulations are expensive, requiring months of calculation on thousands of processors at a time. Through NSF's TeraGrid system and the National Center for Atmospheric Research's supercomputing center, these simulations will give us our first indications of how these scales may interact. An upcoming Natural Environment Research Council observational campaign, called OSMOSIS (Ocean Surface Mixing, Ocean Sub-nesoscale Interaction Study), will provide direct observations of the same phenomena in the real world.



False-color satellite image of submesoscale fronts and eddies in the Tasman Sea.

Vijay Gupta

Understanding Multi-Scale Infiltration in River Basins as a Statistical-Dynamical Problem



Last year, my colleagues and I uncovered that "random self-similarity" in the spatial branching pattern of river networks provides a key physical basis to understand the underlying spatial pattern of floods. Self-similarity means that each part of a network is a tiny version of the whole. The observed pattern in floods appears as a power law, or a scaling relation, that is being tested in several river basins of the world.

The presence of power laws in floods is being used to develop a predictive model based in multi-scale solutions of mass and momentum conservation equations in random self-similar channel networks. It requires a predictive understanding of infiltration and runoff generation as a multi-scale problem. We are developing and testing a theory of multi-scale infiltration in the Goodwin Creek Experimental Watershed (GCEW) in Mississippi. GCEW is an experimental watershed of Agriculture Research Service (ARS). It has excellent space-time observations of rainfall and stream flows for about 30 years, which are needed to understand multi-scale infiltration.

Our goal is to develop a rainfall-runoff model that can be used to assign infiltration thresholds to hillslopes, which are the smallest geomorphic units in a river basin. To reach this goal, we represent threshold values for a rainfall-runoff event at three different spatial scales: 1) the drainage area of a ``parent'' basin; 2) the drainage area of unnested sub-basins within the parent basin; and 3) the drainage area of hillslopes within the unnested sub-basins. For GCEW, the drainage area at the outlet of the largest stream gauged basin gives 21 km^2. The drainage areas of unnested gauged sub-basins within GCEW range from 0.17 to 3.58 km^2 such that mean area is approximately 1.6 km^2. Likewise, the mean drainage area of hillslopes within GCEW is approximately 0.038 km^2. Observations needed to determine infiltration thresholds are generally available for the entire basin and at several sub-basins that are typical of medium-size basins worldwide. However, they have not been made at the hillslope scale, which is practically impossible because the number of hillslopes is typically very large; GCEW has approximately 800 hillslopes. Our model is being developed under the postulate that certain threshold properties observed in sub-basins are preserved at the hillslope scale. It requires a statistical-dynamical formulation that is being developed and tested.

Goodwin Creek Experimental Watershed (GCEW) in Mississippi.

Craig Jones

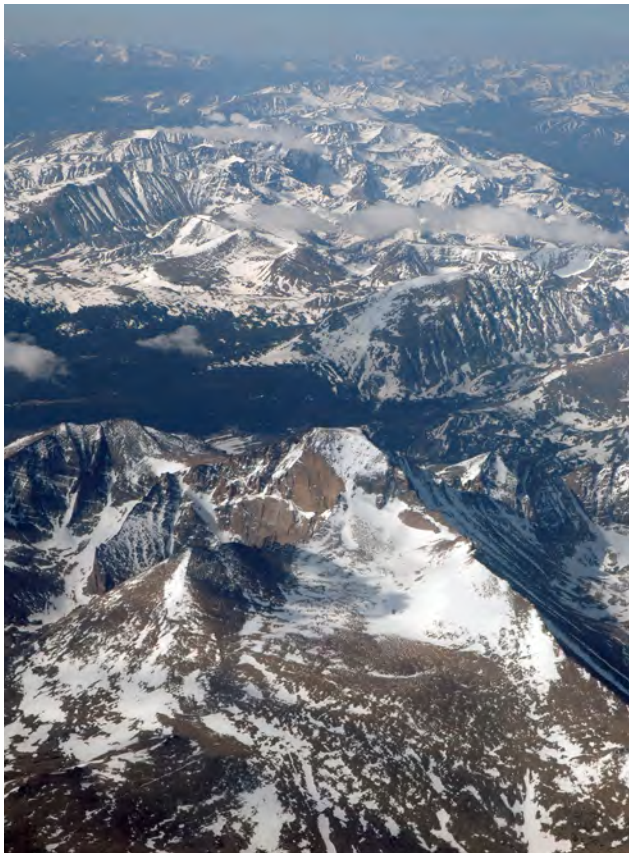
Understanding the Origin of Mountains in the Western U.S.

FUNDING: NATIONAL SCIENCE FOUNDATION (TECTONICS, EARTHSCOPE AND CONTINENTAL DYNAMICS PROGRAMS)

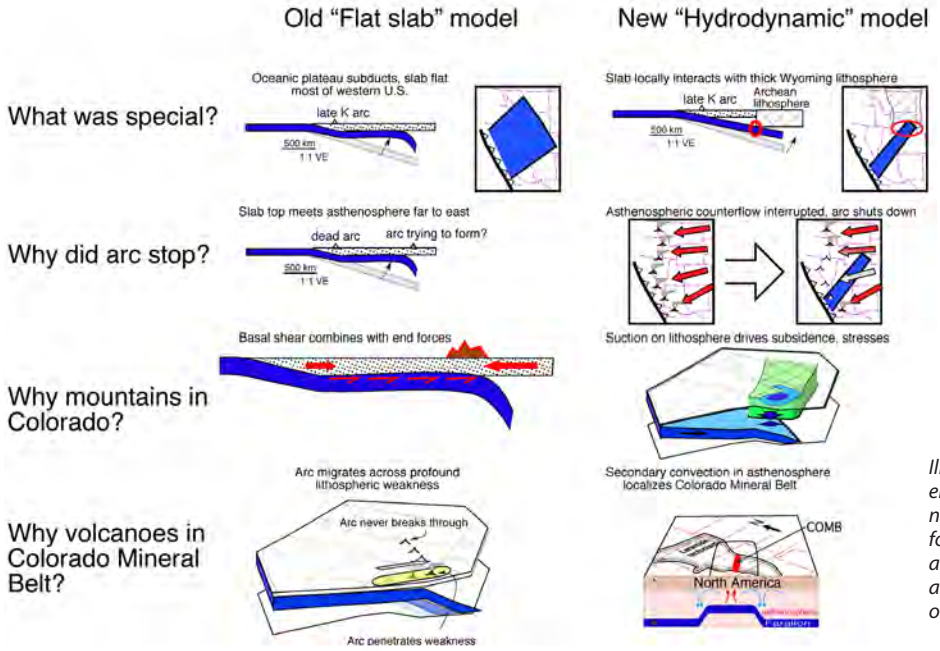
Mountains in the western U.S. form at times and in manners that seemingly disregard the way North America interacts with oceanic plates to the west. At present, my group's research focuses on two areas: the Sierra Nevada in California and the Southern Rockies in Colorado and Wyoming.

Studies of the Sierra Nevada have centered around a major seismological deployment from 2005–2007. Images of the crust and mantle in the range show that the crust is actually thicker under the low western foothills than the high part of the range. It appears that the western part of the range has dense material under it that has recently been removed from the High Sierra, causing the High Sierra to rise up relatively recently.

In the Rockies, colleagues Lang Farmer (CIRES), Shijie Zhong (CU Physics), Brad Sageman (Northwestern University) and I have proposed a new means to make the Rockies. In essence, the idea is that thick, ancient continental plate in Wyoming was sucked down by subducting oceanic plate that got unusually close to the plate's base. In pulling down the Colorado-Wyoming region, this created a hole filled by the Pierre Shale, a marine sedimentary rock responsible for bowing up basements around the Boulder area. By pulling down on this area, the sucking causes the side to crowd in to fill the hole, and this creates the forces that deform the crust and build the Rockies.



Longs Peak in Colorado.



Illustrations contrasting elements of existing and new explanations for geologic events about 70 million years ago that led to creation of the Southern Rockies.

Grand Lake in summer, looking west.

William Lewis, Jr.

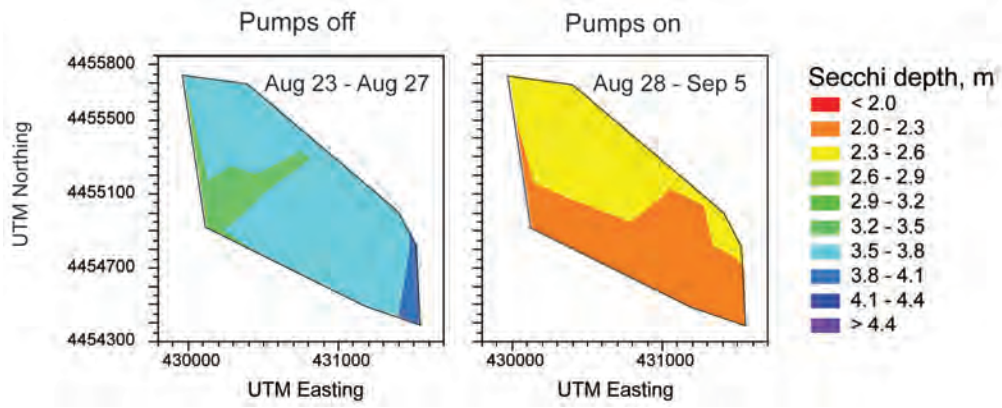
Trouble at Grand Lake

Grand Lake is the largest and deepest natural lake in Colorado. The name and first-place rank of this lake would suggest that it is gigantic, but actually it is rather small (507 acres in area and 265 feet deep), reflective of Colorado's population of abundant but miniature glacier lakes. The setting for Grand Lake is the Colorado River headwaters (8,367 feet) near Rocky Mountain National Park, which for a century has attracted visitors and cabin builders who want to be near the lake.

Residents and admirers of Grand Lake are upset by what they perceive to be declining transparency and loss of the deep-blue color of Grand Lake. They attribute these changes to water management under the supervision of the Northern Colorado Water Conservancy District's Colorado-Big Thompson Project (C-BT). The District passes mountain runoff into two storage reservoirs, Granby and Shadow Mountain, which in turn pass water to Grand Lake. Water exits Grand Lake to the east, through the Adams Tunnel, which was completed in 1947. Since 1947, the passage of water through the tunnel to the agricultural lands east of the Continental Divide has been augmented in volume and diversified in source to the extent that the lake now is dominated by imported water rather than water from its own watershed.

The exact characteristics of Grand Lake prior to any water development are unknown, but there is a tantalizing record of transparency measured by Secchi disk (a white disk lowered to the point of disappearance in the water column) recorded as 9.2 m in 1941 by Professor Robert Pennak of the University of Colorado faculty. At present, the Secchi depths observed in the lake average 3.5 m. Friends of Grand Lake suspect that water management has greatly impaired the transparency of the lake.

With support from a collaboration involving Grand County and the Northern District, the CU Limnology Center, under leadership of James McCutchan, analyzed data relevant to optical characteristics of the lake and its water sources. The data indicate that color from dissolved substances, particles and nutrients that generate growth of algae in the lake's water column all account for some extinction of light in the lake. A comparison with the waters draining from the watershed (which are very low in nutrients, particles and dissolved organic matter) suggests that the original transparency of the lake was much higher than it is today because of the use of the lake as a passageway for water from other sources. The Northern District is probing the validity of the analysis, while it also considers ways of moderating the effect of water transfers on water quality.



Transparency maps of Grand Lake shown as Secchi depth (depth at which a standardized white disk can be seen). Left: With water transfers in progress. Right: With water transfers experimentally shut down for four days. Data from GCWIN monitoring.

Peter Molnar

Tibet and the Asian Monsoon System

I devoted a part of my research effort in FY11 to synthesizing evidence that pertains to the growth of the Tibetan Plateau and to the Asian monsoon, in modern and geologic time.

The extreme breadth and height of the Tibetan Plateau are commonly assigned key roles in the Asian monsoon system, and hence most imagine that the geologic history of the Asian monsoon is closely related to the growth of Tibet. According to this view, heating of the air immediately above Tibet induces ascent and cross-equatorial circulation that comprises the upper branch of the monsoon circulation. A new view is emerging, however, in which the role of Tibet is little more than a barrier to the flow of cool, dry air from northern Eurasia, and heating over the plateau plays a minor role, at least in the South Asian (or Indian) monsoon. Together with William Boos of Harvard University and David Battisti, I reviewed not only this new view, but also the geologic history of Tibet and the Asian monsoon (Molnar et al., 2010).

One of the breakthroughs in geology in the past 20 years has been the development of methods for determining paleoelevations. When applied to Tibet, virtually all studies show elevations comparable to present-day elevations, with the one exception in northern Tibet (Figure 1). If a part of Tibet rose recently, since about 10 million years ago, when some evidence suggesting a strengthening of the monsoon occurred, that part must be northern Tibet.

The view that heating of Tibet plays a key role in the strength of the monsoon loses some credibility when upper atmospheric temperatures are plotted (Figure 2); the hottest upper troposphere is not over Tibet, but to its south over northern India. Moreover, current theories hold that the edge of the monsoon circulation should lie over the region of highest specific entropy, which also lies not over Tibet, but over northern India (Figure 2). It seems that the Himalaya, the southern edge of Tibet, plays a key role by blocking cool, dry air from farther north, air that would reduce the specific entropy of air over India if it could interact with the

hot, moist air formed over the Indian subcontinent. That blockage, not the heating of Tibet, allows the South Asian monsoon to become very strong. If so, the growth of Tibet is unlikely to have played a key role in the development of the South Asian monsoon.

This review presents a summary of the recent thinking on both the growth of Tibet and its significance for the geologic history of the Asian monsoon.

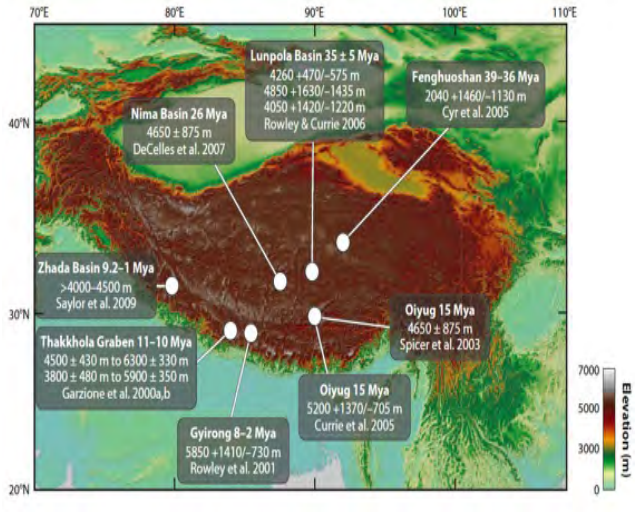


Figure 1: *Topographic map of Tibet showing estimates of paleoaltimetry.*

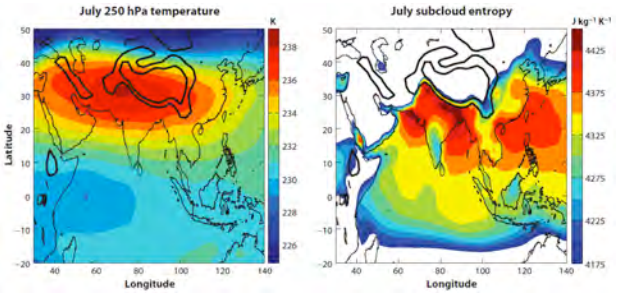


Figure 2: *(Left) Upper-tropospheric temperature (250 hPa) over Asia in July; the maximum overlies northern India and Pakistan, not the Tibetan Plateau. (Right) The moist entropy in July on a terrain-following model level within 50 hPa (about 500 m) of the surface. All quantities are means for 1979–2002 from the ERA-40 reanalysis data set.*

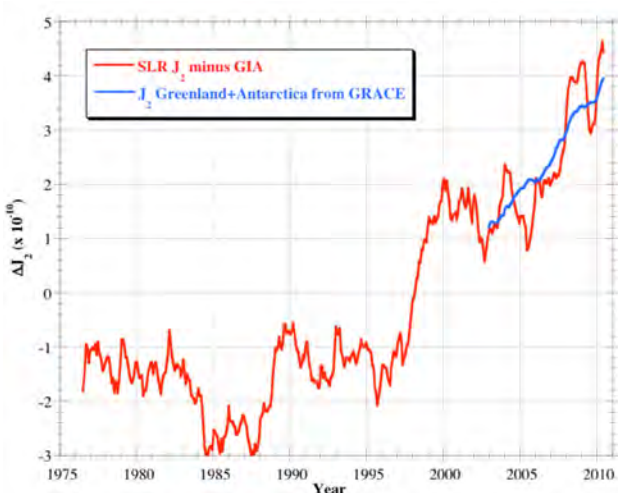
R. Steven Nerem

Satellite Observations of Present Day Sea-Level Change

Observations of long-term sea-level change can provide important corroboration of climate variations predicted by models and can also help us prepare for the socioeconomic impacts of sea-level change. The Topography Experiment/Poseidon (TOPEX/Poseidon, 1992), Jason-1 (2001) and Jason-2 (2008) satellites have observed a mean rate of sea-level rise of 3.2 mm/year since 1993 (http://sealevel.colorado.edu; Nerem et al., 2010). The Gravity Recovery and Climate Experiment (GRACE) satellite mission has precisely measured temporal variations in the Earth's gravitational field since 2002. As the melting of ice in mountain glaciers and ice sheets, in addition to other runoff, adds water mass to the oceans, GRACE has demonstrated the ability to directly measure this change in mass.

Recently, GRACE data have been used to assess the impact of melting ice in Greenland and Antarctica on changes in the Earth's oblateness (J2) [(Nerem and Wahr, 2011). These changes were then compared to a long time series of J2 variations from satellite laser ranging observations (1975–present). The results (Figure 1) show that Greenland and Antarctica caused most of the observed change in J2 since 2002 after correcting for glacial isostatic adjustment (GIA). Because the SLR J2 observations started to change character in the mid-1990s, one interpretation of these results is that ice-mass loss from Greenland and Antarctica started to accelerate in the mid-1990s, which is consistent with other glaciological and tide-gauge evidence.

The GRACE observations of Earth's gravity field changes coupled with the longer time series of J2 observations from SLR data suggest that mass loss from Greenland and Antarctica is accelerating, and this acceleration began in the mid-1990s. This is important information as we assess the current contributions to sea-level change and what may happen to the rate of sea-level change in the future.



Variations in the Earth's oblateness (J2) from satellite laser ranging (SLR) tracking data (red) and from GRACE measurements of Greenland and Antarctica (blue) [Nerem and Wahr, 2011].

Satellite altimeter and gravity measurements are expected to have a major role in the formulation of the fifth Intergovernmental Panel on Climate Change (IPCC) climate assessment in 2013, of which I am a Lead Author for the sea-level change chapter. Satellite altimetry has shown conclusively that sea-level rise has been greater over the last 18 years as compared to the last century. The record of ice-mass changes from the GRACE mission (nine years), while too short to definitively detect climate signals, has demonstrated the ability to measure changes in the mass of the oceans and the mass of the polar ice sheets. Thus, as this time series becomes longer, it is expected that satellite gravity missions will play an equally important role to satellite altimetry in diagnosing the magnitude of sea-level change and its causes.

David Noone

A Modern Approach to Past Climate: Isotope Meteorology in Greenland

The stable isotopic records from the Greenland Ice Sheet are the gold standard for understanding climate variations in the Arctic over the last 100,000 years. While the basic tenets that underlie interpretation of isotopic information appear robust in a mean sense, meterological and glaciological processes can confound simple interpretations. Processes of concern are variations in moisture sources, cloud processes, surface ablation, blowing snow and vapor diffusion in the firn. Layering of snow at the surface of the ice sheet (Figure 1) is easily seen in shallow snow pits, and water vapor transport is known to redistribute the isotopic signal via diffusion and wind pumping. How the isotopic signal is changed before the layers are compacted into solid ice (at about 100 m depth) remains unclear. New laser spectrometers can measure the isotopic composition of vapor and thereby provide the key tool to obtain direct evidence for the processes previously unobservable.

At Summit Camp in Greenland, precipitation spectrometers to measure the amount, size distribution and approximate habit of falling and blowing snow, along with turbulence sensors to measure snow lofting and surface latent heat flux (ablation and frost), have been installed on a 50-m tower. Short high-resolution firn cores allow us to reconcile our detailed measurements and modeling of the source variations, cloud processes and post-depositional influences with the glaciological records. The transport of water from the atmosphere to the surface is associated with snowfall, frosting and the deposition of fog cloud particles. The rate of deposition of fog depends on the size of the particles. Figure 3 shows an example of a fog event in which the early morning fog droplets form from condensation in the ambient vapor, and grow to a size of about 30 μm. As ambient temperature rises at about 6 a.m. local time, the fog dissipates. Once this information is combined with the isotopic information, a new understanding of the interplay between low-level vapor, fog and the isotopic composition of the firn will emerge.

The isotope measurements at Summit are part of an emerging global observatory to measure water vapor isotopic composition that has been established by our group with international partners (Figure 2). The intent of the network is to provide information about the changing behavior of the global water cycle in response to climate change.

Figure 1: *David Noone studies the layers of snow at Summit Camp in Greenland. Layers with different density form due to wind events, and sublimation and frosting are easily found in the top 1 meter of snow in Greenland.*

Figure 2: *Locations of water vapor isotope monitoring stations: Darwin, Australia; Mauna Lao, Hawaii; Niwot Ridge, Boulder, Colo.; Summit Station, Greenland; Reykjavik, Iceland; Eureka, Canada; and Barrow, Alaska.*

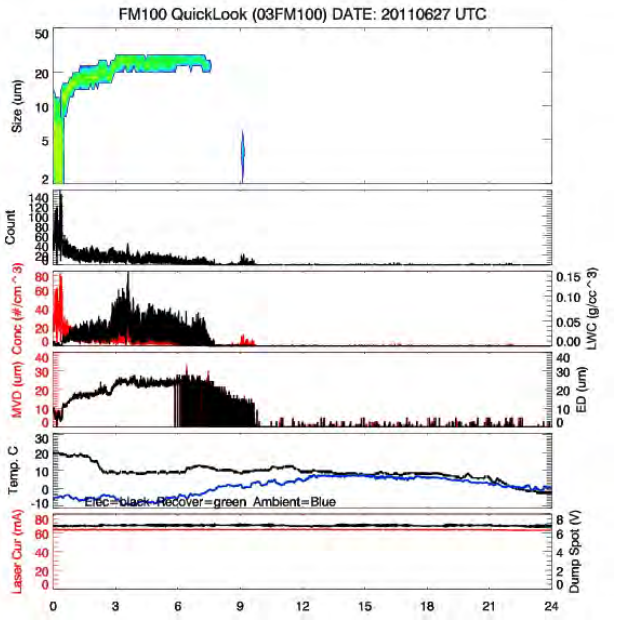


Figure 3: *Fog cloud particle size distribution showing the formation of fog at local midnight on June 27, 2011. Small particles grew from around 5 µm to a maximum size of about 30 µm at 7 a.m. local time.*

Advanced meteorological instruments and trace gas analysers are installed on the 50-m Swiss Tower at Summit Camp on top of the Greenland Ice Sheet. The profile information, along with estimate of surface energy and water fluxes, combined with information on turbulence and blowing snow allows new understanding of the way in which the atmospheric signatures of climate are ultimately recorded in the ice-core records.

Judith Perlwitz

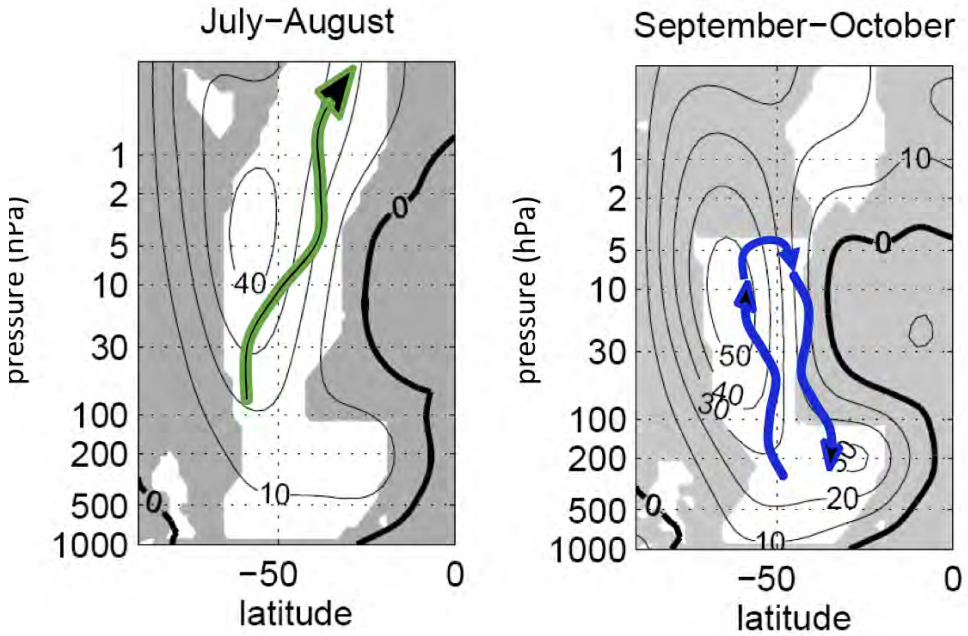
Exploring Mechanisms by which the Stratosphere Influences Climate

FUNDING: NASA, NOAA CLIMATE PROGRAM OFFICE

Over the past two decades, observational and modeling studies have fundamentally changed our understanding of the stratosphere's role in surface weather and climate. In the past, the general understanding was that the dynamical coupling between troposphere and stratosphere is mainly upward. Now, we have manifold evidence for a two-way interaction between both layers of the atmosphere, including evidence for a downward influence. For example, it has been found that stratospheric ozone loss has affected the climate of the Southern Hemisphere by causing a poleward shift of the jet stream and precipitation patterns, as well as by warming the Antarctic Peninsula. It also has been shown that stratospheric variability affects short-term and seasonal forecasts, connecting the tropics and midlatitudes and guiding storm-track dynamics.

During the last year, we carried out three studies that establish a new dynamical mechanism involving downward wave coupling wherein stratospheric ozone changes can affect climate. Downward wave coupling occurs when planetary waves generated in the troposphere are reflected in the stratosphere and modify the tropospheric flow. We investigated the nature of downward wave coupling in the Southern Hemisphere; illustrated that downward wave-1 coupling from September to December has increased over the last three decades; and showed that temporal changes in stratospheric ozone associated with past depletion and future recovery significantly impact downward wave coupling.

To further facility progress in the research area of stratosphere-troposphere coupling, we organized a CIRES- and NOAA-hosted international Dynamics and Variability (DynVar) of the Stratosphere-Troposphere System (DynVar 2) Workshop, Nov. 3–5, 2010, in Boulder, Colo. This workshop provided a forum for discussing advancements in key scientific areas on the influence of the stratosphere on the global climate system and also coordinated the analysis of the new Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report model experiments and the Stratosphere-resolving Historical Forecast experiments, a project of the World Climate Research Programme.



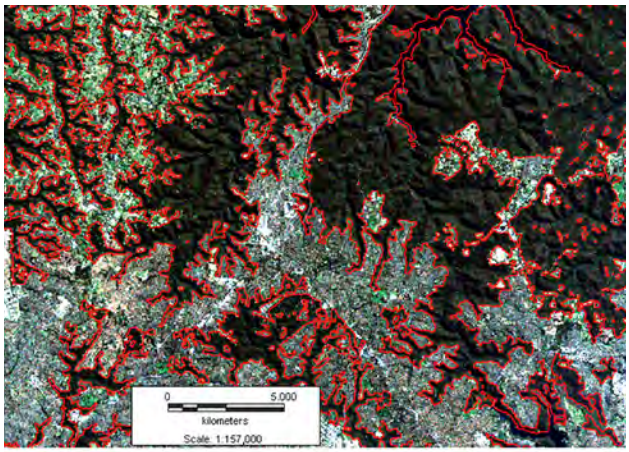
July–August (left) and September–October (right) climatology of zonal mean zonal wind (m/s, isolines) in the Southern Hemisphere together with estimates of the wave geometry of the basic flow. Shaded are regions of wave evanescence. Thus, waves of zonal wave number one can only propagate in regions that are not shaded. During July-August waves can propagate all the wave up to the upper stratosphere (green arrow). During September–October a reflective surface for vertically propagating waves forms at around 5 hPa, and upward propagating waves are reflected back into the troposphere (blue arrow).

Roger Pielke, Jr.

Influence of Location, Population and Climate on Building Damage and Fatalities Due to Australian Bushfire: 1925–2009

FUNDING: NATIONAL SCIENCE FOUNDATION

This study (Crompton et al., 2010), conducted in collaboration with colleagues at Macquarie University in Sydney, Australia, reevaluates the history of building damage and loss of life due to bushfire (wildfire) in Australia since 1925 in light of the 2009 Black Saturday fires in Victoria in which 173 people lost their lives and 2,298 homes were destroyed along with many other structures. Historical records are normalized to estimate building damage and fatalities had events occurred under the societal conditions of 2008/09. There are relationships between normalized building damage and the El Niño–Southern Oscillation and Indian Ocean dipole phenomena, but there is no discernable evidence that the normalized data are being influenced by climatic change due to the emission of greenhouse gases.



Aerial view of northern Sydney showing the highly dissected and complex interface (red line) between brushland (dark green) and urban areas.

Our result—that there is no discernable evidence that normalized building damage is being influenced by climate change due to the emission of greenhouse gases—is not surprising when you consider that bushfire damage is not solely a function of bushfire weather; far from it, in fact. Even given a gradual aggravation of bushfire weather due to anthropogenic climate change or other factors, a bushfire still has to be ignited. Once ignited, a bushfire then has to traverse the landscape and impact a populated area, where outcomes in terms of damage will be a function of the spatial disposition of dwellings with respect to the fire front, and especially distance of properties from the bushland boundary (McAneney et al., 2009). These factors all contribute a large degree of stochasticity to eventual event-loss outcomes.

Annual Aggregated Bushfire HE/Fatalities and Corresponding Normalized Values for Bushfire Years 192-2008

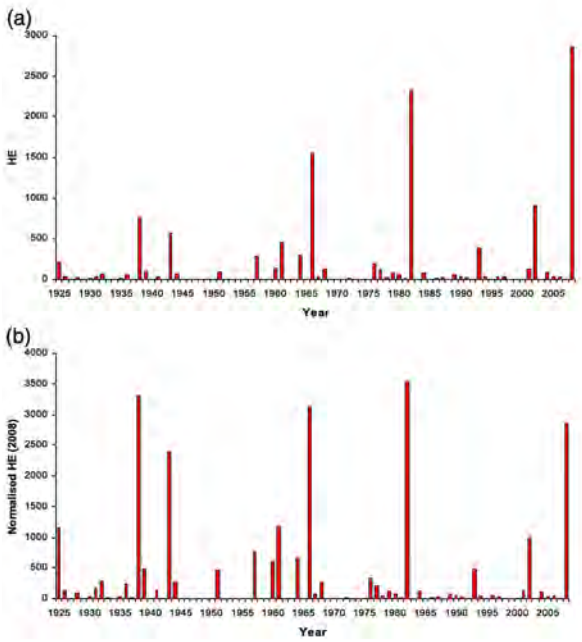


Figure 1: *(a) Annual aggregate house equivalents (HE)for bushfire events in Peril, Australia, for years beginning July 1; (b) as in (a) but with HE normalized to 2008 brushfire year values.*

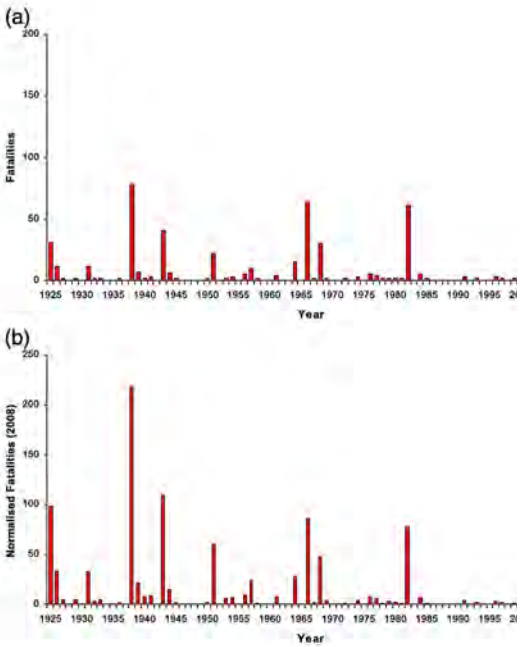


Figure 2: *(a) Annual aggregate fatalities for brushfire events in the Haynes et al. (2010) database for years beginning July 1; (b) as in (a) but with fatalities normalized to 2008 brushfire year values.*

Balaji Rajagopalan

with graduate student Kenneth Nowak

Multidecadal Variability of Colorado River Streamflow

FUNDING: NOAA–WESTERN WATER ASSESSMENT ,
U.S. BUREAU OF RECLAMATION

The Colorado River, with its large reservoir storage capacity, is the main driver of socio-economic growth in the Southwest, more so since the beginning of the 20th century. The prolonged drought during the recent decade is placing enormous stress on the water-resources supply from the river. This decade-long dry spell is unprecedented in observed history, and the question on water-resource managers' minds is: How does the Colorado River flow vary on a multidecadal time scale? Understanding this variability is crucial for efficient management of water resources in the future. We performed a systematic analysis of Colorado River streamflow to identify its variability from observed and paleo-reconstructed flow, and we propose an interesting hypothesis.

Wavelet spectrum of the Colorado River streamflow at the Lees Ferry gauge shows significant power in the 8-to-16-year-period (decadal) band since about 1970. The annual precipitation over the Upper Colorado River Basin (UCRB, the basin that generates almost all of the flow) also exhibits similar spectral characteristics (Figure 1). In addition, there is strong power around the 64-year period (low frequency) that is seen in the UCRB temperatures. This led to an interesting indication that the decadal-scale modulation of streamflow is from the moisture delivery (i.e., precipitation) while the lower-frequency modulation is due to temperature.

Spectrum of long paleo-reconstructed flow (Figure 2) also shows these features, suggesting that the decadal and low-frequency variability seen in the observational data are robust. Furthermore, the power at the 8-to-16-year-period band is modulated at around 60- to 70-year timescales. Runoff efficiency (precipitation/flow) also has a similar spectral signature. The series of the strength of the 8-to-16-year-period band shows this modulation, and a moving window (about 30-year) variance of the Colorado River flow indicates that the two vary together—i.e., increased variance with increased strength of the decadal band, such as the current period.

The low-frequency band seems to vary with the Atlantic Multidecadal Oscillation (AMO) index—consistent with other studies that link the variability of Western U.S. temperatures with AMO.

Based on these analyses, we propose the following hypothesis for multidecadal variability of Colorado River flow:

- UCRB temperature modulates at a very low frequency (about a 64-year period).
- The warmer phase of the modulation creates boundary conditions for lower runoff efficiency.
- Precipitation variability is driven by Pacific forcings.
- The streamflow evolves with the precipitation but is constrained by the runoff efficiency regime created by the temperature blanket.

These results are part of a larger research effort to develop consistent and robust stochastic streamflow simulations at multiple locations on multidecadal timescales, for use in efficient water-resources planning and management in the Colorado River Basin.

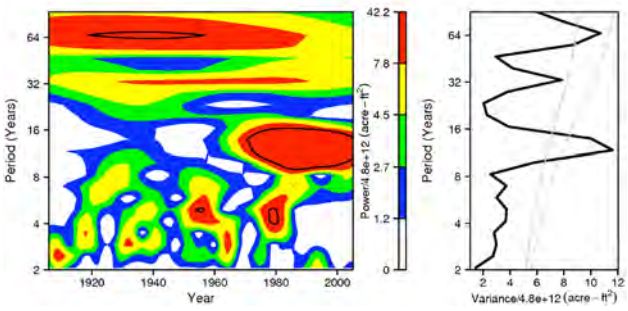


Figure 1. *Wavelet power spectrum of Lees Ferry Flow. Features of interest: 1) decadal (active past 30 years) 2) low frequency (more persistent).*

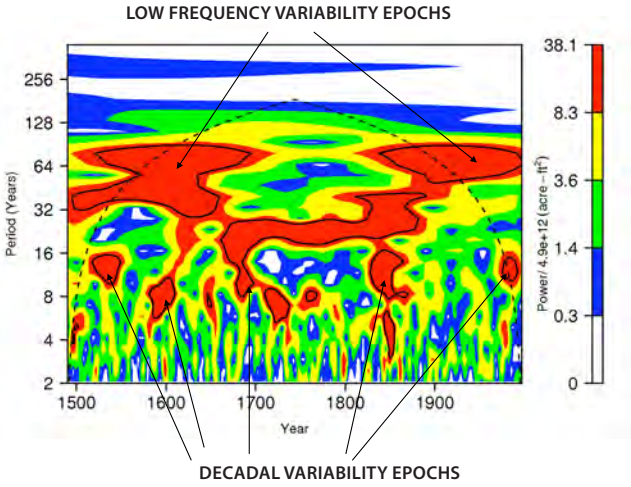


Figure 2: *Wavelet Spectrum of Paleo Reconstructed Lees Ferry Flow.*

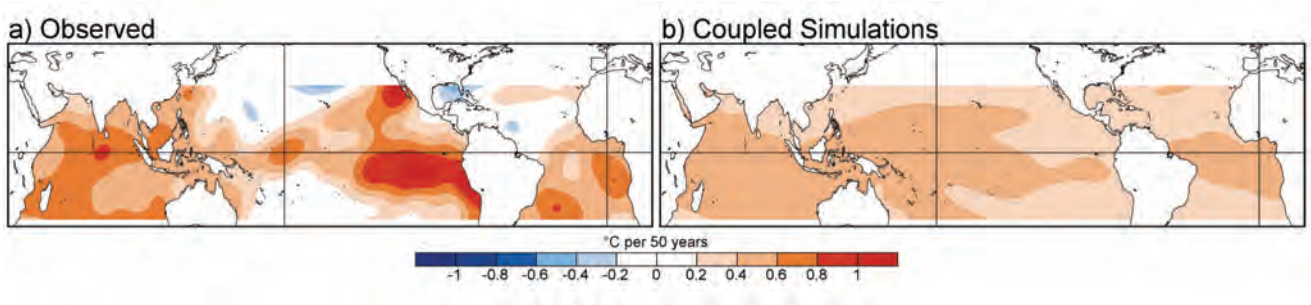
Prashant Sardeshmukh

Why Is It Difficult for Climate Models to Predict Regional Climate Changes?

We have recently published a paper (Shin and Sardeshmukh, 2011) that gives one pause concerning the ability of climate models, including those used in the 2007 Intergovernmental Panel on Climate Change (IPCC) report, to represent climate changes on the regional scales that arguably matter most for climate policy. Briefly, the paper shows that 1) even in a world that is warming in response to increasing greenhouse gases, in order to get the regional climate changes right, one has to get the tropical sea-surface temperature (SST) changes right, and 2) climate models are not getting the tropical SST changes right.

We arrived at these conclusions after comparing multi-model ensemble simulations of the last half-century with corresponding observations, focusing on the landmasses around the North Atlantic Ocean: North America, Greenland, Europe and North Africa. We found that the patterns of the trends over these regions were generally not well captured by IPCC coupled atmosphere-ocean models with prescribed observed radiative forcing changes associated with anthropogenic greenhouse gases and other forcings. On the other hand, even uncoupled atmospheric models without the prescribed radiative forcing changes—but with the observed SST changes prescribed only in the tropics—were demonstrably more successful in this regard. The basic reason for the poor performance of the coupled models was, thus, their poor representation of the tropical SSTs. We showed that errors in representing both the observed SST climatology and the spatial pattern of the observed SST trends were important in this regard. The pattern error, in particular, had a large impact on the simulation of both the local and remote precipitation trends.

The sensitivity of the global mean climate to the pattern of tropical oceanic warming was already highlighted in some of our previous work (e.g., Barsugli, Shin and Sardeshmukh, 2006). In this new study, we provided evidence of a similar large sensitivity also of regional climate changes, even in regions remote from the tropics. The fact that even with full atmosphere-ocean coupling, many current climate models with prescribed observed radiative forcing changes are not able to capture the pattern of the observed tropical oceanic warming suggests one of two things: Either the radiatively forced component of this warming pattern was sufficiently small in recent decades to be dwarfed by natural tropical SST variability, or the coupled models are misrepresenting some important tropical physics. Our study suggests that the discrepancy of the simulated trends with respect to observations is not just due to climate noise but also due to model errors. The existence of mean tropical SST biases in the coupled models, whose impact on remote trends is also significant, further supports our argument. Reducing such tropical SST errors is key to significantly improving regional climate predictions around the globe.



Trends of annual mean Tropical (30°S–30°N) sea-surface temperatures (SSTs) in 1951–1999 derived from a) observations and b) the multi-model ensemble mean of 76 Intergovernmental Panel on Climate Change Fourth Assessment Report coupled model simulations with prescribed observed radiative forcings. From Shin and Sardeshmukh, 2010, Climate Dynamics, *DOI 10.1007/s00382-009-0732-3.*

Mark C. Serreze

Rapid Arctic Change

FUNDING: NATIONAL SCIENCE FOUNDATION, NASA

My research has focused on understanding the causes and impacts of rapid climate change in the Arctic. One of the most visible signs of change is the accelerating decline in September sea-ice extent. This appears to reflect several processes working together. With more open water in September than there used to be, ice cover in the following spring is thinner than in the past and is especially vulnerable to melting out the next summer. Earlier spring melt fosters a feedback whereby dark open-water areas readily absorb the sun's energy, which fosters even more ice melt. The thinner ice is also more easily broken up by winds associated with passing storms. Finally, general warming of the Arctic has reduced the likelihood of cold years that could bring about recovery. With less ice, the Arctic is becoming more accessible to marine shipping and extraction of natural resources, increasing the strategic importance of the region.

Air temperatures in the Arctic have risen faster than for the globe as a whole, a process called Arctic amplification. While clearly associated with reduced September sea-ice extent—which promotes strong transfers of ocean heat to the atmosphere in autumn and winter—other processes also appear to be contributing. These include changes in atmospheric and ocean circulation that bring more heat into the Arctic; increases in cloud cover and water vapor that bolster the flux of longwave (heat) radiation to the surface; soot on snow that darkens the surface; and heightened concentrations of black carbon aerosols. The latter two lead to stronger absorption of solar energy at the surface and in the atmosphere, respectively. The Arctic amplification observed today will become stronger in coming decades, invoking changes in atmospheric circulation, vegetation and the carbon cycle, with impacts both within and beyond the Arctic.

MARK SERREZE

Serreze measures snow depth on the North Slope of Alaska, April 2011.

Anne Sheehan

Deep Structure Beneath Rocky Mountain Foreland Arches and Sedimentary Basins

FUNDING: NATIONAL SCIENCE FOUNDATION

The Bighorns Arch Experiment is an integrated seismological and structural geology investigation to understand how basement-involved foreland arches form; how they are connected to plate tectonics; and what they reveal about the rheology of the continental lithosphere. Basement-involved arches—characteristic of the Laramide orogeny that formed the Rocky Mountains 60 million years ago—are uplifts of deep crystalline basement rocks, which are rocks beneath what is often several kilometers or more of sedimentary cover. They are typically flanked by deep sedimentary basins. Hypotheses for the formation of basement-involved arches include subcrustal shear during shallow subduction, crustal detachment, lithospheric buckling and domino-style lithospheric faulting. All of these hypotheses predict different lower crustal and crust-mantle boundary geometries beneath foreland arches. These hypotheses and others are being tested by combining the near-surface geology of the Bighorn Arch of northern Wyoming with a combined active/passive source EarthScope Flexible Array seismic experiment. The Bighorn Arch was chosen because it is minimally affected by pre- and post-Laramide tectonic events, preserving the sedimentary sequence. It has a relatively planar, west-dipping backlimb inclined into the Bighorn Basin and a more abrupt, east-dipping forelimb facing the Powder River Basin.

The passive seismic experiment uses naturally occurring seismic sources, such as earthquakes and ambient noise. The active-source experiment includes the use of controlled sources, 20 single-fired shots ranging from 500 to 2,000 lbs. in size. The seismic experiment was a three-phase deployment with a 15-month deployment of 41 broadband seismometers (deployed summer/fall 2009); a six-month deployment of 170 three-component short-period seismometers; a four-month deployment of three five-element seismic arrays (supported by an Air Force Research Laboratory seismic discrimination contract); an active-source experiment with 20 single-fired shots recorded on 1,800 geophones; and a passive-source geophone deployment with 850 geophones deployed in passive-source mode for 12 days. The combination of these approaches is being used to develop structural crustal images at high resolution at all levels of the crust.

Ongoing analysis with the data collected includes the use of seismic mode-converted waves to map out subsurface interfaces such as the crust-mantle boundary. Vertical component multiply-reflected waves from distant earthquakes (teleseisms) have been used to map out sedimentary basin structure. This is the first time to our knowledge that recordings of distant earthquakes on a dense array of industry-style geophones have been used to map out sedimentary basin structure at this level of detail. This technique shows great promise, and as passive-source seismology is increasingly applied in oil and gas and geothermal reservoir modeling, the reverberation image method could be used to extract structural information from the passive data. Ambient noise surface wave tomography analysis has been performed and provides constraints on crustal shear velocity.

CIRES undergraduate assistant Jeremiah Silver installs a short period seismometer in Bighorn Mountains, Wyo.

ANNE SHEEHAN

Robert Sievers

Innovative Vaccine Delivery Methods for Disease Control in Warm Climates

FUNDING: FOUNDATION FOR THE NATIONAL INSTITUTES OF HEALTH (FNIH); FOUNDATION FOR THE NIH IN THE BILL AND MELINDA GATES FOUNDATION'S GRAND CHALLENGES IN GLOBAL HEALTH INITIATIVE; AKTIV-DRY, LLC; MONTANA STATE UNIVERSITY; CIRES INNOVATIVE RESEARCH GRANT

Increased stability and safety of aerosol, needle-free, inhalable vaccines are goals of the CIRES team effort in Global Health. Efficacy of generating a protective immune response in test animals by inhalation of a measles virus vaccine has been published in *Proceedings of the National Academy of Sciences*. We have demonstrated that the powder formulation is stable and satisfies the World Health Organization's short-term stability requirement at 37°C. It also possesses good stability characteristics over a much longer period (less than 1 log loss of potency after more than three years storage at 2–8°C). In addition, CIRES' collaborators in Pune, India, have established room-temperature stability of our dry powder aerosol vaccine for six months.

Final approval from the Indian regulatory authority (DCGI) to begin Phase I clinical trials in human volunteers is being awaited. The FNIH-supported Sievers team from Aktiv-Dry LLC, CU-CIRES, the Serum Institute of India, Sristek Private Ltd., Centers for Disease Control and Prevention (CDC), Johns Hopkins University and BD Technologies has made plans to begin subject recruitment. The agency program manager at the Foundation for the National Institutes of Health has acclaimed in the media the team's progress: "It has tremendous implications…It's remarkable to get this far in a relatively short period of time." Achievements include reformulating with myo-inositol (a newly discovered stabilizer) an existing measles vaccine as a potent live attenuated virus vaccine and developing two inhalation devices for administering the vaccine powder to children in the developing world. CIRES patent applications have been submitted.

Sievers also accepted the invitation of Doctors Without Borders to describe in a briefing at their Paris headquarters the new results of hepatitis B vaccine stabilization, packaging and delivery studies supported by the NIH National Institute of Allergy and Infectious Diseases. Subsequently, EpiCentre, the international pediatrics arm of Doctors Without Borders, has proposed a cooperative joint field and lab study utilizing vaccines and delivery devices developed in Colorado. The recent resurgence of measles and other diseases in Africa and higher death rates make this a high-priority activity.

GLENN ASAKAWA

Bob Sievers, with help from his 11-year-old grandson, Benjamin Louis Sievers, demonstrates how vaccines can be delivered by inhaling from a bag.

Konrad Steffen

with William Colgan

Melt-Flow Acceleration of the Greenland Ice Sheet

FUNDING: NASA GODDARD SPACE FLIGHT CENTER

This research is in support of the continuous GPS network on the Greenland Ice Sheet in the vicinity of the Swiss Camp (SC, Figure 1), at the western slope of the ice sheet at approximately 70° N. The GPS network consists of a total of eight GPS Trimble 4000 SSE, R5 and R7 receivers with the objective to monitor the melt-flow acceleration and surface-height change. The GPS receivers are aligned along the main flow direction of the ice sheet (UP50 to JAR2), and three receivers were placed at the mean equilibrium line altitude (ELA) at Swiss Camp, Up50 and S16. Up50 is located 50 km from SC, N70 is 70 km north of SC and S16 is approximately 16 km south of SC.

At present, Greenland's mass loss appears to be equally split between surface mass balance (i.e., melt and runoff) and ice dynamics (i.e., ice discharge). Predicting the relative contributions of these two terms to future sea-level rise is complicated by potential nonlinear feedbacks. Generally, however, the future ice-dynamic contribution is regarded as more difficult to forecast than its surface-mass-balance counterpart. This is due to the inability to establish the mechanism responsible for the recent widespread acceleration of outlet glaciers.

The research conducted over the past year has focused on better understanding mechanisms by which (i) increased surface meltwater production results in enhanced basal sliding and (ii) the recent acceleration may be the onset of a long-term response to increased effective driving stress stemming from a loss of terminus back-stress. The ablation zone northeast of Ilulissat has an annual velocity cycle comprised of a summer speedup event followed by a fall slowdown event (Figure 2). At the onset of this project, it was not evident whether seasonally enhanced basal sliding or seasonally reduced terminus back-stress was responsible for this annual velocity cycle. Our findings now suggest that enhanced basal sliding is more important than reduced terminus back-stress in determining inland ice velocities.

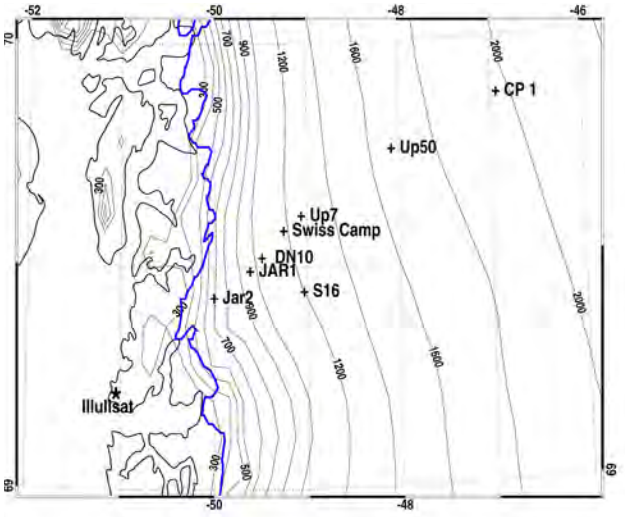


Figure 1: *GPS network on the western slope of the Greenland Ice Sheet monitors the melt-flow acceleration northwest of Ilulissat. The box around the graph gives the latitude and longitude coordinates; the blue line depicts the ice-sheet margin.*

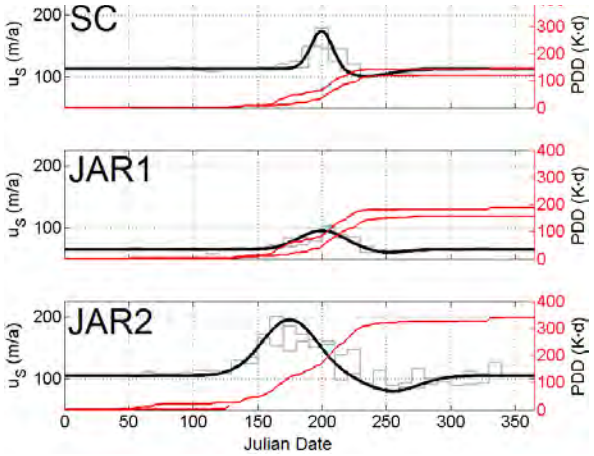
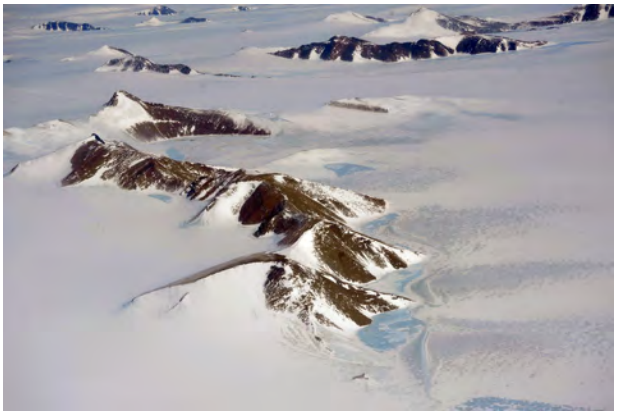


Figure 2: *Observed 10-day mean ice-surface velocities (grey) and cumulative positive-degree days (PDD; red) in 2005 and 2006 at Swiss Camp (SC), JAR1 and JAR2 (where available) versus Julian Date. Black lines denote the bi-Gaussian characterization of the annual ice-surface velocity cycle at each station.*



Above: Nunataks on the eastern slope of the Greenland Ice Sheet close to Kulusuk—blue ice areas form on the downwind side of the mountains.

Left: GPS unit with solar panels and climate instruments at S16 (see Figure 1).

Margaret Tolbert

Laboratory Studies of Clouds and Aerosols

FUNDING: NASA, NATIONAL SCIENCE FOUNDATION

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. 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 visible wavelengths, allowing most, but not all, sunlight to reach the Earth's surface. In contrast, the outgoing infrared radiation is efficiently absorbed by cirrus ice particles. While the net effect of cirrus clouds on climate is usually a warming at the surface, the microphysical properties of the clouds dictate the overall climatic impact. The microphysical properties, in turn, depend on the nucleation mechanism of ice in the atmosphere. In laboratory studies, our research group is 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 are using a combination of optical and Raman microscopy. In 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 addition to laboratory studies on well-defined particles of known composition, studies are also probing the ice-nucleating ability of particles collected in the field.

Other work in our laboratory is examining the direct effect of aerosols on climate. Here cavity ring down aerosol spectroscopy is used to determine the real and imaginary refractive indices of particles likely to be present in the atmosphere. Studies are also performed to determine how the particle optical properties change upon exposure to increased relative humidity. In this work, studies are performed on both well-characterized laboratory samples and on model secondary organic aerosol particles formed in chambers. Ongoing work is examining how the optical properties of the particles change as they are aged through simulated oxidation in the atmosphere.

In parallel to studies of clouds and aerosols in the Earth's atmosphere, additional studies are probing clouds and aerosols in other planetary environments. In one project, we are studying the chemical composition and optical properties of the organic haze that completely shrouds Titan, a moon of Saturn. Another project focuses on understanding heterogeneous (gas-surface) chemistry in the Martian environment. Finally, studies that compare these faraway places today with our own Earth, billions of years ago, are underway to examine Earth's earliest atmosphere.

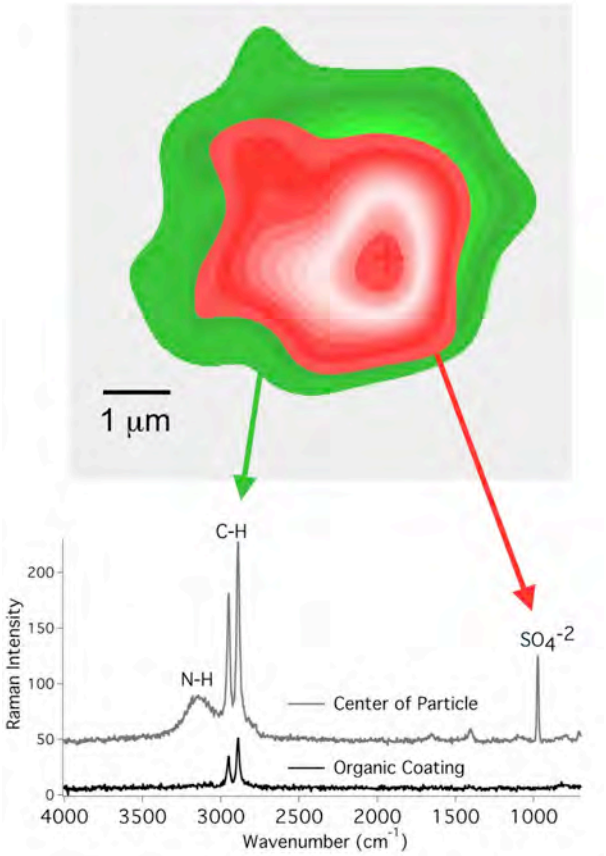


Figure 1. *Raman map of a particle collected at Storm Peak Laboratory during Storm Peak Aerosol and Cloud Characterization Study (SPACCS) in 2010. Many of the observed particles were composed of mixtures of sulfates and organics. Raman mapping allows the mixing state of the particles to be determined. This particle shows a sulfate core with an organic coating. Ice nucleation studies are performed on the samples collected during the Storm Peak study.*

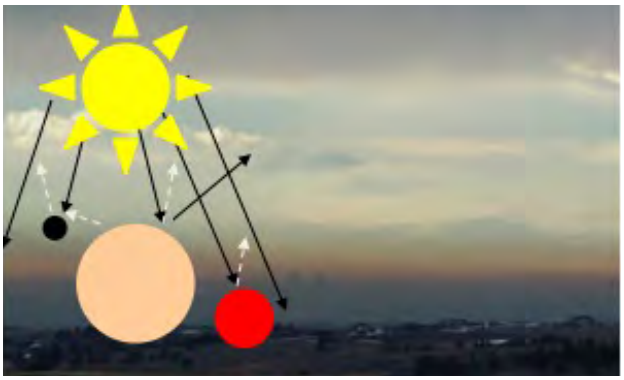


Figure 2. *Particles scatter and absorb sunlight and, thus, directly impact climate and visibility. Large (wet) particles scatter more light than small particles. We are using cavity ring down (CRD) aerosol extinction spectroscopy to probe the direct effect of particles on climate.*

William Travis

Extreme Events: Agents of Adaptation?

FUNDING: NOAA

Theory holds that extreme events override political and economic barriers to create windows of opportunity for hazard mitigation. The idea has intuitive appeal and may even be partially right. But the desire to quickly return to pre-disaster conditions, as well as a commitment to traditional responses (such as building higher levees) rather than new approaches, thwarts the potential for post-disaster mitigation. Much of the research conducted by faculty and students at the Center for Science and Technology Policy Research (CSTPR) focuses on extremes and their roles in shaping policy. Motivated by debate over links between weather extremes and global warming—but also by abiding questions about how societies respond to environmental extremes—I am exploring several hypotheses about adaptation.

Graduate student Gene Longenecker and I are studying the possibility that some hazard responses actually increase losses in the long run. Longenecker worked for the Federal Emergency Management Agency (FEMA) since obtaining his master's in Geography at CU, and he is back for a Ph.D., armed with the latest hazard loss simulation model (HazUS) to test ways we might detect this effect were it to hold in the real world.

Graduate student Mary Huisenga and I are using another simulation model to test hypotheses about a more subtle role of extremes: Might they act as pacemakers of adaption to underlying trends, like climate change? One hypothesis reflects the window-of-opportunity theory: Occasional extremes evoke adaptation that fills in the "adaptation deficit" built up over a period of gradual change. But extremes provide inherently noisy information, and may point in the wrong direction or trip premature and inefficient adaption. Both of these effects show up in a simple model initialized with real data for a Great Plains wheat farm put through a couple of decades in which the mean of the distribution of yields is slowly ratcheted down. The farmer can switch from continuous cropping to alternating fallow, a technique that gets better yields from less moisture. We model an adaptive and nonadaptive farm under gradual change to find the point where fallow is adopted and raises net income (Figure 1). We then add variously timed droughts to test their pace-making role. It works out that a luckily timed drought can, indeed, evoke adaption such that the adaptive farmer's net income (here plotted as the midpoint of the distribution) spends fewer years below zero (Figure 2). There's much more to explore here, including other climate-sensitive systems, such as flood control, and other adaptations, like insurance.

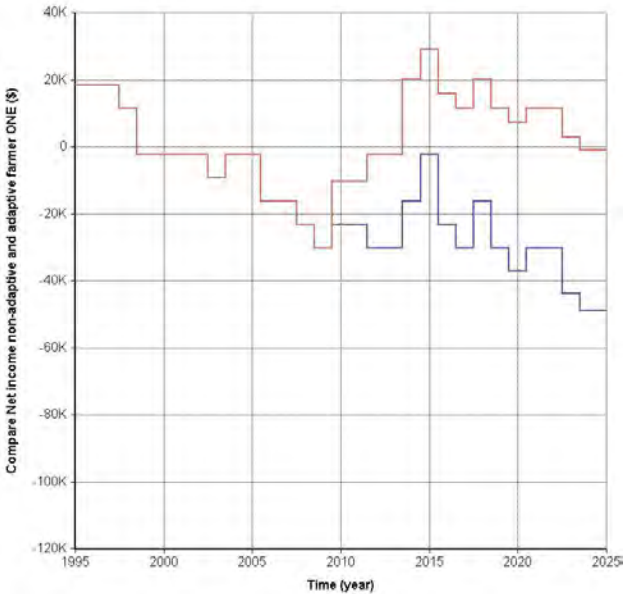


Figure 1. *Compare Net income non-adaptive and adaptive farmer ONE ($).*
— Net income GC for all cropping ONE — GC Net income non-adaptive farmer ONE

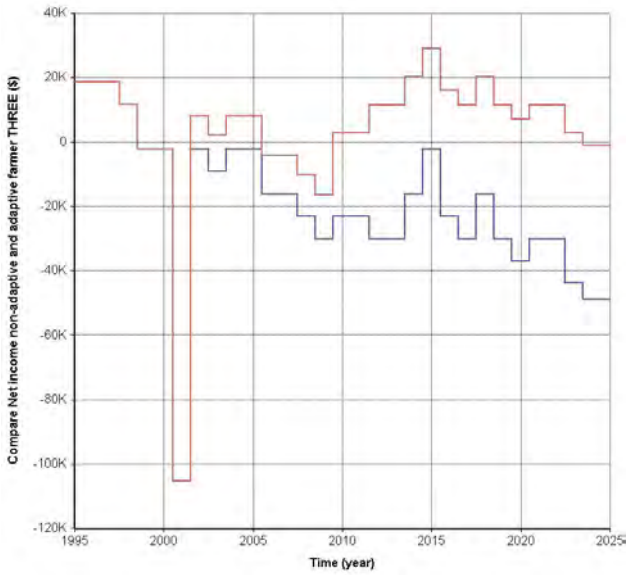


Figure 1. *Compare Net income non-adaptive and adaptive farmer THREE ($).*
— Net income GC for all cropping THREE — GC Net income non-adaptive farmer TWO

Greg Tucker

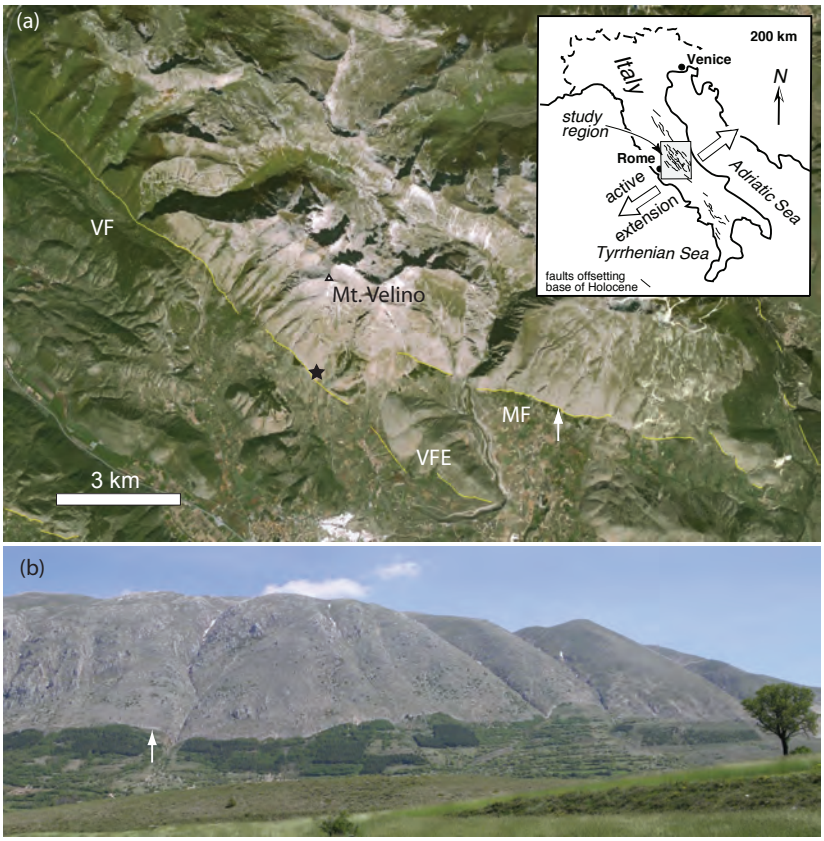
Is Climate Change Etched into Mountain Hillslopes?

FUNDING: NATIONAL SCIENCE FOUNDATION

If you sit down at a café in central Italy and gaze out at the surrounding scenery, you'll notice a mysterious white-gray band that runs along the foot of each mountainside. At first glance, it looks like the work of an ambitious but unimaginative graffiti artist. In fact, what you're seeing is the legacy of thousands of years' worth of earthquakes. The white bands in Italy—which have equivalents in places as far flung as the Grand Tetons, Lake Baikal and the East African Rift Valley—are fault scarps created by extensional tectonics. Geologic dating reveals that the Apennine fault scarps are young, created by a series of earthquakes over roughly the last 10,000 years. Yet in Italy, as in many other extensional tectonic settings, earthquakes have been slowly building mountains for far longer—up to 3 million years in the case of the Apennines. So why then aren't the fault scarps far higher and older?

A recent study by our team suggests that the answer lies in erosion and climate change. When an earthquake brings fresh rock to the surface along a fault line, weathering breaks down the exposed rock. The weathering rate depends partly on rock type and partly on climate. A new mathematical model predicts that the rate is, surprisingly, recorded in the shape of the mountain front. Analysis of a well-known scarp in Italy suggests that weathering rates were about 30 times higher in the last ice age than they are today. The high glacial-age rate was probably driven by frost shattering of rocks, a process that requires sustained subzero temperatures. The Italian fault scarps not only shed light on the role of climate in shaping mountains, but also provide valuable data on rates of rock breakdown and erosion.

CIRES graduate student Scott McCoy studies an Italian fault scarp.



Top: Satellite image of Velino-Magnola Mountains, central Italy, showing the Velino and Magnola faults (yellow lines). Bottom: The Magnola mountain front. Arrow indicates fault scarp. Source: Tucker, GE, SW McCoy, AC Whittaker, GP Roberts, ST Lancaster, and R Phillips (2011), Geomorphic significance of postglacial bedrock scarps on normal-fault footwalls, J. Geophys. Res., 116, *F01022, doi:10.1029/2010JF001861.*

Veronica Vaida

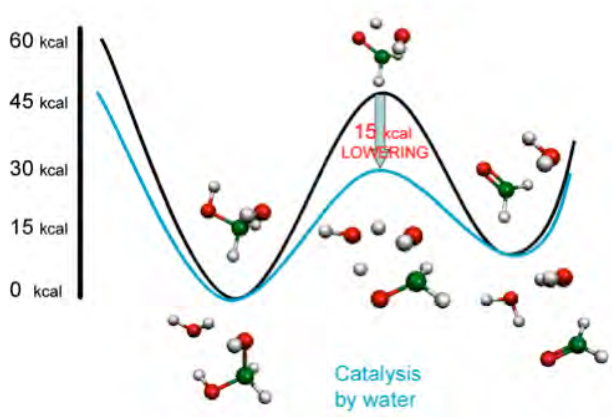
Light- and Water-Mediated Chemistry in the Earth's Atmosphere

FUNDING: NATIONAL SCIENCE FOUNDATION,
CIRES INNOVATION RESEARCH PROGRAM

Our program, at the interface of physical chemistry and atmospheric science, has originated in the last decade new ideas concerning water- and sunlight-mediated processes in planetary atmospheres, including the contemporary and prebiotic Earth. My approach uses fundamental chemical physics to address complex problems where atmospheric measurements and models disagree.

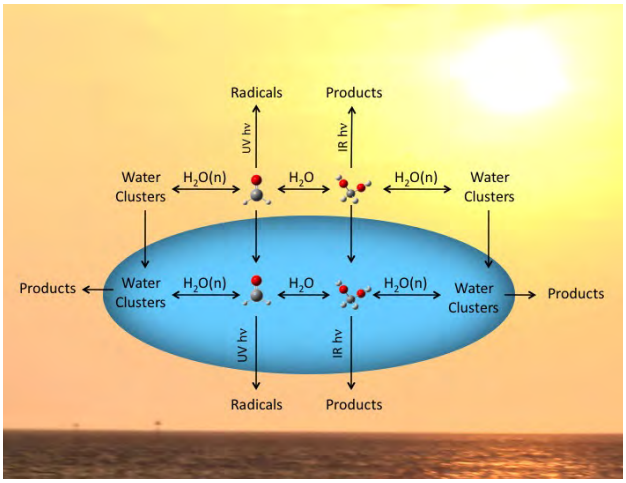
In response to observations of high radical concentrations with the Sun near the horizon, our group, using red-light-initiated photochemistry, pointed to the role of water in catalysis and/or suppression of atmospheric reactions. This chemistry resulted in mechanisms connecting volatile organic compounds to aerosol nucleation.

Properties of atmospheric aerosols are highly nonlinear, resulting in uncomfortably large uncertainties in aerosol effects on climate. Inspired by atmospheric measurements, which established that aerosols have a large organic content, we proposed that a significant population of organic aerosols consists of an aqueous core with an organic surface film and pointed to the profound consequences to their morphology and optical and chemical properties. Our research group investigates the fundamental physical chemistry of interfacial organic films and explores the consequences of these results with theoretical models.



KAITO TAKAHASHI (SKODJE GROUP)

Figure 1: *Lowering of the transition state energy by water in the hydration of formaldehyde to methanediol.*



JESSICA AXSON (VAIDA GROUP)

Figure 2: *The water- and light-mediated chemistry of organic atmospheric molecules affects their chemistry and aerosol nucleation.*

Rainer Volkamer

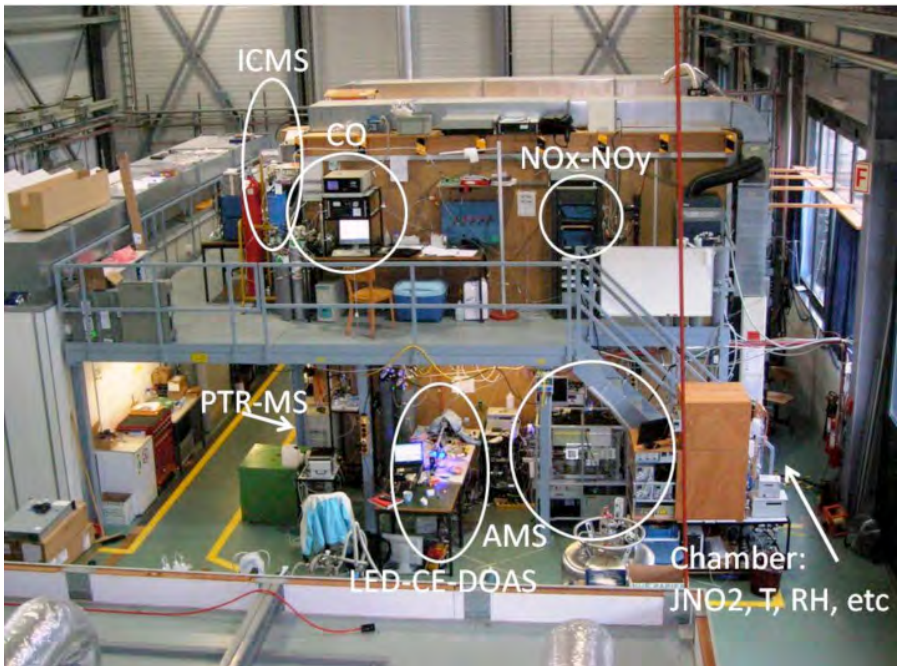
Simulation Chamber Experiments of Relevance to Atmospheric Chemistry

FUNDING: NATIONAL SCIENCE FOUNDATION

Simulation chambers are tools to study the chemical kinetics and products of chemical reactions in absence of the convoluted complexity of field observations, which arises from multiple emission sources, atmospheric transport and chemical transformations. Understanding the reaction mechanism and kinetics of chemical reactions is needed to represent atmospheric chemistry in numerical models. Our group has more than 15 years of experience in developing simulation chambers, and in 2011 we carried out simulation-chamber experiments using facilities at the Paul Scherrer Institute (PSI), in Switzerland, and at the University of Manchester (UoM), United Kingdom.

Traditional models represent secondary organic aerosol (SOA) formation based on the gas-phase oxidation of a limited set of organic precursor molecules. However, these models tend to underestimate the degree of oxygenation of actual SOA, indicating missing processes. One SOA source increasingly recognized as important—yet currently not well understood—is glyoxal (CHOCHO), the smallest alpha-dicarbonyl. Unlike traditional SOA precursors, glyoxal forms SOA by partitioning to the aqueous phase (Ervens and Volkamer, 2010). At PSI, we have studied Henry's Law constants for glyoxal uptake to laboratory-generated aerosols containing sulfate. These studies combined University of Colorado Light Emitting Diode Cavity Enhanced Differential Optical Absorption Spectroscopy (CU LED-CE-DOAS, Sinreich et al., 2010) measurements of gas-phase glyoxal with online High Resolution Time-of-Flight Aerosol Mass Spectrometry (HR-Tof-AMS) and time-resolved High-Performance Liquid Chromatography Electrospray Ionization Tandem Mass Spectrometry (HPLC ESI MS/MS) particle-phase measurements. We characterize for the first time the time-resolved evolution of glyoxal partitioning; relate molecular-specific measurements to AMS mass spectra; and investigated the effects of visible light on the reversibility of glyoxal uptake to ammonium sulfate (AS) and mixed AS/fulvic acid seed aerosols under relative-humidity (RH) conditions ranging from 50 percent to 85 percent RH.

Another set of simulation-chamber experiments further investigated recent field evidence that glyoxal is present in elevated concentrations in the marine boundary layer over the tropical Pacific Ocean more than 3,000 km from any land (Thalman and Volkamer, 2010). At UoM, the source for glyoxal was investigated by means of simulation-chamber and flow-tube studies that used two custom-made CU LED-CE-DOAS, designed and assembled in Boulder, Colo., to probe whether glyoxal is released as the result of the exposure of atmospheric oxidants (O3, OH) to organics within sea-spray aerosols, and on a bulk surface proxy ocean.



CU LED-CE-DOAS setup at the PSI simulation chamber.

John Wahr

Applications of Time-Variable Gravity Measurements from GRACE

FUNDING: NASA, JET PROPULSION LABORATORY

The GRACE (Gravity Recovery and Climate Experiment) 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 GRACE data can be used to estimate month-to-month changes in the Earth's mass distribution. GRACE can recover mass variability at scales of about 250–300 km and larger.

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.

As one example, because of its large effective footprint and its sensitivity to mass, GRACE offers the best available method for measuring the total mass balance of the polar ice sheets. Figure 1 shows monthly GRACE results (black line; the orange line is a smoothed version) for the mass variability summed over the entire Greenland ice sheet, between April 2002 and March 2011. The trend of the best-fitting straight line is about 220 gigatons/yr of ice-mass loss, which corresponds to enough water each year to cover all of Colorado to a depth of almost 1 meter. There is a notable downward curvature to the results, indicating that the mass-loss rate was increasing during this time period. But hiding behind this reasonably simple single time series is a mass-loss signal of considerable spatial and temporal complexity. Figure 2, for example, shows how the mass-loss rate was distributed across Greenland for four two-year timespans, as determined from the GRACE solutions. It shows the mass loss began in earnest in about 2005, in southeast Greenland. That region tended to stabilize in 2007, while at the same time significant mass loss appeared in the northwest. During the last couple of years, the mass-loss pattern reverted to something closer to the 2005–2007 pattern. The main source of these dramatic mass-loss rates is increased velocities of outlet glaciers. The GRACE results indicate how volatile those velocities have been and suggest that the dynamics controlling those velocities will be difficult to sort out.

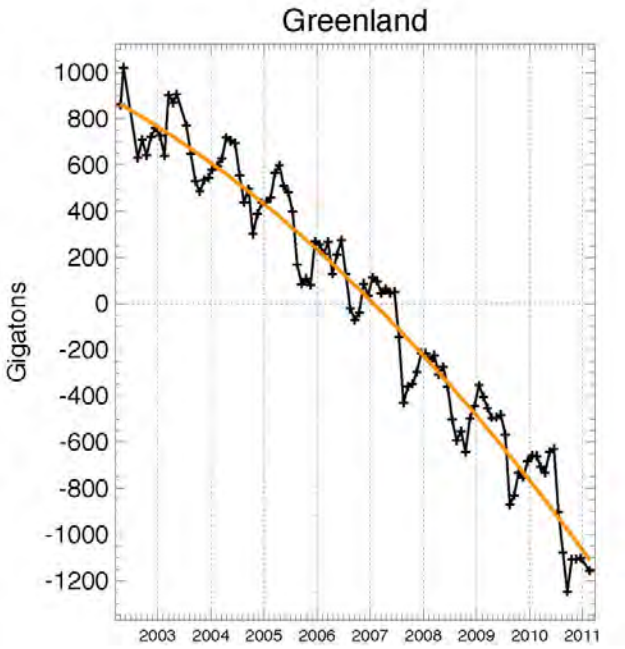


Figure 1: *Monthly GRACE results (black line; the orange line is a smoothed version) for the mass variability summed over the entire Greenland ice sheet, between April 2002 and March 2011.*

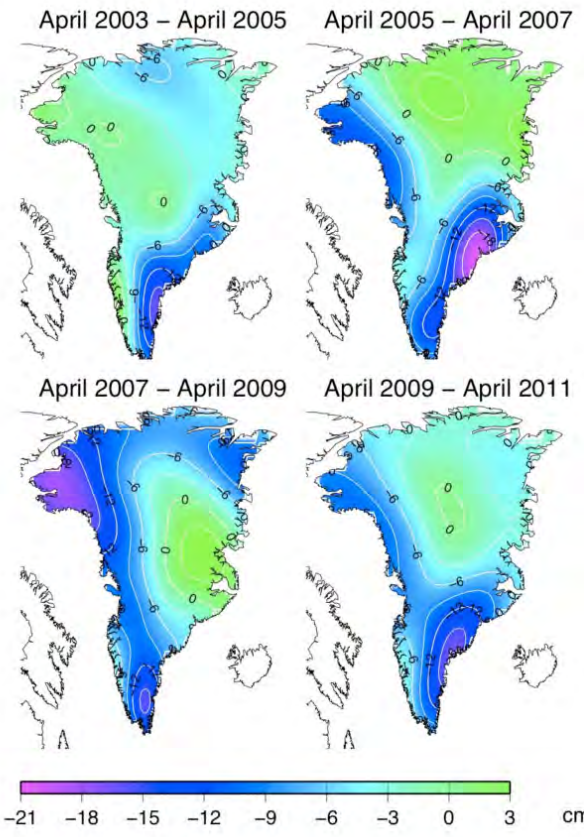


Figure 2: *How the mass-loss rate was distributed across Greenland for four two-year timespans, as determined from the GRACE solutions.*

Carol Wessman

with graduate students

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

FUNDING: CIRES, CU-BOULDER ECOLOGY & EVOLUTIONARY BIOLOGY, NATIONAL SCIENCE FOUNDATION

Climate change and human activity are rapidly changing disturbance regimes, likely leading to forest disturbances of greater frequency, extent, intensity and variety. Future disturbance interactions may be unprecedented and unpredictable. Cascading large-scale disturbances, such as drought, insects and fire, will interact to shape future forest landscapes and ecosystem services by altering successional rates and pathways.

Colorado's Routt National Forest has experienced several catastrophic disturbances over a short period: record windthrow in 1997; salvage logging from 1999–2001; and regional wildfire in 2002. Epidemic spruce-beetle and mountain-pine-beetle infestations are widespread. Historical records of such disturbance complexes are rare and lack information on processes important to ecosystem recovery.

The objective of a 2010 study was to determine if disturbance history in subalpine forest influenced characteristics of a subsequent disturbance—possibly creating a novel disturbance with effects significantly different from what would be expected from the final disturbance alone (fire-only). Ninety-nine study plots were established on a gradient of disturbance-interaction severities. Fire-only areas provided a baseline fire response, and salvage logging served as an experimental treatment of pre-fire fuel reduction. Fire-effects modeling indicated that the combination of severe blowdown and fire created an uncharacteristically long-lived fire; geographic information system (GIS) analyses demonstrated an increase in patch size of areas experiencing both severe blowdown and fire (thus, requiring long distances for seed dispersal) in contrast to fire alone. These two characteristics directly impact the two major fire-resilience mechanisms of subalpine forest: cone serotiny and seed dispersal. Consequently, increasing blowdown severity prior to the fire was significantly correlated with decreasing conifer regeneration, and resilience was crippled in areas where atypical fire characteristics resulted from the disturbance interactions. Due to the ability of alternate cover types (such as aspen and grassland) to exclude seedling establishment, substantial future recruitment is unlikely, leading to long-term changes in the spatial heterogeneity of regional composition and function.

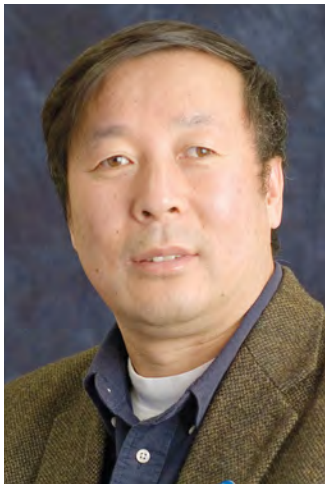
Ph.D. student and CIRES Graduate Fellow Brian Buma (left) and MA student Adam Markovits in an undisturbed subalpine forest, Routt National Forest, Colorado.

PHOTOS BY CAROL WESSMAN

Severely blown-down forest created high-fuel loads going into the 2002 fire. The interaction of the blowdown and fire disturbances damaged forest-resilience mechanisms, resulting in little to no conifer regeneration eight years after the fire.

Tingjun Zhang

Degrading Permafrost on the Qinghai-Xizang (Tibet) Plateau



The Qinghai-Xizang (Tibet) Plateau has an average elevation of greater than 4,000 m above sea level (a.s.l.) and is known as "The Roof of The World." As a result, permafrost is well-developed over the majority of the plateau's area. Due to the impacts of climate warming and human activities, such as the newly constructed Qinghai-Tibet Railroad, permafrost on the plateau is experiencing significant warming and degradation during the past few decades. Changes in permafrost conditions would have dramatic impact on local and regional ecosystems, hydrological and carbon cycles, landscape and, more importantly, engineering infrastructure. In collaboration with Prof. Qingbai Wu and his colleagues from the Cold and Arid Regions Environmental and Engineering Research Institute, Chinese Academy of Sciences, we established in the past few years a long-term permafrost-monitoring network, which is still expanding, along the Qinghai-Xizang (Tibet) Railroad (Figure 1).

The preliminary results indicate that among the 28 monitoring sites along the network, average active-layer thickness is about 3.1 m with a range from about 1.2 m to 4.9 m (Figure 2). From 2006 through 2010, active-layer thickness has increased at a rate of about 6.3 cm/year. Permafrost temperature at the depth of zero amplitude (i.e., mean annual ground temperature, MAGT) ranges from about -3.0°C to -0.1°C (Figure 2). Although permafrost along the network is relatively warm, permafrost temperature at the depth of zero amplitude is increasing at a rate of about 0.01°C per year over the past five years. The magnitude of permafrost-temperature increase is greater for relatively colder permafrost (MAGT of less than -1.0°C) than for relatively warm permafrost (MAGT less than -1.0°C). This is consistent with observations in the Arctic, primarily due to the effect of latent heat as unfrozen water content increases with permafrost temperature increase. This permafrost monitoring will continue for the next 10 years.

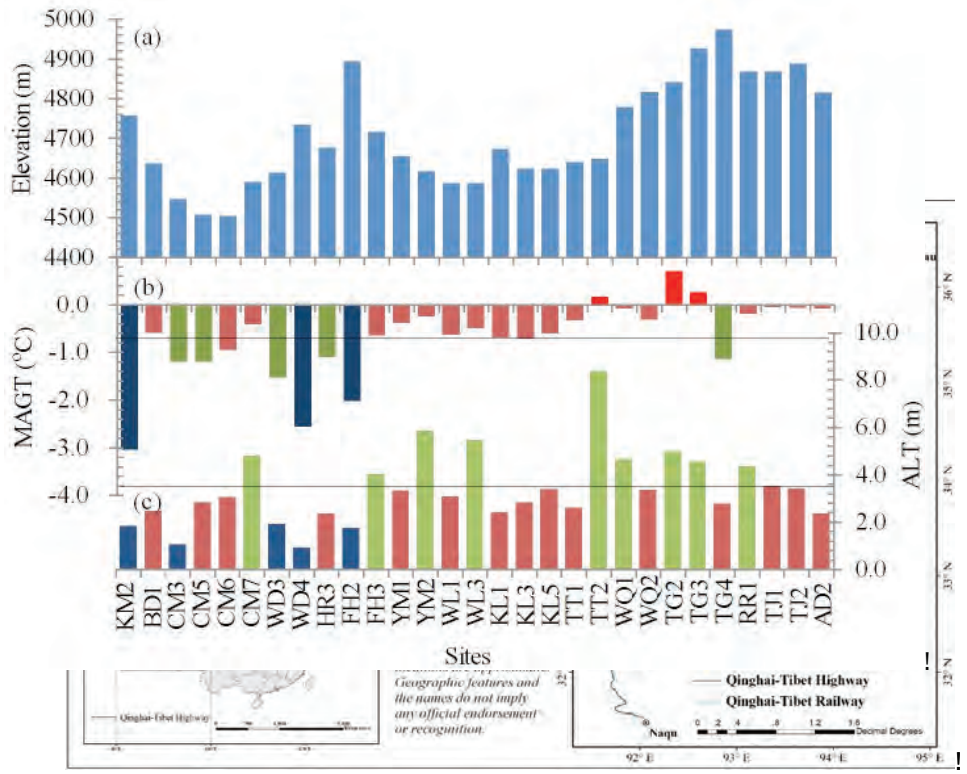


Figure 1: *(a) Site elevation; (b) mean annual ground temperature (MAGT) at depth of zero amplitude; and (c) active layer thickness (ALT) along the Qinghai-Xizang (Tibet) Railroad.*

Center for Limnology

The Center for Limnology supports research and graduate education related to biogeochemistry and metabolic functions of aquatic ecosystems. During 2010, the Center continued its work on the biogeochemical effects of pine bark beetles on montane watersheds in Colorado. Strong disturbance of vegetation by practices such as clearcutting or herbicide treatment is known to cause radical changes in the nitrogen cycle of watersheds, as reflected in the chemistry of streams within watersheds. For example, classical studies of clearcutting and herbicide treatment in experimental watersheds of New Hampshire showed a 50-fold increase in the export of nitrate from watersheds as a result of treatment. Because of the work in New Hampshire and elsewhere, biogeochemically oriented scientists in the Rocky Mountain region have anticipated massive loss of nutrients, and especially inorganic nitrogen, from watersheds that are severely infested with pine beetles. Because vegetation takes up nutrients, elimination of vegetation by any mechanism, including severe pine beetle infestation, is likely to cause release of nutrients. Nutrient release has been studied by Center staff, including CIRES Ph.D. student Leigh Cooper.

The results of biogeochemical studies across a range of infestation intensities for pine beetle in the Colorado Rockies have shown effects that range from negligible to very mild. Thus, the observations are unexpected and require some explanation. Staff scientist James McCutchan has proposed an explanation that is derived from the mechanism of pine beetle infestation. The infestation comes on incrementally over a period of years. The effect of the incremental nature of infestation can be modeled by the use of watershed biogeochemistry models that predict the loss of nitrate and other nutrients from disturbed watersheds (Figure 1). Modifying the model to acknowledge the staged nature of vegetation losses associated with pine beetle mortality shows that the model predicts what we are now observing (i.e., a suppression of peak losses associated with sudden disturbances such as clearcutting or herbicide treatment). These findings are being prepared for publication in collaboration with other research groups working on the biogeochemical effects of pine beetle infestation.

Top, Bluebird Lake, Rocky Mountain National Park (RMNP). Bottom, endangered greenback cutthroat, the original resident trout of RMNP.

PHOTO BY C. RHOADES, AUGUST 2006.

Spatially heterogeneous progression of mountain pine beetle infestation is the cause of the "red hand of death" pattern in a small watershed of the U.S. Forest Service Fraser Experimental Forest, Colo., as bark beetles initially infest large, mature lodgepole pine and avoid smaller trees regenerating in previously logged areas.

The Center also continues to work on comparisons of food web structure in lakes that contain fish and lakes that lack fish. The lakes under study are in Rocky Mountain National Park, where stocking is currently prohibited. This is one of the few places where multiple waterbodies of similar morphometry and size can be compared on the basis of presence or absence of fish. CIRES Ph.D. student Thomas Detmer is leading the research.

The Center for Limnology also continues its studies of metabolism of the South Platte River downstream of Denver. Large changes in chemistry of the river are expected as new treatment facilities are constructed for removal of nitrogen and phosphorus, in compliance with new nutrient standards adopted by the State of Colorado. The interplay between nitrogen and organic matter will be especially interesting. Denitrifying microbes, which use nitrate as an electron acceptor, require abundant labile organic matter to grow. They also require anoxic conditions, which they find now below the sediment surface. A change in the balance between labile organic matter and nitrate in the future could drastically affect the denitrifying capabilities of the river, which are beneficial in reducing high concentrations of nitrate that originate from effluent and from nonpoint sources including agriculture. Modeling and experiments are underway to determine the probable effects of change in wastewater quality.

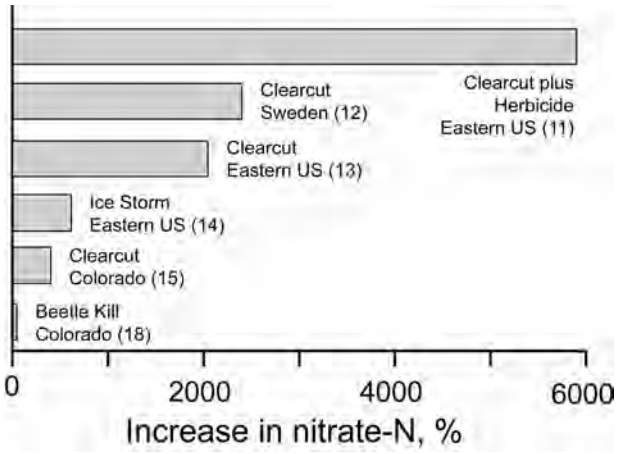


Figure 1: *Examples of nitrate release from watersheds in response to several kinds of canopy disturbance, including tree mortality caused by beetles.*

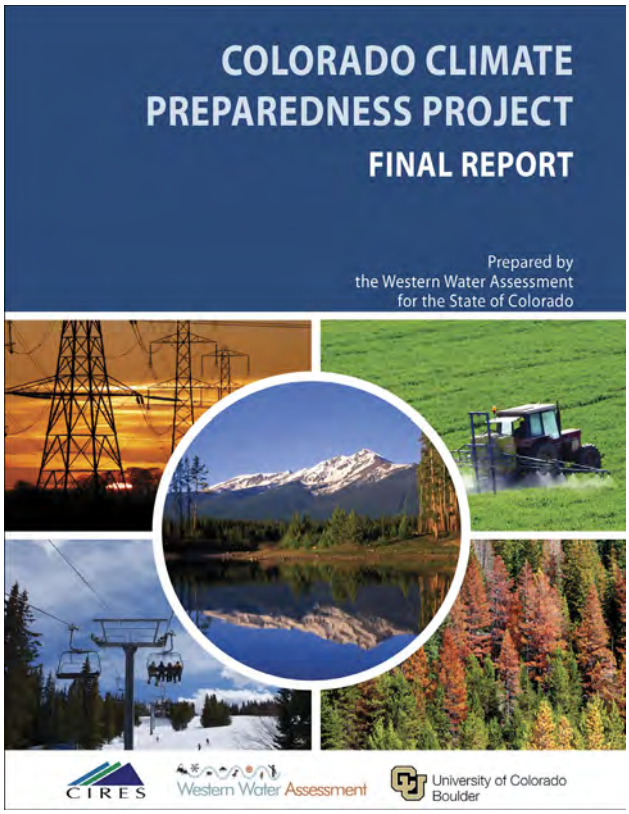
Center for Science and Technology Policy Research

The Center for Science and Technology Policy Research (CSTPR) was established within CIRES in 2001 to conduct research, education and outreach at the interface of science, technology and the needs of decision makers in public and private settings. The Center focuses on the intersection of the environment and society, applying the social and policy sciences to problems of environmental change, management and sustainability. The Center's research is integrated with the ongoing activities of CIRES, NOAA, CU-Boulder and the broader science and technology community.

Much of our work poses questions about how people and institutions make decisions under uncertainty; how perception and technical information influence choices; and how, over time, those choices affect the co-evolution of science, technology and policy. Outcomes of particular interest to Center faculty include trends in natural-disaster losses and their underlying causes; factors affecting the supply and demand of climate science; and ethics and trends in environmental management and policy, including efforts to limit greenhouse gases in the atmosphere, manage natural hazards and adapt to environmental change.

Current projects are examining the interaction of short-term municipal drought response with long-term vulnerability to climate change; tradeoffs that land managers face when contemplating incorporating carbon into a suite of multiple-use objectives; and how climate-related information is used in different water-management contexts. We are also tracking worldwide newspaper coverage of climate change or global warming on a monthly basis. Our work is reported via research articles, books, reports and several outreach methods, including a regular newsletter, briefings for decision makers, faculty blogs, news media and frequent seminars and workshops.

Recent highlights include publication of the final report of the Colorado Climate Preparedness Project, summarizing climate impacts and adaptation strategies in five climate-sensitive sectors in Colorado; a completed graduate thesis on the drought-coping strategies among ranchers in the Interior West (both in cooperation with the Western Water Assessment); and research publications on the new carbon economy, media reporting of sea-level rise, geo-engineering, ocean fertilization, economic impacts of tropical cyclones and an evaluation of the targets and timetables of proposed Australian greenhouse-gas-emissions reduction policies.

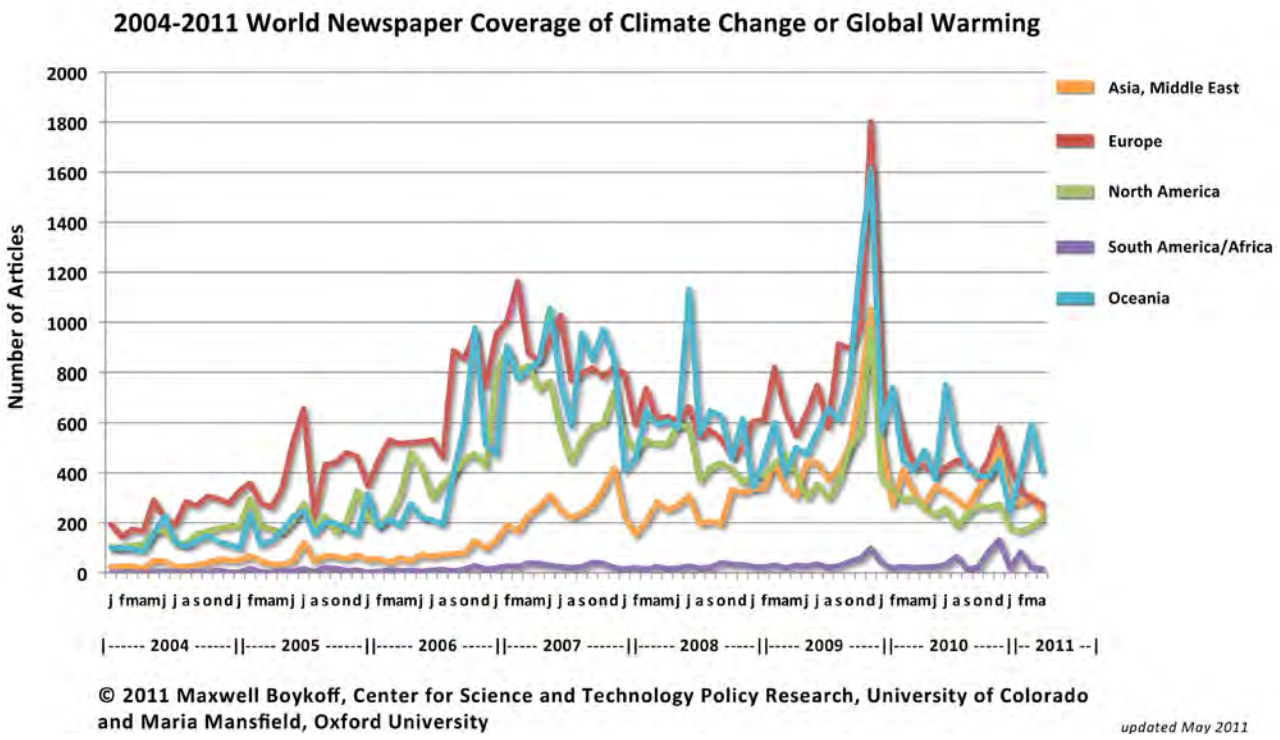


COVER DESIGN BY AMI NACU-SCHMIDT

Final report of the Colorado Climate Preparedness Project, prepared by the Western Water Assessment for the State of Colorado (CSTPR participants: William Travis and Bobbie Klein).

DFDPHOTOGRAPHY

Lisa Dilling addresses the Asilomar Conference on Climate Intervention Technologies in Pacific Grove, Calif., March 22–26, 2010.



This figure, updated monthly, shows newspaper coverage of climate change or global warming in 50 newspapers across 20 countries and six continents.

DFDPHOTOGRAPHY

Maxwell Boykoff addresses the Asilomar Conference on Climate Intervention Technologies in Pacific Grove, Calif., March 22–26, 2010.

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 of direct relevance to society. CDC's goal is to establish the causes of regional climate variations around the globe on time scales of weeks to millennia, by 1) developing and applying new diagnostic techniques to global observations and model simulations; 2) developing new observational data sets and performing new climate model integrations as needed for this purpose; and 3) developing new techniques to diagnose and reduce model errors.

Research disciplines include, but are not limited to, the atmospheric sciences, oceanography, stochastic dynamics and 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 2010–2011, CDC published 23 peer-reviewed papers on topics that included:

- The Twentieth Century Reanalysis (20CR) project, a major international effort led by CDC and NOAA to produce a comprehensive global atmospheric circulation data set spanning the period 1871 to the present, assimilating only surface pressure reports and using observed monthly sea-surface temperatures and sea-ice distributions as boundary conditions. The submission of this paper was invited by a peer-reviewed journal (*QJRMS*), a distinct honor.
- A demonstration (using the 20CR data set) that the 1918/19 El Niño event, which coincided with the "Great Influenza Epidemic," may have been much stronger than previously thought.
- A critical evaluation of techniques for removing El Niño–Southern Oscillation (ENSO) related variations from the historical climate record to better isolate climate change signals, and implementing a new technique that suggests that the ENSO-related contribution to 20th century warming may have been larger than previously thought.
- Demonstrating the critical influence of the pattern of tropical ocean warming on remote climate trends, and also the inability of the climate models used in the Intergovernmental Panel on Climate Change (IPCC) 2007 report to represent such patterns.
- Assessing the realism of the local and remote feedbacks on tropical ocean temperatures in the IPCC models, and showing that climate models are significantly deficient in representing the remote feedbacks.
- Distinguishing the roles of natural and anthropogenically forced decadal climate variability in the world's oceans.
- Determining the optimal tropical sea surface temperature pattern for inducing North American drought
- Highlighting the sensitivity of global surface temperature trend estimates to the choice of the time interval used.
- Explicitly accounting for clouds in atmospheric data assimilation.
- Documenting newly discovered features of the South American monsoon system, including the 1970s climate transition.
- Interannual ENSO variability forced through coupled atmosphere-ocean feedback loops.

ISTOCK

Additionally, CDC continued developing several observational and atmospheric circulation data sets and forecast products, and provided scientific input to international programs. These efforts included:

- Completing production of the 20CR data set for 1871 to the present, and making the data set widely available through a web interface. For more, see: http://www.esrl.noaa.gov/psd/data/gridded/data.20thC_Rean.html.
- Providing leadership in the international Global Climate Observing System Surface-Pressure Working Group, to promote the development of long-term, high-quality surface-pressure data sets.
- Providing leadership in the U.S. CLIVAR (Climate Variability and Predictability) Working Group on Decadal Predictability.
- Developing and releasing an experimental forecast product (jointly with NOAA Earth System Research Laboratory's [ESRL] Physical Sciences Division) for subseasonal tropical forecasts based on a coupled linear inverse model of weekly tropical SSTs and outgoing longwave radiation variations. For more, see: http://www.cdc.noaa.gov/forecasts/clim/.

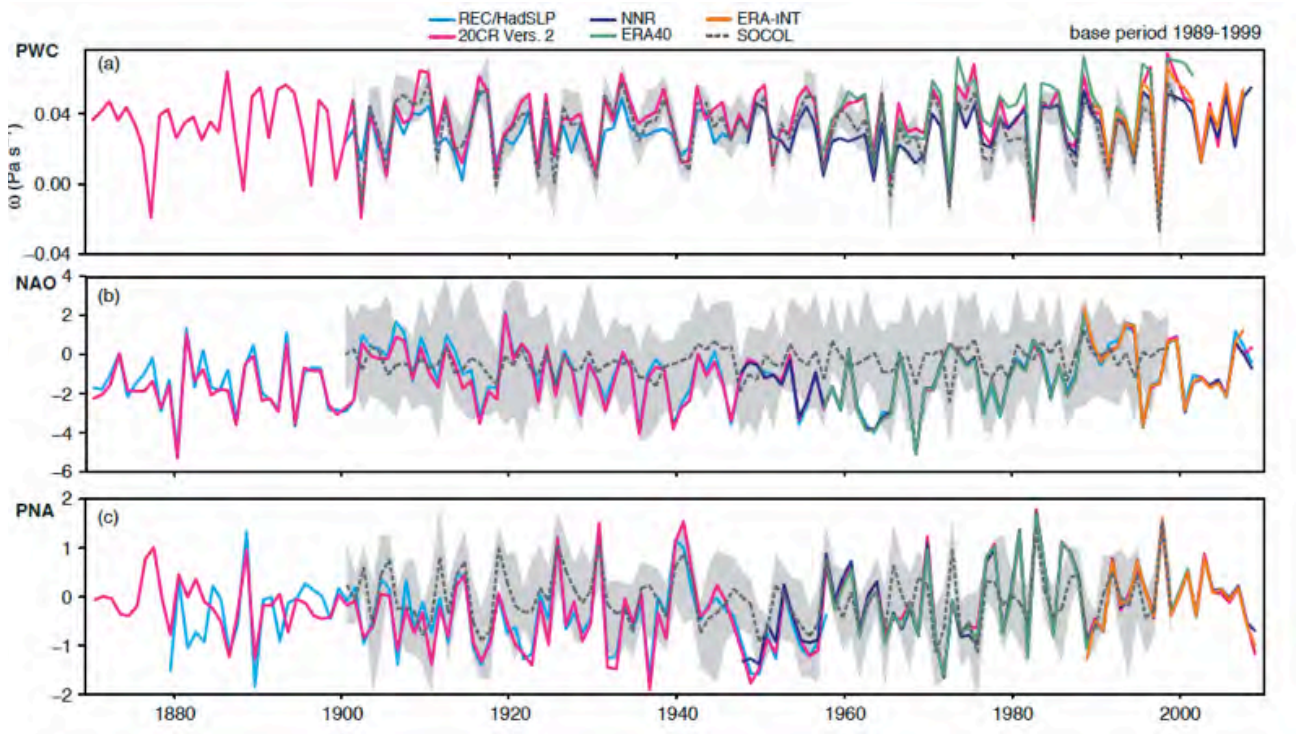


Figure 1: *Time series of seasonally averaged climate indices representing (top panel) the tropical Pacific Walker Circulation PWC; (middle panel) the North Atlantic Oscillation NAO; and (bottom panel) the Pacific North America pattern PNA. The pink curves are obtained from the Twentieth Century Reanalysis (20CR) data set, and may be compared with the curves obtained from other observational data sets over their periods of overlap. Where the pink curve is not visible, it is indistinguishable from the curve drawn over it. The grey curve and grey shading are from an ensemble of 20th century climate model simulations with indicated uncertainties. The main point of this figure is that there is no statistically significant trend in these important climate indices over the full period of record (1871 to 2007) in the 20CR data set, even though some trends are evident over shorter periods. From Compo, et al. (2011).*

The completion, publication and universal distribution of the 20CR data set are widely acknowledged major contributions. It is anticipated that the data set will be a valuable resource to the climate-research community for model validation and diagnostic studies. Some surprising features of the data set are already evident. For instance, the long-term trends of indices representing the North Atlantic Oscillation, the tropical Pacific Walker Circulation and the Pacific-North American pattern are weak or nonexistent over the full period of record (1871 to the present) in this data set. The long-term trends of zonally averaged precipitation minus evaporation also differ in character from those in climate model simulations of the 20th century. These results have important implications for how global warming is influencing atmospheric circulation variability, and to what extent climate models are correctly representing those influences.

The demonstration of the critical importance of correctly representing the pattern of tropical oceanic warming in order to capture regional climate trends around the globe—and that climate models are significantly deficient in this regard—is another major contribution of the Center and has been featured in many invited presentations, as well as noted in NOAA's review of ESRL's Physical Sciences Division last year.

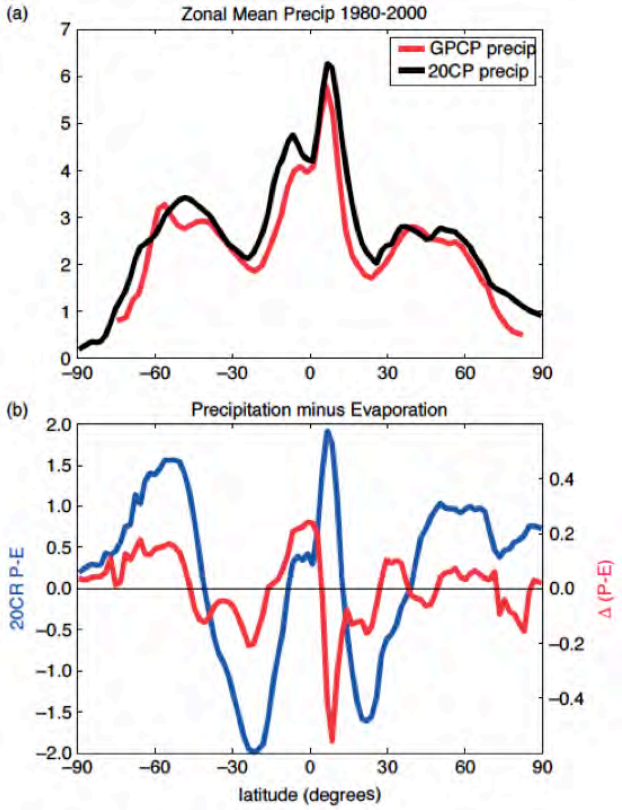


Figure 2: *(Top panel) Zonal mean precipitation rate P (in units of mm/day) averaged over 1980–2000 from the 20CR data set (black curve), and from the independent GPCP Version 2 data set (red curve). (Bottom panel) Zonal Mean precipitation rate P minus the evaporation rate E averaged over 1980–2000 from the 20CR data set (blue curve), and the 1980–2000 P-E average minus the 1871–1891 P-E average (red curve). The prevailing theory of the global response of the hydrological cycle to global warming would predict the red and blue curves to be similar. That they are not is interesting and important for our understanding of 20th century climate change. From Compo, et al. (2011).*

Earth Science and Observation Center

The southern lights at McMurdo, Antarctica.
ZHIBIN YU/CIRES

CIRES' Earth Science and Observation Center (ESOC) provides a focus for the development and application of modern remote-sensing techniques used in the research of all aspects of Earth sciences at CU-Boulder. Our 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 seven faculty associates during FY11, 26 graduate students, eight post docs and two visiting fellows. Below, ESOC accomplishments and activities are summarized by topic.

Cryospheric Change

We continued to monitor the climate on the Greenland Ice Sheet using 18 automatic weather stations and two permanent research sites (Swiss Camp at the equilibrium line altitude and Summit Station close to the highest point on the ice sheet). This data set, initiated during the Program for Arctic Regional Climate Assessment (PARCA) in 1995, is the longest in situ meteorological time series capturing the recent climate warming in the ice sheet. Decadal temperature increases of 1.0°C in the fall; between 1.5 and 2.0°C in the summer and spring; and up to 3°C in winter were measured on the western slope of the ice sheet at Swiss Camp between 1995 and 2009. Other activities within ESOC's cryospheric-change research group include the development of an ice model to study the englacial effect of meltwater, the development of a glacio-hydrological model and the study of a moulin system in the ablation region close to Swiss Camp. In the Southern Hemisphere, we completed our second successful field campaign on the Larsen C Ice Shelf in the Antarctic Peninsula by monitoring the shelf-ice thickness using surface-based ground-penetrating radar along a total of 500 km. We established an advanced monitoring station at Summit Camp in Greenland to link the isotopic composition, used to develop long ice cores, to snow-formation processes and the surface energy balance. This work uses state-of-the-art laser-imaging spectrometers to measure the shape falling snow crystals alongside the measurements of isotopic composition of vapor to better understand the origin of the isotopic signals in ice cores and, thereby, improve our understanding of the climate history of the Greenland Ice Sheet.

Land Surface Effects on Climate

We continue to examine the impact of surface hydrology on climate, particularly in the massively irrigated regions of Asia, and have found evidence of substantial impacts both in observational and model-simulation studies. We have continued examining minimum temperature regulation by convection at high latitudes and are proposing to extend this to maximum temperatures in future work. We also have been looking into low-level inversions in the western United States, which we found to have substantially decreased over the period of record in six Western cities. This is of interest because air quality in the U.S. West is a function of inversion frequency and strength, and because climate models have predicted that inversions would be more frequent in a warming climate.

Ecology

Future disturbances to forest ecosystems are expected to be of greater frequency, extent, intensity and variety as a result of a changing climate. In addition, human-forest interactions (e.g., forest management and wildland-urban interface) will increase the complexity of disturbance impacts and forest recovery. Our ongoing study of several catastrophic disturbances in a northern Colorado subalpine forest is yielding interesting insights into disturbance interactions and their influence on the current and future landscape mosaic. Our analyses of conifer seedling establishment patterns following a stand-replacing fire in 2002 show a strong influence of prefire disturbances (such as 1997 catastrophic blowdown and salvage logging) on forest recovery rates. MODIS (Moderate-Resolution Imaging Spectrometer) Normalized Difference Vegetation Index time-series data indicate that these different recovery patterns are evident at landscape scales. Importantly, our recent studies suggest that satellite data can provide regional information on forest response to disturbance, thus assisting larger-scale efforts such as forest management and regional-to-global ecological modeling.

Hydrology

A core hypothesis in a newly developing nonlinear geophysical theory of floods says that solutions of conservation equations in self-similar river networks exhibit spatial scaling (power laws). Our analysis of 26 medium-size river basins (about 3,000 km^2) confirmed the presence of self-similarity in networks, thus supporting the hypothesis. This is the first time the theory has been put to the test on medium-size

basins (about 32,000 km^2), giving a major boost to 20 years of flood research. Remote sensing plays a key role in estimating rainfall intensities in time and space in this theory. The findings offer a new approach for real-time flood forecasting and estimation of annual flood frequencies for the management of flood plains in a changing climate.

Atmospheric Lidar Development and Application

The atmosphere is the essential part to make the Earth a habitable planet for humankind. It also has been increasingly and largely impacted by anthropic activities. The ability to understand and predict the short- and long-term changes of the atmosphere, the weather and the climate is critical for the well-being of modern society. To advance the atmosphere physics and chemistry, Xinzhao Chu's research group within ESOC are developing and deploying three resonance-fluorescence lidars. First, we are developing the National Science Foundation (NSF) Major Research Instrumentation Fe-resonance/Rayleigh/Mie Doppler lidar. It focuses on the measurements of middle and upper atmosphere with extended coverage to the lower atmosphere. The lidar technology development was truly innovative, and the group won the Best Paper Award at the 25th International Laser Radar Conference in St. Petersburg, Russia, in July 2010. Secondly, we have deployed an Fe Boltzmann lidar to McMurdo, Antarctica, to measure the polar atmosphere for at least three years. This lidar was developed by Chu and her colleagues more than 10 years ago, and then upgraded with advanced technologies in 2010 before this deployment. In combination with the previous lidar measurements made by Chu at the South Pole and Rothera, Antarctica, the McMurdo lidar campaign is completing an observational chain and exploring new science frontiers in Antarctica. Exciting science discoveries have already emerged from the first year measurements, including new findings on polar mesospheric clouds, neutral Fe layers, temperatures and gravity waves. Thirdly, a STAR (Student Training and Atmospheric Research) Na Doppler lidar has been developed and is being further improved by graduate students at CU. They have achieved 800 counts per shot of Na signal levels, nearly 10 times what other lidar groups achieved under similar conditions. The STAR lidar has been successfully used as a community education/training tool and equipment/technology test bed. It also provided valuable data for science study.

Water Cycle and Climate

Appreciating the changing relationships between the Earth's water cycles and climate is central to adapting to environmental change. We seek to improve understanding of the mechanisms that control the exchange of water between the Earth's surface and the atmosphere and in clouds. A critical limitation in climate models is accurately simulating exchange of water and other gases through the boundary layer. We have established a monitoring station at the 300-m tower at the NOAA Boulder Atmospheric Observatory in Colorado to provide data on the isotopic composition of water vapor and CO2 concentration alongside surface energy balance to provide the critical tests of climate model parameterizations. A second site at the NSF Long Term Ecological Research station at Niwot Ridge, Colo., is being established to compare the grassland environments with alpine forest conditions. The data show that state-of-the-art climate models inadequately capture the gas transport, and they offer guidance as to how the models can be improved. Using remote-sensing estimates of the isotopic composition of water vapor, we have tested the sequencing of some of the mechanisms associated with propagation of the Madden-Julien oscillation in the Tropics, which is a phenomenon that is poorly simulated in all climate models. We have used the unique information provided by the isotope ratios of water to identify which processes are responsible for the "moist bias" that plagues state-of-the-art climate models.

Satellite and Aircraft Missions

We continue to play an important scientific leadership role for NASA's Ice Cloud and land Elevation Satellite-2 (ICESat-2) laser altimetry mission, planned for launch in 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, and provide input to NASA and the ICESat-2 project on scientific matters. We are actively involved in the planning of 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 work extensively with data from NASA's Gravity, Recovery, and Climate Experiment (GRACE) mission; the Total Emission Spectrometer (TES) on the Aura Spacecraft; and MODIS (Moderate Resolution Imaging Spectroradiometer). We are also actively involved in NASA's Deformation Ecosystem Structure and Dynamics of Ice mission. This year, a new area for us is in detection of potential geothermal heat sources using high-resolution thermal infrared data from Landsat, MODIS and ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer). We partnered with Flint Geothermal, LLC, on a $5 million grant. We participated in the NSF Ice in Clouds Experiment–Tropics (ICE-T) aircraft mission and made measurements of the isotopic composition of water vapor and cloud particles to understand the differences in the dynamics of developing convective clouds associated with the availability of ice condensation nuclei. This work built on the success of a deployment at the Storm Peak Laboratory in Steamboat Springs, Colo., to measure the isotopic composition of snow and mixed-phase cloud as part of the Department of Energy's Storm Peak Laboratory Cloud Property Validation Experiment (StormVEX).

National Snow and Ice Data Center

The mission of the National Snow and Ice Data Center (NSIDC) is to improve our understanding of the Earth's frozen realms: the floating sea-ice cover, lake ice, glaciers, ice sheets, snow cover and frozen ground, collectively known as the cryosphere. NSIDC advances its mission through:

- Managing, distributing and stewarding cryospheric and related data from Earth-orbiting satellites, aircraft missions and surface observations;
- Researching major elements of the cryosphere, with increasing focus on understanding how and why the cryosphere is changing and the implications of these changes;
- Conducting informatics research to find better ways to discover, integrate and distill the vast and growing volume of cryospheric and climate data; and
- Educating the public about the cryosphere, the changes being observed and their implications.

NSIDC makes hundreds of scientific data sets accessible to researchers around the world. Our data-management practices ensure the physical and scientific integrity of the data we manage and disseminate. We manage data under sponsorship from NASA, NOAA and the National Science Foundation (NSF).

Major areas of research at NSIDC include:

- The processes driving the downward trend in Arctic sea-ice extent;
- The environmental impacts of this sea-ice loss both within and beyond the Arctic;
- The behavior of the Greenland and Antarctic ice sheets and Himalayan glaciers and their contributions to sea-level rise;
- Links between snowfall, temperature and streamflow; and
- The implications of changes in Earth's permafrost.

Informatics research includes:

- Developing alternative database structures for more efficient searches through vast data volumes to answer science questions;
- Development of technologies to making NSIDC data more visible to more researchers;
- Investigating new directions in data stewardship involving the University library system; and
- Enhancing data discovery through semantic interoperability.

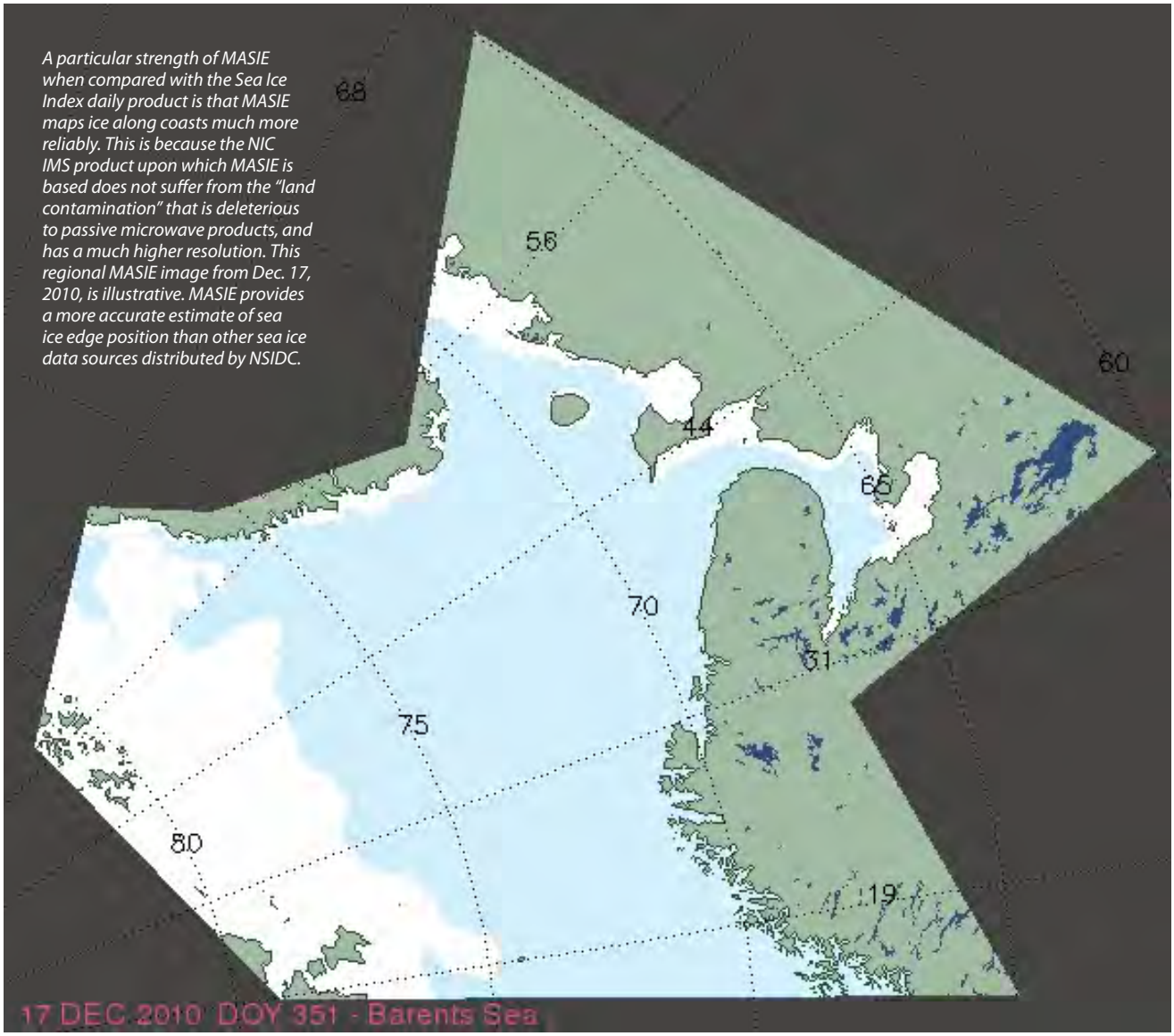
NSIDC's education and outreach efforts are wide-ranging. NSIDC scientists are in high demand by the media to lend their expertise on environmental issues involving cryospheric change. Arctic Sea Ice News and Analysis (http://nsidc.org/arcticseaicenews/index.html) provides daily updates of Arctic sea-ice extent, along with scientific analysis of evolving conditions, that are accurate and accessible to a wide audience. The NSIDC Education Center (http://nsidc.org/cryosphere/) provides a range of information about Earth's snow and ice, from comprehensive "All About" sections to quick facts on popular snow and ice topics.

MICHAEL STUDINGER/NASA

This view from a NASA DC-8 aircraft flying over the Antarctic Peninsula gives a glimpse of the ice sheet and the glaciers that Operation IceBridge is observing with an array of onboard remote-sensing instruments. The mission ensures a continuous set of observations that may help scientists understand changing ice mass for Earth's ice sheets, glaciers and sea ice.

2010 NSIDC Highlights

■ **IceBridge data:** Scientists studying changes in the mass balance of polar ice and its potential to contribute to global sea-level change are now able to access a new source of data at NSIDC: NASA's IceBridge mission. IceBridge addresses the gap between ICESat-I (Ice, Cloud and land Elevation Satellite), which concluded operations in early 2010, and the next satellite, ICESat-II, planned for launch in 2015. Begun in 2009, IceBridge is a six-year campaign of annual flights over the poles. The IceBridge aircraft carry an array of instruments to map ice-surface topography, bedrock topography beneath the ice sheets and grounding line position. Other instruments measure ice and snow thickness, sea-ice distribution and sea-ice freeboard. Data from laser altimeters and radar sounders are paired with gravimeter, magnetometer, mapping camera and other data to provide dynamic, high-value, repeat measure-



A particular strength of MASIE when compared with the Sea Ice Index daily product is that MASIE maps ice along coasts much more reliably. This is because the NIC IMS product upon which MASIE is based does not suffer from the "land contamination" that is deleterious to passive microwave products, and has a much higher resolution. This regional MASIE image from Dec. 17, 2010, is illustrative. MASIE provides a more accurate estimate of sea ice edge position than other sea ice data sources distributed by NSIDC.

ments of rapidly changing areas of land and sea ice. NSIDC has begun corralling these data from the various mission groups and creating data access points. NSIDC also will organize and process the data into products that can be used with much less data manipulation and programming than the raw mission data.

■ **MASIE sea-ice edge data:** To give the best available Arctic-wide answer to the question, "Where is Arctic sea ice NOW?" NSIDC worked with the U.S. National Ice Center to create MASIE (the Multisensor Analyzed Sea Ice Extent) project. Data about sea-ice edge include Northern Hemisphere–wide sea-ice coverage for yesterday and the last four weeks; sea-ice coverage by region; and more. Similar to NSIDC's Sea Ice Index (SII) product, MASIE is easy to use and gives a graphical view of ice extent in various formats. MASIE was developed with support from the National Ice Center and the Naval Oceanographic Office and is hosted by the NOAA at NSIDC project.

■ **SCICEX data:** From 1995 to 1999, Navy submarines made an annual cruise under the ice to collect research data on ice and ocean conditions. Until recently, some of the data from these submarine missions, called SCICEX (Science Ice Exercise), had no home and were scattered among several institutions. NSIDC is leading the efforts with other data centers to create a SCICEX data archive. SCICEX data constitute one of the best mappings of the ice canopy in the central Arctic Basin—collecting an extraordinary volume of ice-draft measurements and orders of magnitude more depth soundings of the Arctic Basin than ever before. SCICEX observations have helped scientists form and validate hypotheses about the oceans and climate.

■ **LARISSA expedition:** NSIDC Lead Scientist Ted Scambos and NSIDC researchers Terry Haran and Rob Bauer traveled to the Antarctic Peninsula to explore the causes and effects of ice-shelf breakup. From December 2009 to March 2010, they joined scientists from several disciplines aboard the Research Vessel Nathaniel B. Palmer, on the National Science Foundation–sponsored Larsen Ice Shelf System, Antarctica (LARISSA) expedition. Scambos's team, the glaciology group, set up instruments on the glaciers that feed into the remaining portion of the Larsen ice shelf. The stations record weather conditions, GPS location, photographs and other data and send them back via satellite.

WESTERN WATER ASSESSMENT

- Impacts of Climate Change and Dust Deposition on Water Resources in the Colorado River Basin
- Climate Adaptation on Western National Forests
- Colorado Climate Preparedness Project
- Ongoing Stakeholder Engagement and Collaborations

The Western Water Assessment (WWA) is one of 11 NOAA-funded Regional Integrated Sciences and Assessments (RISA) programs across the country. Using multidisciplinary teams of experts in climate, water, law and economics, the WWA team works with decision makers across the Intermountain West to produce policy-relevant information about climate variability and change. By building relationships and networks of decision makers, WWA is able to develop practical research programs and useful information products.

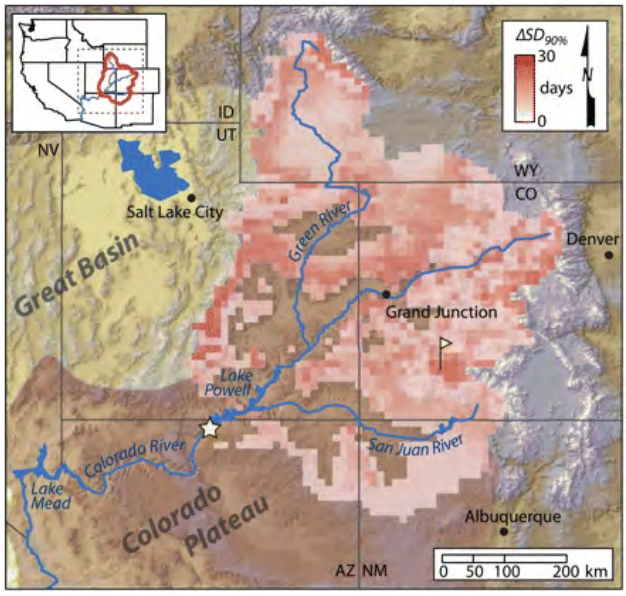
In FY11, the WWA research team continued to expand its research and decision-support products into three major thematic categories: 1) Decision Support for the Colorado River Basin and Headwaters; 2) Ecological Vulnerabilities, Impacts and Adaptation, and 3) Emerging Initiatives and Adaptation Strategies to Inform Climate Services. WWA's ongoing projects and newer initiatives were well-received by the broad community of federal, state, local and private stakeholders with whom we work, and several major endeavors emerged as particularly important efforts.

Impacts of Climate Change and Dust Deposition on Water Resources in the Colorado River Basin

Specific WWA research activities in FY11 included a significant effort to understand a question on the minds of numerous stakeholders in the region: To what extent does the deposition of dust from the Colorado Plateau region on high-elevation snowpack in the Colorado River headwaters affect runoff timing and volume? Using the Variable Infiltration Capacity (VIC) hydrologic model, WWA researchers were able to show that dust deposition is not only causing early spring runoff, but also may be responsible for evaporative losses equivalent to 800,000 acre-feet per year, or nearly 5 percent of the average total annual flow in the river. These results were published in *Proceedings of the National Academy of Sciences* and communicated directly to decision makers at the Department of Interior, the White House Office of Science and Technology Policy and other agencies. Ongoing and future work will incorporate future climate projections into the model.

Climate Adaptation on Western National Forests

As part of a broader U.S. Forest Service effort entitled "A Toolkit for Adapting to Climate Change on Western National Forests: Incorporating Climate into Resource Management and Planning," WWA is working with Forest Service researchers at the Rocky Mountain Research Station on a pilot project for the Shoshone National Forest in Wyoming. As part of this project, a WWA researcher worked directly with management and planning staff at the Shoshone Forest to understand specific parameters of interest. She then developed a climate-vulnerability assessment for the forest, focusing on shifts in available range for whitebark pine and aspen, along with changes in streamflow that could impact Yellowstone cutthroat trout and water supplies.



Modeled change in date of 90% snow depletion due to dust loading. From Painter, T, J Deems, J Belnap, A Hamlet, C Landry, and B Udall (2010), Response of Colorado River runoff to dust radiative forcing in snow, Proceedings of the National Academy of Sciences, 107*(40), 17125–17130.*

Colorado Climate Preparedness Project data base, screenshot.

Colorado Climate Preparedness Project

At the request of the State of Colorado, WWA researchers completed the Colorado Climate Preparedness Project (CCPP), a survey of climate impacts and adaptation

SCOTT COPELAND

Gannett Peak in Shoshone National Forest (Wyoming), with Dinwoody Creek in the foreground.

options in five sectors: water; electricity; wildlife, ecosystems and forests; agriculture; and outdoor recreation. This effort followed up on the 2008 Climate Change in Colorado report authored by WWA and responded directly to a call in Governor Bill Ritter's 2007 Colorado Climate Action Plan to "prepare the state to adapt to those climate changes that cannot be avoided." The CCPP includes a database (http://www.coloadaptationprofile.org) and a final report (http://wwa.colorado.edu/CCPP_report.pdf), both of which have been presented to the new governor's administration. The database and report are intended to facilitate future vulnerability-assessment and adaptation-planning efforts across the state.

Ongoing Stakeholder Engagement and Collaborations

WWA also continued its longstanding reputation with stakeholders and decision makers as a trusted source of climate information. Collectively, WWA researchers gave more than 35 public talks and seminars; published 16 articles and book chapters; were cited, quoted or interviewed by the media numerous times; served as members of many committees and organizations; and sponsored many workshops across the Intermountain West.

EDUCATION AND OUTREACH

- Climate Science Education
- Graduate Student Education
- Sun-Earth Connections

The CIRES Education and Outreach (EO) group is active across the spectrum of geosciences education, including teacher and scientist professional development, digital learning resources and courses, graduate student fellowships and more.

Climate Science Education

CIRES and NOAA climate scientists make our climate-education projects possible. CIRES climate scientists partner with CIRES Education and Outreach as part of their research projects; contribute to education projects as presenters, reviewers and learning-resource providers; and star in scientific video clips. This involvement by scientists helps teachers to have confidence that the resources provided by CIRES EO are scientifically sound and up-to-date.

To provide students with accurate information about climate and energy science, educators require scientifically and pedagogically robust teaching materials. To address this need, the Climate Literacy and Energy Awareness Network (CLEAN) has launched a new peer-reviewed digital collection as part of the National Science Digital Library (NSDL). The CLEAN Pathways project features teaching materials centered on climate and energy science for grades 6 through 16. As an NSDL Pathways project, CLEAN makes climate and energy education resources more visible and useful for educators. Each featured teaching resource has undergone a rigorous review process and provides expert teaching tips on how to implement the resource in the classroom. All materials are aligned with the Benchmarks for Science Literacy and the Essential Principles of Climate Science. The CLEAN user community is being built through a series of virtual workshops and webinars and through social media. CLEAN is funded by grants from the National Science Foundation (NSF). Learn more at cleanet.org.

> "The ICEE workshop last June helped me to gain the knowledge (and courage) to develop my climate literacy class, which was part of our school's 21st Century Learners program. Good news, no parents called to protest the curriculum and I've now got the "green light" from admin to teach the class each quarter next year (so essentially all 6th graders in our school will get a head start on being climate literate citizens)."
>
> **ICEE teacher on the ICEE forum (iceeonline.org/forum)**

Erin Pierson and David Ward learn how to test water quality during the COSEE West–Colorado Collaborative Summer Institute.

The Inspiring Climate Education Excellence (ICEE) project, funded through a NASA Global Climate Change Education grant, complements CLEAN as a professional development program for science educators. ICEE supports teachers to use best-practices teaching strategies in their climate-science instruction, including knowing how to integrate solutions into instruction and how to forestall controversy. Teachers who attended a professional development workshop through ICEE demonstrated a deeper understanding of climate-science concepts and better agreement with scientific statements about climate change, and they have implemented climate and energy content in their classrooms. Since 70 percent of educators who teach climate and energy topics in the classroom use

Emily Kellagher works with teachers during the ICEE climate science workshop.

magazines, websites and films to teach themselves climate science, ICEE is developing a suite of web-based modules to help teachers learn the Essential Principles of Climate Science. Based on a workshop held in June 2010, a suite of materials, including videos, activities and teaching tips, has been made available online on the ICEE 101 website: http://cires.colorado.edu/education/outreach/ICEE/workshop/. A community forum for teachers to share ideas and address challenges is on the ICEE Online website (http://iceeonline.org/forum), and a full online course is in development for those seeking more in-depth experience.

Graduate Student Education

CIRES Outreach leads an NSF-funded, grades K-12 program to place science graduate students in classrooms within the Boulder Valley School District (BVSD). The project enhances the acquisition of STEM (Science, Technology, Engineering and Math) skills by fourth and fifth graders and middle-school students in the more socioeconomically diverse BVSD schools by giving them the opportunity to study the ecology of extreme environments. Graduate student "Fellows" assist teachers while still conducting their own research. Some of the K-12 students will be the first in their family to graduate from high school, and Fellows are able to help them understand what it's like to be a scientist and to know more about what it's like to be at a university.

Colorado teacher Jennifer Taylor examines a classroom demonstration activity during the ICEE climate science workshop.

Sun-Earth Connections

The Solar Dynamics Observatory (SDO) launched February 2010, and as the lead education team for one of the SDO instruments, the Extreme Ultraviolet Variability Experiment, CIRES Outreach provides teacher professional development as well as classroom kits. The CIRES team involved with the project has collaborated with other SDO teams to make SDO data more accessible and meaningful to educators and their students. CIRES is developing a video solar library of terms that uses SDO data to supplement the solar learning kits. Solar science lessons also will be developed for SMART board technologies so that teachers can use them in their classrooms.

VISITING FELLOWS

With partial sponsorship by NOAA, CIRES offers visiting fellowships at the University of Colorado Boulder. Every year, CIRES awards several fellowships to visiting scientists at many levels, from postdoctoral to senior. These fellowships promote collaborative and cutting-edge research. Since 1967, 267 people have been visiting fellows at CIRES, including previous CIRES Director Susan Avery and current Director Konrad Steffen.

Matthew Druckenmiller

Postdoctoral

Ph.D., University of Alaska, Fairbanks
Project: Providing usable sea ice information to Arctic coastal communities in Alaska

Matthew Druckenmiller will earn a doctorate in geophysics this summer from the University of Alaska, Fairbanks, and then begin his postdoctoral research at CIRES investigating how sea-ice retreat in the Chukchi and Beaufort Seas affects marine mammals and coastal communities. As Alaska's Arctic coasts experience rapid change in the sea ice and coastal environment, policymakers and other stakeholders face difficult decisions regarding related issues such as coastal erosion, offshore oil and gas development, and subsistence hunting. Such decisions require accessible, understandable and relevant environmental data sets.

Partnering with the National Snow and Ice Data Center and Alaska's North Slope Borough Department of Wildlife Management, Druckenmiller will identify the baseline data needed for tracking sea-ice impacts and develop strategies for communicating that information to Arctic coastal communities so they can proactively address changing conditions. He also will collaborate on a study to examine how sea-ice retreat in the Beaufort Sea relates to the body size of bowhead whales, since less sea-ice cover equates to a larger feeding area.

Sponsor: Mark Serreze

Alison Duvall

Postdoctoral

Ph.D., University of Michigan
Project: Landscape response to strike-slip faulting: A case study of the Marlborough Fault Zone, South Island, New Zealand

Alison Duvall is working within Greg Tucker's geomorphology and landscape-evolution group and also is collaborating with Peter Molnar's group (mountain range formation and continental lithosphere deformation) and Roger Bilham's group (earthquakes and tectonic plate motions). She is investigating how strike-slip faulting—when two blocks of the Earth's crust slide past each other—changes hill slopes, river channels and other landscape features.

Tectonically active strike-slip faults pose a major earthquake hazard, especially in heavily populated areas such as the West Coast of the United States and much of Asia. Unfortunately, measuring the activity of these faults is difficult with standard techniques. By learning to correlate specific strike-slip fault characteristics to specific landscape features, Duvall hopes to develop new ways of recognizing and analyzing fault activity. For her research, she is conducting a case study of New Zealand's Marlborough Fault System, which contains faults with widely varying slip rates. She will combine field data (geomorphic mapping, field surveys and analysis of digital topographic data) with computer modeling of landscape evolution to explore how the Earth's surface responds to strike-slip faulting.

Sponsor: Greg Tucker

Juliane Fry

Sabbatical

Ph.D., California Institute of Technology

Project: Investigating nitrate-initiated secondary organic aerosol formation in the laboratory and in Colorado Front Range forests

Juliane Fry is an assistant professor of chemistry and environmental studies at Reed College, in Portland, Ore. Fry's research focuses on atmospheric chemistry, aerosol formation and air pollution. She is investigating the source of particulate hazes—dirty-looking, low-visibility air filled with microscopic particles—that form in forests downwind of industrial and urban centers.

These tiny atmospheric particulates are important to public health because they are linked to asthma and cardiac disease. While scientists know that nitrogen oxide gases—emitted from such sources as coal and fossil-fuel combustion—initiate the particulate formation, they don't fully understand which nitrates and reaction mechanisms are involved. Working with Fred Fehsenfeld, Steve Brown, Jose-Luis Jimenez, Doug Day and Jim Smith, Fry will assemble a group of instruments capable of measuring various species of nitrates and particulate size. They will then monitor pollution plumes flowing into the Manitou Forest Observatory, near Woodland Park, Colo., and also conduct chamber experiments at NCAR to pinpoint the responsible agents. Successful results would assist policy makers in developing strategies to reduce haze.

Sponsor: Fred Fehsenfeld

Klara Hlouchova

Postdoctoral

Ph.D., Charles University in Prague, Czech Republic

Project: Study of pentachlorophenol hydroxylase, a key enzyme in a novel microbial metabolic pathway for pentachlorophenol degradation

Klara Hlouchova is working in Shelley Copley's group investigating a novel metabolic pathway that has evolved in the soil bacterium *Sphingobium chlorophenolicum* in response to the extensive use of pentachlorophenol (PCP)—a pesticide that has been contaminating the environment since the 1930s.

The *S. chlorophenolicum* pathway can degrade PCP, but because the pathway is at a very earl stage of evolution, it is still quite inefficient. Hlouchova intends to uncover the structures of the key PCP degradation enzymes from *S. chlorophenolicum* and to address the reasons for their poor catalytic ability. Using in vitro evolution techniques, her goal is to evolve an improved version of *S. chlorophenolicum* that could be used for remediation of PCP-contaminated waste streams.

Sponsor: Shelley Copley

Krishna Kumar Kanikicharla

Postdoctoral

Ph.D., University of Pune, India

Project: Seasonal forecasting of Indian summer monsoon rainfall: Diagnostics and synthesis of regional and global signals

Krishna Kumar Kanikicharla studies how anthropogenic climate change affects the variability and predictability of the Indian and East African monsoons. Monsoonal rains can provide up to 90 percent of a region's yearly precipitation, and billions of people depend upon them for agriculture, hydroelectric power and drinking water.

Temperature differentials between two areas—principally cooler air over the sea and warmer air over land—drive, in large part, the changing wind and precipitation patterns characteristic of monsoons. Consequently, climate models show that global warming may alter some monsoon behavior, causing more sporadic drought in some places and floods in others. Kanikicharla will work with Balaji Rajagopalan's group to analyze extensive observational data and design sensitive global models. The ultimate goal is to develop user-friendly interactive Web tools for analyzing and forecasting monsoons and other weather phenomena.

Sponsor: Balaji Rajagopalan

Faezeh Nick

Sabbatical

Ph.D., Institute for Marine and Atmospheric Research Utrecht (IMAU), Utrecht University, The Netherlands
Projects: Numerical modeling of Greenland outlet glaciers and the implementation of calving criteria in 3-D ice sheet models

Faezeh Nick is a postdoctoral researcher at the IMAU and at the Laboratoire de Glaciologie, Université Libre de Bruxelles, in Belgium. While at CIRES, she will collaborate with Konrad Steffen's group to investigate how Greenland's outlet glaciers—fast-flowing tongues of ice that extend from the main ice sheet—contribute to the loss of ice mass into the ocean and rising sea levels.

The Greenland ice sheet is changing significantly in coastal regions, with several of its outlet glaciers thinning and retreating. Icebergs calving off these outlet glaciers account for an estimated half of the ice transferred from the ice sheet into the ocean. Using CIRES data on the Greenland ice sheet's velocity and net mass loss, Nick will refine models to account for the unique dynamics of these narrow, fast-flowing outlet glaciers. Successful results will allow scientists to more accurately predict future ice sheet changes and sea level rise.

Sponsor: Konrad Steffen

Francis Poulin

Sabbatical

Ph.D., Massachusetts Institute of Technology
Project: Western intensification in the ocean by submesoscale dynamics

Francis Poulin is an assistant professor in applied mathematics at the University of Waterloo. His main research interest is geophysical fluid dynamics. Poulin investigates the large-scale dynamics of the ocean, with an emphasis on exploring the instability of currents.

While at CIRES, Poulin will work with Baylor Fox-Kemper's research group to look at wind-generated ocean gyre circulations. Unrelenting winds that pummel the ocean cause the surface water to begin to flow at about 2 percent of the wind speed and pile up in mounds. These large mounds of water and the flow around them—gyres—produce large circular currents in ocean basins. By using high-resolution, accurate numerical simulations, Poulin hopes to elucidate the energy cascade in the western boundary current and to develop parameters that will help improve the accuracy of General Circulation Models.

Sponsor: Baylor Fox-Kemper

Delores Robinson

Sabbatical

Ph.D., University of Arizona
Project: How does erosion affect mountain building?

Delores Robinson is an associate professor at the University of Alabama. She studies how mountain belts grow and change in different environments—evolving from colliding plates to mature ranges.

While at CIRES, she will work with Peter Molnar, Greg Tucker, Roger Bilham and Anne Sheehan to investigate the role erosion plays in orogeny (mountain building). Rivers, rain, freeze-thaw cycles and other forms of erosion displace rocks, changing the landscape's gravitational and frictional balance and, hence, the way the mountain range evolves. Using the Himalaya as her laboratory, Robinson will employ landscape-evolution modeling, data from seismograph stations and numerical experiments to examine how erosion interacts with tectonics. The project will result in an integrated cross-section of the Tibetan Himalaya that quantitatively accounts for how erosion has altered the surface and subsurface anatomy.

Sponsor: Peter Molnar

Laurel Saito

Sabbatical

Ph.D., Colorado State University
Project: Interdisciplinary modeling for climate change impacts on water resources at Shasta Lake

Laurel Saito is an associate professor in the Department of Natural Resources and Environmental Science at the University of Nevada, Reno. Her research focuses on water-resources management—specifically, how climatic factors and human activities, such as reservoirs, wastewater discharge and agriculture, affect aquatic ecosystems.

While at CIRES, Saito will collaborate with Balaji Rajagopalan in the Environmental Observations, Modeling and Forecasting Division, as well as with researchers at the Center for Science and Technology Policy Research, Western Water Assessment and the Institute of Arctic and Alpine Research. Her research will focus on simulating how fish might respond to climate change and altered reservoir operations. Saito will combine this information with stochastic weather generation approaches used by CIRES scientists to gain insight into how climate affects the sustainability of fisheries impacted by reservoir operations. In addition, she will contribute the models she is using to INSTAAR's Community Surface Dynamics Modeling System (CSDMS).

Sponsor: Balaji Rajagopalan

James Sickman

Sabbatical

Ph.D., University of California, Santa Barbara
Project: Inter-decadal variability in aquatic ecosystems of the Sierra Nevada; a synthesis of the 30-year record from Emerald Lake, Sequoia National Park

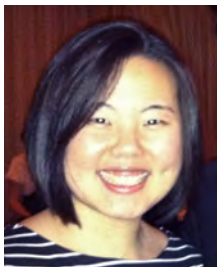
James Sickman is an associate professor of hydrology at the University of California, Riverside. His research interests include global environmental change, biogeochemistry, limnology and environmental isotopes. Over the last 30 years, he has been compiling long-term hydrochemical data (such as pH, alkalinity and nutrient levels) on remote watersheds and lakes in the Sierra Nevada.

While at CIRES, he will work with William Lewis, director of the Center for Limnology, to synthesize and analyze that data. His objective is to better understand how changes in precipitation and global climate affect the hydrochemistry and primary productivity (the manufacture of organic molecules via photosynthesis and chemosynthesis) of high-altitude aquatic ecosystems. In dry regions, like the Sierra Nevada, the amount of rain and snow varies widely with season, year, locale and other factors, so these watersheds are especially responsive to environmental changes, such as warming or fluctuations in snowpack dynamics (depth, duration of snow cover and time of snowmelt in the spring). One main product of Sickman's work will be a book on Sierra Nevada lakes and aquatic ecosystems, written with his co-investigator, John Melack, at the University of California, Santa Barbara, and other colleagues.

Sponsor: William Lewis

Y. Heidi Yoon

Postdoctoral



Ph.D., University of Wisconsin at Madison
Project: Spectroscopic studies of Titan particles

Heidi Yoon is working in Margaret Tolbert's group characterizing the optical properties of the aerosol particles in the atmosphere of Saturn's moon Titan. She will use spectroscopy to study how laboratory analogs of the particles absorb and scatter different wavelengths of light.

The aerosol particles in Titan's atmosphere form a hydrocarbon haze that affects the moon's surface and air temperatures. These particles absorb most of the incident sunlight—keeping it from reaching the surface—but weakly absorb infrared radiation, allowing thermal heat to escape. Both properties cool the moon's surface. Recent work has suggested that early Earth may have had a Titan-like haze, so characterizing the optical properties of that haze is essential for understanding both Titan and early Earth.

Sponsor: Margaret Tolbert

Dirk van As

Sabbatical

Ph.D., Institute for Marine and Atmospheric Research in Utrecht (IMAU), Utrecht University, The Netherlands
Project: Merging Greenland automatic weather station networks for increased accuracy in ice sheet surface mass balance estimates

Dirk van As is a senior scientist at the Geological Survey of Denmark and Greenland (GEUS) in Copenhagen. He studies interactions (such as melting) between the ice and the atmosphere on the Greenland ice sheet. While at CIRES, he will work with Konrad Steffen's group to investigate the Greenland ice sheet's surface mass budget—the annual difference between the mass of snow and ice that accumulates and the mass that ablates via melting, evaporation and wind erosion.

The Greenland ice sheet is losing mass at an accelerating rate, contributing to global sea level rise—a phenomenon that could affect millions of people living on coastal areas around the world. Getting an accurate picture of the ice sheet's stability and melt rates can help scientists and policy makers better predict future changes and take appropriate action. Toward this end, Van As will integrate data from the CIRES weather station network in the high regions of the ice sheet and the GEUS network in the lower regions—for a total of more than 30 weather stations—to produce a spatial distribution of temperature, humidity, solar radiation and other parameters crucial for validating the regional climate models that calculate melt.

Sponsor: Konrad Steffen

INNOVATIVE RESEARCH PROGRAM

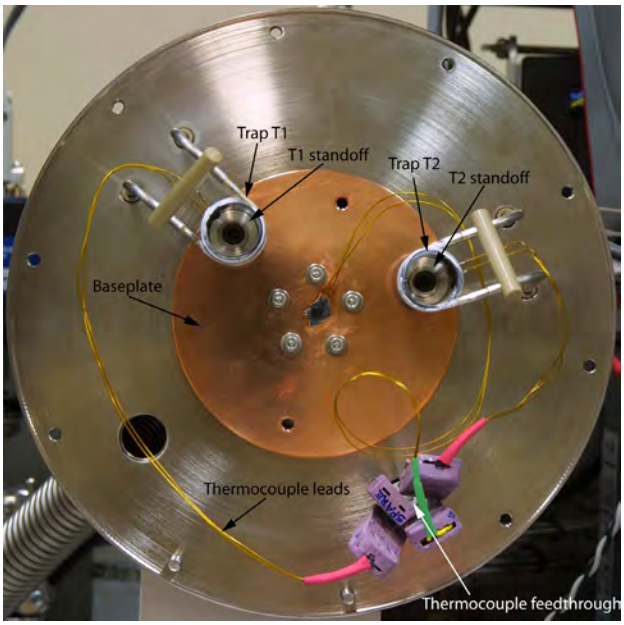
The CIRES Innovative Research Program (IRP) encourages novel, unconventional or fundamental research that might otherwise be difficult to fund. Funded projects are inventive, sometimes opportunistic and do not necessarily have an immediate practical application or guarantee of success. This program supports pilot or exploratory studies, which may include instrument development, lab testing, field observations or model advancement. There were six IRP winners in 2011.

NOAA

Secondary organic aerosol formation from evaporated crude oil

Joost de Gouw (CIRES) and
Jose-Luis Jimenez (CIRES)

In this project, the evaporation of crude oil and the subsequent formation of secondary organic aerosol (SOA) from the resulting hydrocarbons are studied in the laboratory. The study simulates the formation of organic aerosol observed downwind from the Deepwater Horizon Oil Spill in the Gulf of Mexico in 2010, which was attributed to hydrocarbons of a specific range in vapor pressures. The objective of the study is to find which hydrocarbons in crude oil are most important for SOA formation in the polluted atmosphere and how these precursors and products can be measured with state-of-the-art instruments.

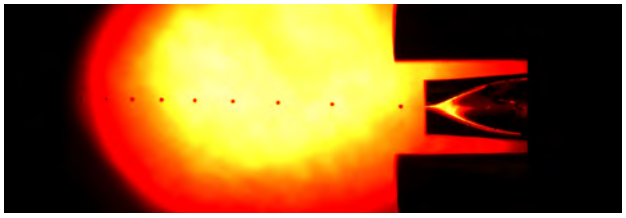


BEN MILLER

A novel cryogenic analyte preconcentration module for trace gas and isotopic analyses

Ben R. Miller (CIRES/ESRL GMD), Jason Winokur (INSTAAR), Bruce Vaughn (INSTAAR), Steve Montzka (CIRES/ESRL GMD) and Pieter Tans (CIRES/ESRL GMD)

A new air sample preconcentration technology, applicable to atmospheric trace gas and isotopic analyses, is being developed to enhance the ability to increase signal-to-noise ratios, remove interferences and add new compounds to the suite of current species. This development will allow the researchers to analyze a wider range of sample types and characteristics, with improved precision and calibration accuracy. Results are expected to improve the study of the sources and sinks of greenhouse gases and ozone-depleting substances.



SARAH LANCE

A stream of water droplets are generated with a piezo electric device, each with a diameter of about 30 microns and with a high degree of uniformity.

Contact freezing on demand: Measurement of contact nuclei with a novel instrument using single droplets levitated in an optical trap

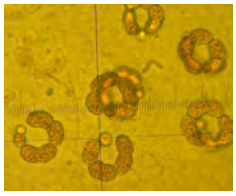
Sara Lance (CIRES/ESRL CSD),
Margaret Tolbert (CIRES) and Josh Gordon (NIST)

Freezing of cloud droplets in the temperature range 0°C to -40°C depends on the properties of aerosol particles acting as ice nuclei (IN). "Contact nucleation," which occurs when a supercooled liquid droplet and IN particle collide, can occur at much warmer temperatures than other freezing mechanisms and may, therefore, have great importance for the phase partitioning of clouds. The researchers are developing an instrument for laboratory experiments of contact nucleation, based on the precise control and detection of individual contact events, which will provide the basis for establishing a program to investigate this ice-formation mechanism.

A test of the role of mixotrophy in regulation of nitrogen fixation by cyanobacteria

James H. McCutchan, Jr. (CIRES)
and William M. Lewis, Jr. (CIRES)

Cyanobacteria (blue-green algae) are important primary producers in aquatic environments and dominate photosynthetic production in the open ocean and in many lakes. Through the work proposed here, the researchers seek to better understand some of the factors controlling cyanobacterial nitrogen fixation in lakes. Information derived from this work will be particularly important as demand grows for production of algal biofuels, and a better understanding of controls on nitrogen fixation also will contribute to the knowledge of the global nitrogen cycle and nutrient limitation in aquatic ecosystems.



Anabaenopsis elenkenii, *which dominated Little Gaynor Lake in 2007–2008. The little ball at the end of each string of cells is a heterocyst, which is where nitrogen fixation occurs. Recently, Little Gaynor Lake has been dominated by Arthrospira, which is also a member of the cyanobacteria but lacks heterocysts.*

Marrying a frequency-agile Fe Doppler lidar with a multi-frequency etalon-based edge-filter for profiling the whole atmosphere wind and temperature

Xinzhao Chu (CIRES), John A. Smith (CIRES student) and Wentao Huang (CIRES)

Collaborators: Mike Hardesty (CIRES/ESRL-CSD) and Hanli Liu (NCAR)

The investigators plan to install a narrowband lidar receiver in a mesosphere/lower thermosphere (MLT) to extend measurements of wind, temperature and perhaps aerosol concentration to the stratosphere and troposphere. It's hoped that this novel receiver design, in conjunction with 3-frequency resonance fluorescence measurements of the MLT, will evolve into a receiver capable of performing routine measurements of wind and temperature through the entire neutral atmosphere. Such measurements promise to greatly expand our understanding of the coupling and dynamics of atmospheric regions.

VATTENFALL

Horns Rev Offshore Wind Farm near Denmark

Developing a lower boundary layer radar for renewable energy research

Christopher R. Williams (CIRES),
Laura Bianco (CIRES), Paul E. Johnston (CIRES),
Daniel C. Law (ESRL CSD) and Scott E. Palo
(CU Aerospace Engineering)

This project will develop a Lower Boundary Layer (LBL) radar capable of estimating the horizontal wind and turbulence from 20 m to over 1 km above ground level with a 10-m vertical resolution. This new radar will use Linear Frequency Modulated Continuous Wave (LFMCW) radar technology enabling fine vertical resolution close to the ground. The researchers call this radar a LFMCW-LBL radar.

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 Fellowship. For 2010–2011, CIRES awarded CIRES Graduate Student Research Fellowships to six students. This year's recipients are exploring topics ranging from the influence of fish-stocking in mountain lakes to an investigation into the sources of ambient aerosol and chemical transformations in the atmosphere. The ESRL-CIRES Fellowships will be awarded in 2012 and funded by participating ESRL divisions.

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 doctoral 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, academic achievements and the likelihood of his or her contribution to environmental science. Independence, passion for science and ability to communicate are also considered.

2010–2011 CIRES GRADUATE STUDENT RESEARCH FELLOWSHIP RECIPIENTS

Kelli Archie
CIRES Ph.D. student: Environmental Studies
■ Advisor: Lisa Dilling
■ Archie's research focuses on climate change adaptation, in particular decision-maker information demand.

Jessica Axson
■ CIRES Ph.D. student: Chemistry
■ Advisor: Veronica Vaida
■ Axson's research focuses on the atmospheric processing of methylglyoxal in aqueous environments.

Scott Bachman
■ CIRES Ph.D. student: Atmospheric and Oceanic Sciences
■ Advisor: Baylor Fox-Kemper
■ Bachman's research focuses on the scaling and parameterization of oceanic mesoscale eddies.

Chad Chaffin
■ CIRES Master's student: Aerospace Engineering Sciences
■ Advisor: Ben Balsley
■ Chaffin's research focuses on atmospheric data acquisition, ranging from wind vectors to air density.

Daniel Feucht
■ CIRES Ph.D. student: Geological Sciences
■ Advisor: Anne Sheehan
■ Feucht's research focuses on the electromagnetic study of crust and mantle electrical conductivity beneath the Rio Grande Rift.

Ulyana Nadia Horodyskyj
■ CIRES Ph.D. student: Geological Sciences
■ Advisor: Roger Bilham
■ Horodyskyj's research focuses on the formation and evolution of supra-glacial lakes on glaciers in the Himalaya and Karakoram.

Rui Li
■ CIRES Ph.D. student: Atmospheric and Oceanic Sciences
■ Advisor: Joost de Gouw
■ Li's research focuses on the use of mass spectrometry to determine emissions and chemistry of atmospheric trace species.

Ryan Thalman
■ CIRES Ph.D. student: Chemistry and Biochemistry
■ Advisor: Rainer Volkamer
■ Thalman's research topic is on the measurement of atmospherically relevant trace gases in the laboratory and field using Light-emitting Diode Cavity Enhanced Differential Optical Absorption Spectroscopy.

Pablo Mendoza Zuniga
■ CIRES Ph.D. student: Civil, Environmental and Architectural Engineering
■ Advisor: Balaji Rajagopalan
■ Zuniga's research focuses on flood forecasting and uncertainty treatment in hydrologic modeling.

DIVERSITY AND UNDERGRADUATE RESEARCH

CIRES is involved in many important efforts to educate undergraduate students and involve them in hands-on research. The two programs 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 field.

■ More: http://www.ucar.edu/soars/

2010 SOARS PROTÉGÉS

Matthew Burger
■ Research: The effects of the 8.2 ka event on the Intertropical Convergence Zone in the Tropical Atlantic
■ CIRES Mentor: Lesley Smith

Javier Lujan
■ Research: Understanding profiler observations of the stratocumulus topped marine boundary layer with the assistance of ceilometer data
■ CIRES Mentors: Leslie Hartten and Paul Johnston

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/

2010 UROP PROGRAM RECIPIENTS

Phillip Chen
■ Project: Combining roughness measures from satellite and airborne campaigns to learn about Earth surfaces and environments: Glaciers, sea ice, forests and more
■ Faculty or CIRES sponsor: Ute Herzfeld

Rachel Ertz
■ Project: The response of foliar nitrogen to mountain pine beetle (*Dendroctonus ponderosae*) infestation
■ Faculty or CIRES sponsor: William Lewis

Brian McDonald
■ Project: Combining roughness measures from satellite and airborne campaigns to learn about Earth surfaces and environments: Glaciers, sea ice, forests and more
■ Faculty or CIRES sponsor: Ute Herzfeld

Theme Reports

Office of Oceanic and Atmospheric Research Earth System Research Laboratory

National Environmental Satellite, Data, and Information Service

National Weather Service Space Weather Predication Center

Other Projects

ADVANCED MODELING AND OBSERVING SYSTEMS

AMOS-01 Instrumentation Design, Prototyping and Analysis

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

CSD-01 Instrumentation for Atmospheric Observation and Analysis

FEDERAL LEADS: MICHAEL HARDESTY, STEVEN BROWN AND DAN MURPHY
CIRES LEAD: CHRISTINE ENNIS

NOAA Goals 2 and 3: Climate and Weather and Water

Project 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 and test a new, fully automated instrument to measure water vapor on board a high-altitude research aircraft. Impact: The new instrument will include in-flight calibration to ensure that water vapor measurements made over a wide dynamic range (1–200 parts per million) have known, high accuracy.

A new chemical ionization mass spectrometry (CIMS) technique was developed for the measurement of low mixing ratios of water vapor in the upper troposphere and lower stratosphere (UT/LS). The instrument sample flow is passed through a radioactive alpha particle source, and the resulting ion-molecule reactions lead to the production of H_3O+ ions that are used to quantify the water vapor mixing ratio. This ionization scheme required the design of a custom alpha particle source capable of efficient operation at low pressure. An existing CIMS instrument, designed for automated operation onboard research aircraft, was modified to use the new ion source and related flow system. To calibrate the instrument during flight, a new calibration system was constructed using catalytic oxidation of hydrogen to produce an accurate and adjustable source of water vapor on demand. The H_2O CIMS instrument is currently the only UT/LS water vapor instrument that conducts in-flight calibration at low water vapor mixing ratios.

The H_2O CIMS instrument was flown on the NASA WB-57 high-altitude research aircraft during the NASA Mid-Latitude Airborne Cirrus Properties Experiment (MACPEX) campaign in March and April 2011. The MACPEX campaign provided a rare opportunity to intercompare a number of different water vapor measurements in order to assess the community's ability to accurately measure water vapor in the UT/LS region. Data reduction from the MACPEX flights is currently in progress, and analysis of the data will begin soon.

Product: Rollins, AW, TD Thornberry, R-S Gao, BD Hall, and DW Fahey (2011), Catalytic oxidation of H_2 on platinum: A method for in situ calibration of hygrometers, *Atmos. Meas. Tech. Discuss.*, *4*, 3083-3095, doi:10.5194/amtd-4-3083-2011.

Thornberry, TD, AW Rollins, R-S Gao, LA Watts, SJ Ciciora, RJ McLaughlin, and DW Fahey, A chemical ionization mass spectrometer for in situ measurement of water vapor in the upper troposphere and lower stratosphere, in preparation.

Milestone 2. Construct and deploy a three-wavelength, photoacoustic/cavity ring-down combination to measure single scattering albedo. Impact: Single scattering albedo controls whether the direct radiative effect of aerosols is a warming or cooling. This instrumentation will make measurements of

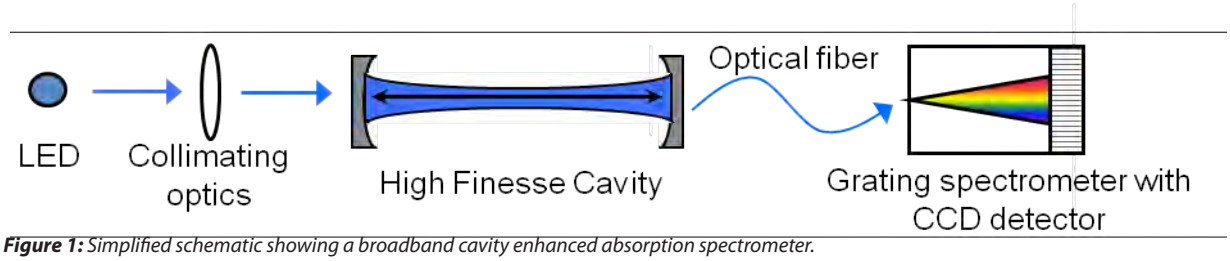


Figure 1: *Simplified schematic showing a broadband cavity enhanced absorption spectrometer.*

single scattering albedo with better sensitivity, higher accuracy, and fewer artifacts than previous instrumentation.

Major development of the new 3-wavelength, 5-channel photo-acoustic aerosol absorption spectrometer has been completed. The instrument was successfully deployed onboard the NOAA P-3 research aircraft during the CalNex field campaign in 2010. Sensitive multi-wavelength aerosol absorption measurements, in addition to multi-wavelength thermally denuded aerosol absorption measurements, were accomplished from a selection of the CalNex flights. This is seen as a major milestone in the measurement of aerosol absorption, as the acoustic technique was shown to provide sensitive measurements despite deployment onboard the noisy aircraft environment. Further development of instrument electronics, optical components and calibration procedures will be necessary based on lessons learned from the CalNex campaign. Laboratory and field experiments and manuscript preparation based on the CalNex data set will continue.

Product: Langridge, J, M Richardson, D Law, D Lack, and DM Murphy, Aircraft instrument for comprehensive characterisation of aerosol optical properties, part 1: Wavelength dependent optical extinction and its relative humidity dependence measured using cavity ringdown spectroscopy, submitted to *Aerosol Sci. Technol.*

Langridge, JM, DA Lack, et al., Evolution of aerosol optical properties with transport in the Los Angeles basin, in preparation.

Lack, DA, CD Cappa, JM Langridge, M Richardson, D Law, R McLaughlin, and DM Murphy, Aircraft instrument for comprehensive characterisation of aerosol optical properties, part 2: Black and brown carbon absorption and absorption enhancement measured with photo acoustic spectroscopy, submitted to *Aerosol Sci. Technol.*

Lack, DA, JM Langridge, R Bahreini, CA Brock, AM Middlebrook, and JP Schwarz, Black and brown carbon absorption attribution within biomass burning particles, in preparation.

Milestone 3. Develop and test cavity enhanced absorbtion spectroscopy (CEAS) instruments for glyoxal, nitrous acid and nitrogen dioxide. Impact: Both glyoxal ($C_2H_2O_2$) and nitrous acid (HONO) are reactive intermediates in atmospheric chemistry that serve as photochemical radical sources and, in the case of glyoxal, may participate in secondary organic aerosol formation. Understanding their abundances is important to both regional air quality and climate.

A new CEAS field instrument (Figure 1) was designed and constructed during 2010. The instrument consists of two CEAS channels, which are centered at 365 nm for nitrous acid (HONO) and nitrogen dioxide (NO_2), and 455 nm for glyoxal (CHOCHO) and NO_2. The optical components are installed in a weatherproof case for installation outdoors. The instrument was successfully deployed at the ground site in Pasadena, Calif., during the CalNex campaign in 2010. Sensitive measurements of HONO, CHOCHO and NO_2 were acquired during the field campaign. Analysis of these data sets are underway, with a scientific focus on CHOCHO contribution to secondary organic aerosol, radical budgets and daytime HONO concentrations. Further development of the optics and electronics is planned to improve the precision and sensitivity of the CEAS instrument for future field deployments.

Product: Washenfelder, RA, CJ Young, SS Brown, W Angevine, EL Atlas, DR Blake, DM Bon, MJ Cubison, JA de Gouw, S Dusanter, J Flynn, JB Gilman, M Graus, S Griffith, N Grossberg, PL Hayes, JL Jimenez, WC Kuster, BL Lefer, IB Pollack, TB Ryerson, H Stark, PS Stevens, and MK Trainer, (2011), The glyoxal budget and its contribution to secondary organic aerosol for Los Angeles during CalNex 2010, in preparation.

Washenfelder, RA, C Young, and SS Brown, (2011), A field instrument for NO_2, HONO, and CHOCHO using incoherent broadband cavity enhanced absorption spectroscopy, in preparation.

Young, CJ, RA Washenfelder, SS Brown, JB Gilman, WC Kuster, J Flynn, N Grossberg, B Lefer, S Alvarez, B Rappenglueck, J Stutz, C Tsai, O Pikelnaya, LH Mielke, HD Osthoff, JM Roberts, S Griffith, S Dusanter, and PS Stevens (2011), Contribution of nitrous acid to the radical budget in urban Los Angeles, in preparation.

Young, CJ, RA Washenfelder, SS Brown, P Veres, AK Cochran, TC VandenBoer, JM Roberts, O Pikelnaya, C Tsai, J Stutz, C Afif, V Michoud, and A Borbon (2011), Intercomparison of nitrous acid measurements in urban Los Angeles, in preparation.

PSD-08 Sensor and Technique Development

FEDERAL LEAD: JIM JORDAN
CIRES LEAD: ANDREY GRACHEV

NOAA Goal 3: Weather and Water

Project 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. Write reports on the use of roving calibration standard for ship flux measurements on two University-National Oceanographic Laboratory System (UNOLS) ships.

Reports were written for the Research Vessel (R/V) Kilo Moana (Bariteau, et al., Intercomparison of meteorological observation systems on the R/V Kilo Moana and WHOTS buoys) and the R/V Knorr (Wolfe, et al., Shipboard meteorological sensor comparison: ICEALOT 2008).

Milestone 2. Perform laboratory study on crosstalk and sensitivity of new fast carbon dioxide (CO_2) sensor.

This study was performed at the David Skaggs Research Center in May–June 2011. Byron Blomquist (University of Hawaii) and Ludovic Bariteau did a series of comparisons of the Picarro G1300 fast CO_2 sensor and the Licor Li7200 CO2/H2O sensor in controlled conditions. Tests were done for motion and water vapor contamination as a function of temperature. A Nafion membrane drier was evaluated as a method to reduce water-vapor crosstalk. A report is in preparation.

Milestone 3. Install and make test flights of PSD W-band radar on NOAA P-3.

This milestone is delayed because flight time on the NOAA WP-3D aircraft was not available this year. The radar will be sent back to ProSensing for packaging for possible tests next year.

CET-01 Remote Hydrologic Sensing

FEDERAL LEAD: TIM SCHNEIDER
CIRES LEAD: ALBIN GASIEWSKI

NOAA Goal 3: Weather and Water

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

Milestone 1. Develop sensors and perform observations to understand Arctic processes.

Researcher did not provide an update.

Milestone 2. Improve radiative transfer and assimilation techniques for remote sensing and numerical forecasting.

Researcher did not provide an update.

Milestone 3. Develop sensors and perform observations to understand Arctic processes.

Researcher did not provide an update.

AMOS-02 Data Management, Products and Infrastructure Systems

- CSD-11 Processes in the Marine Boundary Layer
- 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

CSD-11 Processes in the Marine Boundary Layer

FEDERAL LEAD: ROBERT BANTA
CIRES LEAD: CHRISTINE ENNIS

NOAA Goal 2: Climate

Project Goal: Understand dynamic processes in the marine boundary layer, such as the distribution of wind flow characteristics, including development of nocturnal low-level jets, the primary source of wind resources for offshore wind farms.

Milestone 1. Develop a detailed analysis of spatial and temporal variability of the offshore boundary layer wind flow characteristics using past experiment Doppler lidar measurements in the Atlantic off the coast of the northeastern United States. Impact: This research will advance the understanding of the spatial and temporal variability of wind flow characteristics responsible for mixing and transport processes in the offshore boundary layer, ultimately providing accurate estimates of wind resources at the heights where multi-megawatt wind turbines operate. The results can also be used for validation of satellite estimates of wind flow characteristics and in numerical models.

The motion-compensated wind measurements by the High Resolution Doppler Lidar (HRDL) during the offshore experiment in the Gulf of Maine in 2004 were used to obtain high-resolution, high-precision profiles of wind speed and direction. Profiles, averaged over 15 minutes, were combined into time-height cross sections along ship-track segments, and analyzed for diurnal cycle. These kilometer-deep curtains of wind-speed profiles illustrate the strong vertical, horizontal and temporal variability of the winds aloft often encountered in the coastal zone. A closer look at the wind variability shows considerable difference between nighttime (0000–1200 UTC) and daytime (about 1200–2300 UTC) winds at turbine heights of 50–150 m and well above.

The analyses of time series, distributions of quantities such as wind speed and wind shear through the blade layer show strong spatial and temporal variability to the wind field in the marine boundary layer. Winds near the coast show diurnal behavior, and frequent occurrences of low-level jet structure are evident especially during nocturnal periods. Persistent patterns of spatial variability of the flow field due to coastal irregularities should be of particular concern for wind-energy planning, because this affects the representativeness of fixed-location measurements and implies that some areas would be favored for wind-energy production, whereas others would not.

Product: The paper "Doppler-lidar-based wind-profile measurement system for offshore wind-energy and other marine-boundary-layer applications" and a correction for the paper were submitted to the *Journal of Atmospheric Meteorology and Climate* in February 2011.

Conference papers:

Pichugina, YL, RM Banta, WA Brewer, and RM Hardesty (2010), Doppler lidar measurements of wind flow characteristics over flat terrain and over ocean, 15th International Symposium for the Advancement of Boundary Layer Remote Sensing, June 28–30, Paris, France.

Pichugina, YL, RM Banta, WA Brewer, SP Sandberg, and RM Hardesty (2010), Offshore wind measurements by Doppler lidar, International Laser Radar Conference (ILRC25), July 5–9, St. Petersburg, Russia.

Pichugina, YL, RM Banta, WA Brewer, SP Sandberg, and RM Hardesty (2010), Wind flow characteristics from ship-borne lidar measurements in support of wind energy research, 19th Symposium on Boundary Layers and Turbulence, August, Keystone, Colorado.

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

FEDERAL LEAD: RAY HABERMANN
CIRES LEAD: RICHARD FOZZARD

NOAA Goal 3: Weather and Water

Project Goal: Develop methods and processes for integrating multiple types of observations (e.g., 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 (FGDC) and International Standards Organization (ISO) 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 to support data set discovery, documentation, lineage and usage (metadata) using international standards.

Current events such as the Deepwater Horizon Oil Spill and the political debate over climate change have dramatically raised the visibility of NOAA data. While accurate, well-structured documentation has always been important to the usefulness of science data, Congress, reporters, bloggers and the general public are now examining data sets and asking how they were collected. NOAA's National Geophysical Data Center (NGDC) and CIRES are spearheading the initiative to provide high-quality metadata for hundreds of data sets across NOAA using the ISO 19115-2 and related standards. We have developed a collection of metadata authoring, archiving and access tools known as the Enterprise Metadata System (EMS), currently serving more than 40 Web Accessible Folders and thousands of metadata records.

One component of the EMS is the ncISO software, which automates the generation of ISO metadata for netCDF (Network Common Data Form) files. NetCDF is a common file format within the atmospheric and oceanographic scientific communities. By collaborating with Unidata, NGDC and CIRES were able to embed ncISO within THREDDS (Thematic Realtime Environmental Distributed Data Services) software, greatly increasing the amount of documentation available using ISO standards.

Product: http://www.ioos.gov/catalog/

Milestone 2. Design, develop and demonstrate systems that provide integrated access to and visualization of in situ and satellite environmental observations. Employ Open Geospatial Consortium (OGC) standards, as well as emerging international approaches, to ensure interoperability across systems.

CIRES staff at the NGDC have extensively improved

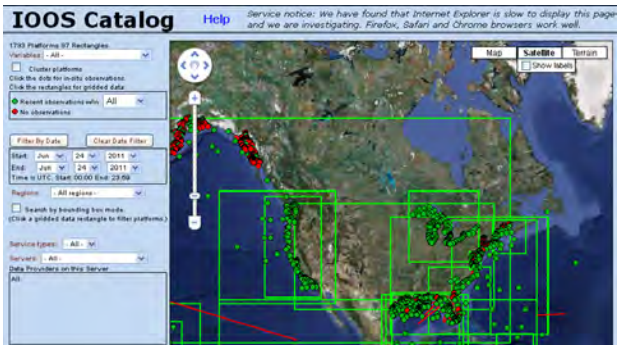


Figure1: *The Integrated Ocean Observing System (IOOS) Catalog uses ISO metadata and Open Geospatial Consortium (OGC) services to provide a centralized gateway for the discovery of ocean observation-based data sets.*

Figure2: *NOAA's Observing Systems Architecture Google Map providing metadata for a station in the NOAA's Office of Oceanic and Atmospheric Research Aerosol Observing System.*

NOAA's Observing Systems Architecture (NOSA) documentation for more than 100 separate data sets, while converting from FGDC metadata standard to ISO 19115-2. We have developed systems to use that metadata to visualize NOAA in situ environmental data sets. For example, metadata is transformed dynamically into a KML file and presented in a Google Map or in Google Earth.

Product: http://www.nosa.noaa.gov/google_earth.html

Milestone 3. Design, develop and demonstrate systems to support in situ and satellite data set ingest, archival and data quality monitoring.

CIRES staff at the NGDC developed a tape archive retrieval system for NGDC's 800 terabyte science data holdings. This prioritizes and tracks orders; verifies requested files against the archive inventory, size and security limits; packages results; and notifies users when an order is complete. An initial prototype of a web service providing controlled access to the archive was completed in December 2010, and a revision in the Grails database is now nearly complete.

We have created a file inventory pipeline project to inventory Space Weather satellite data files for the Solar-Ter-

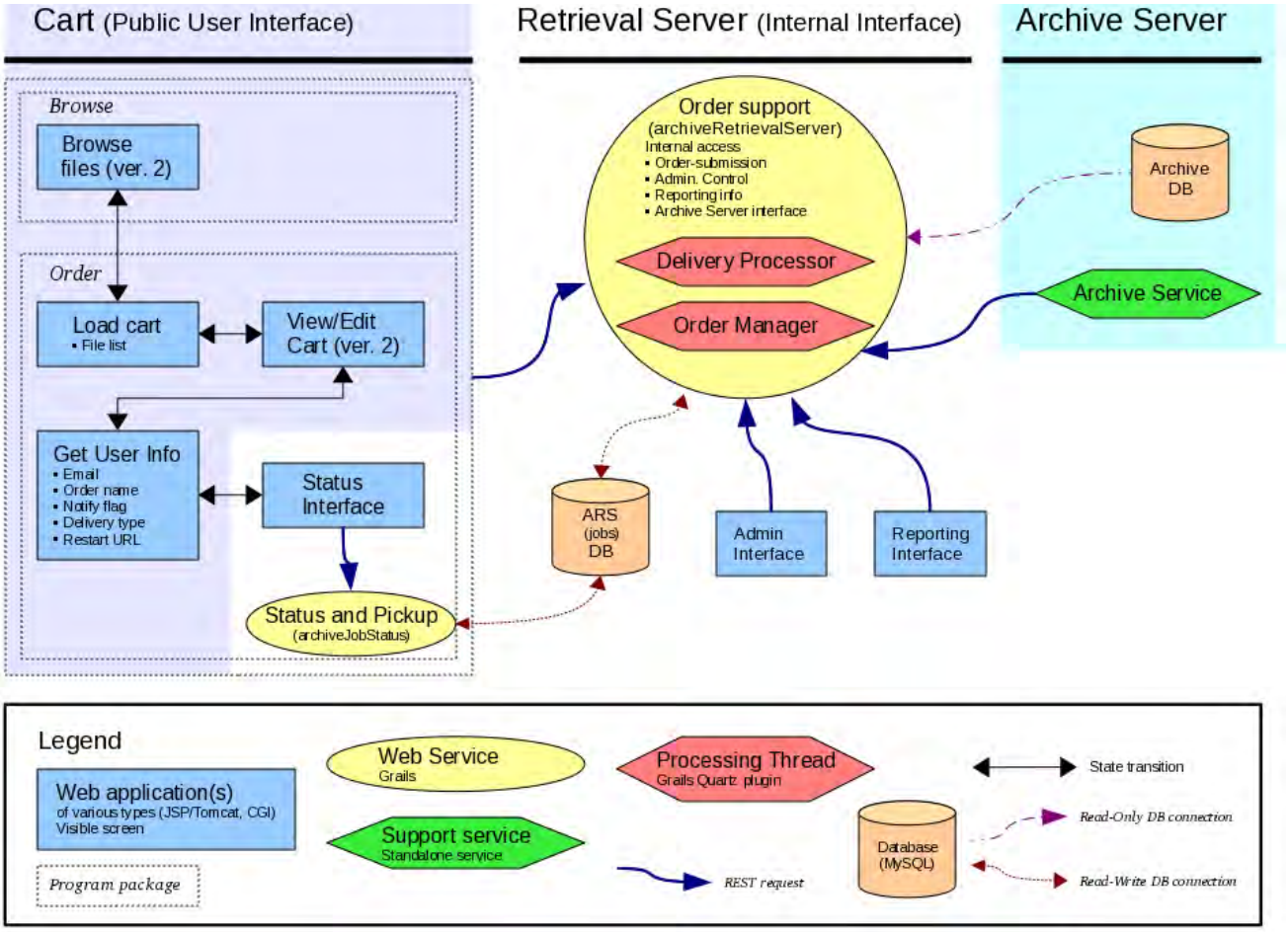


Figure 3: *Archive Retrieval Service architecture, May 23, 2011.*

restrial Physics division. This program has been scheduled to run nightly and picks up changes to the data files daily. If desired, it can be run manually for immediate website results. This information is available to customers online through the Interface Database (IDB) web service.

Product: http://www.ngdc.noaa.gov/nndc/struts/results?t=102827&s=1&d=1001,1002,9

Milestone 4. Enhance the the Comprehensive Large Array Stewardship System (CLASS) to meet NGDC archive requirements. This involves working with scientific, contract and federal teams to understand, document and define CLASS capabilities for scientific data stewardship. This milestone will result in a system that houses and manages NGDC data using CLASS technology.

Three distinct types of services are required to support NOAA data center operations. Data access for the purpose of supporting outward-facing applications will be supported by the NOAA Enterprise Archive Access Tool (NEAAT). Data management will be supported by a set of Data Management Tools (DMT). Data ingest will be governed by Interface Control Documents (ICD), and supported by both data center pre-ingest software and CLASS ingest software. During the past year, CIRES staff have supported progress in all three of these areas.

CIRES staff guide, test and review CLASS development of NEAAT. The project has implemented a course-grained form of data-discovery, inventory-inspection and data ordering of CLASS data families. Requirements for more effective fine-grained control in terms of individual offerings have been completed.

CIRES staff have completed an initial report defining the functional requirements for DMT. These tools will support the ability to discover, examine and generate statistics; report on archived holdings; and retrieve data for inward-facing applications, like archive verification.

CIRES staff supported writing of an ICD governing the transfer of data from the NGDC to CLASS data ingest. This document describes the nature of the data being transferred, the operational protocols for doing so and the division of ingest responsibilities between NGDC and CLASS. The document is comprised of a generic base and a CORS (Continuously Operating Reference Stations) data set–specific appendix. Based on these requirements, CIRES staff developed a pre-ingestor that feeds data to a CLASS-maintained landing area. It is undergoing final integration testing.

NGDC-02 Marine Geophysics Data Stewardship

FEDERAL LEAD: SUSAN McLEAN
CIRES LEAD: BARRY EAKINS

NOAA Goal 4: Transportation

Project 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 and historical marine geophysical data (e.g., bathymetry, gravity, seismic and magnetics) from the global oceanographic community.

Since July 2010, 230 multibeam swath sonar surveys (904,199 nautical miles) and 26 trackline (single-beam bathymetry, magnetics, gravity and seismic reflection) surveys (67,462 nautical miles), throughout all of the world's oceans, have been added to the National Geophysical Data Center's (NGDC) global marine geophysical archives by NGDC and CIRES staff. Both national and international 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. NGDC provides long-term archiving, stewardship and delivery of data to scientists and the public by utilizing standard metadata, spatially enabled databases, robotic tape archive and standards-based web services.

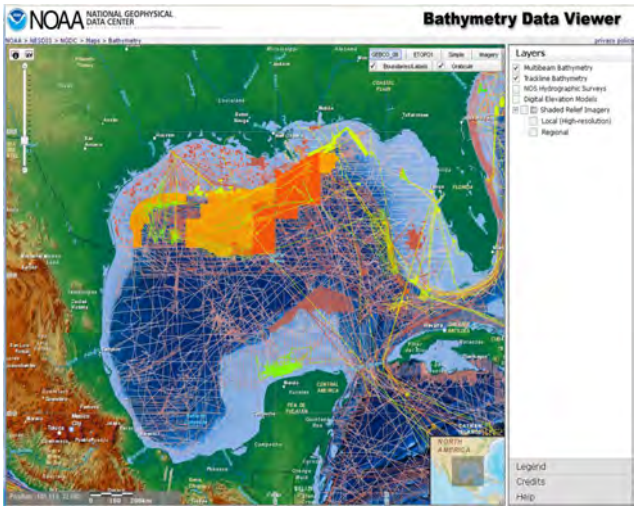


Figure 1: *Screen grab of NGDC's interactive 'Bathymetry Data Viewer.' Lines represent ship tracks in the Gulf of Mexico with publicly available multibeam swath sonar and single-beam bathymetric data.*

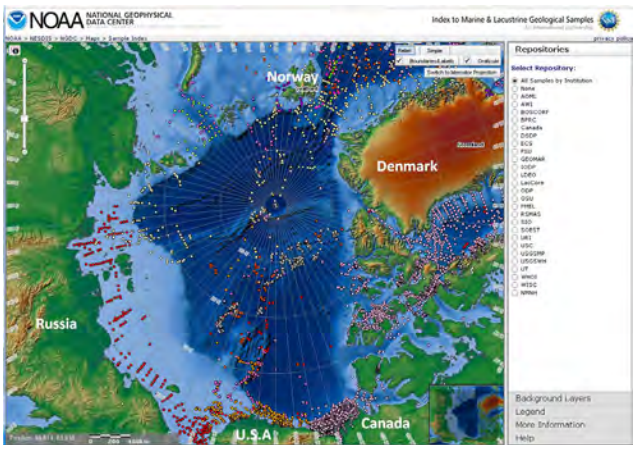


Figure 2: *New polar projection web map of the Arctic Ocean. The circles represent the location of geological samples collected in and around the Arctic Ocean.*

Milestone 2. Improve metadata content and data discovery capability for marine geophysical data in support of the U.S. Extended Continental Shelf and Integrated Ocean and Coastal Modeling projects, including a "Data Inventory" that enables comment and access to a variety of marine geophysical data in a geographically distributed environment.

In the past year CIRES and NGDC staff have collaborated with scientists and data experts from several U.S federal agencies and academic science data centers on developing common metadata standards for marine seismic reflection data, multibeam bathymetric data, bottom geologic samples and cruise level data for both the U.S. ECS project and the IOCM program. This includes templates, vocabularies, documentation rules, best practices and crosswalks to federal and international standards. An NGDC/CIRES-developed metadata editor tool along with templates was deployed on a Gulf of Alaska cruise to enable scientists to complete metadata information while at sea. Data and metadata collected and identified as relevant for the U.S. ECS project will be used to define the maximum extent of the U.S. continental shelf.

Staff have also enhanced the capability of NGDC's interactive web maps, including adding a polar projection, and improved the user interfaces. New web map tools have been created for identifying, querying and commenting on the suitability of geophysical surveys within the ECS 'Dynamic Inventory' web map, which shows the spatial coverage of all available marine geophysical surveys from a variety of federal government and academic sources. Scientists on the ECS Project can assess the existing data and metadata to determine suitability for use in the project, and identify gaps where additional data or metadata are required.

Milestone 3. Improve access to a variety of regional and global coastlines through development of an interactive map service and updating of other online services to provide the most direct and up-to-date links to various vector shoreline data, including a new high-resolution community coastline data set developed at NGDC.

Access to the NGDC's coastline data sets was improved through the migration of the Coastline Extractor Tool to new technologies. Also, the Global Self-consistent, Hierarchical, High-resolution Shoreline (GSHHS) data set was updated and the new version made available at NGDC (http://www.ngdc.noaa.gov/mgg/shorelines/gshhs.html).

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

FEDERAL LEAD: SUSAN MCLEAN
CIRES LEAD: BARRY EAKINS

NOAA Goal 3: Weather and Water

Project Goal: Improve integration of coastal data and develop

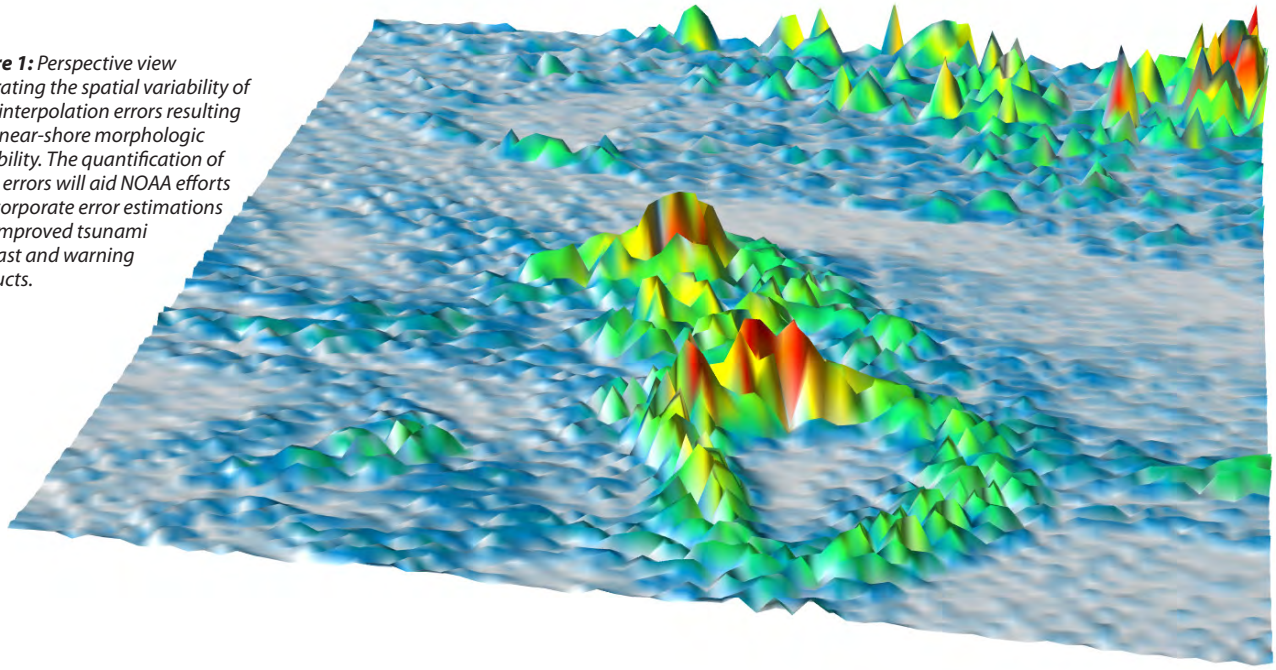


Figure 1: *Perspective view illustrating the spatial variability of DEM interpolation errors resulting from near-shore morphologic variability. The quantification of these errors will aid NOAA efforts to incorporate error estimations into improved tsunami forecast and warning products.*

new products that promote community resiliency through better assessments of hazards, coastal vulnerability and risk. Research goals include the development of seamless, accurate, high-resolution digital elevation models (DEMs) to improve the accuracy of coastal inundation modeling; the development and expansion of historic events databases and tsunami deposits databases; and hazard assessments.

Milestone 1. Produce nine to 14 seamless, integrated, bathymetric–topographic digital elevation models of select U.S. coastal communities to support tsunami forecast and warning, hurricane storm-surge modeling and coastal inundation mapping.

During FY11, CIRES staff at the National Geophysical Data Center (NGDC) developed 17 community and five regional seamless, integrated, bathymetric–topographic DEMs of U.S. coasts, including Alaska, Hawaii and the Virgin Islands. These high-resolution coastal DEMs serve as a base layer for a variety of uses including: 1) modeling of coastal processes (storms, tsunamis, ocean currents, sediment transport, sea-level rise, etc.); 2) ecosystems management and habitat research; 3) coastal and marine spatial planning; and 4) community hazard preparedness and disaster mitigation. The coastal DEMs are used by NOAA's Tsunami Warning Centers, the NOAA Center for Tsunami Research, Coast Survey Development Laboratory and the National Tsunami Hazard Mitigation Program for computing inundation from tsunamis and hurricane storm-surge.

CIRES staff at NGDC also developed new education and outreach materials, including a 'Coastal DEM Best Practices' handout, and interactive online magazines of NGDC coastal DEMs of various U.S. coastal regions. We also assisted other researchers and the public with achieving their DEM needs, including providing a Gulf of Mexico DEM that *National Geographic Magazine* used as the source of bathymetry for its October 2010 award-winning map 'Gulf of Mexico: A Geography of Offshore Oil.'

Current DEM research includes developing new techniques to build different types of DEMs, quantifying DEM inaccuracies and assessing the impact of DEM inaccuracies on inundation mapping results. NGDC's coastal DEMs, accompanying technical reports and education materials

Figure 2: *Clockwise from upper left: a) award-winning* National Geographic *map for which NGDC contributed the bathymetry DEM; b) DEM Best Practices handout; c) interactive online DEM magazine, and d) perspective image of the Port Townsend, Wash., coastal DEM.*

are available online at http://www.ngdc.noaa.gov/mgg/coastal/.

Milestone 2. Investigate the effects of different gridding algorithms and near-shore morphologic features on integrated bathymetric–topographic digital elevation models, and their impacts on coastal inundation that result from tsunami modeling.

The effects of different gridding algorithms and near-shore morphologic features on integrated bathymetric-topographic DEMs are being quantified using a computer program developed by CIRES scientists. The program utilizes a split-sample methodology, in which a percentage of the xyz points are omitted, a gridding algorithm is applied and the interpolation errors are quantified as the difference between the interpolated elevations and the omitted elevations.

Products generated by the program include a grid of the interpolation errors, a histogram of these errors and

statistical measurements such as the minimum, maximum, mean and root-mean-square error (RMSE). These products are being used to assess the effects of different gridding algorithms and near-shore morphologic features on the accuracy of DEMs in areas with varying relief and data density.

The split-sample computer program is also useful for determining the optimal gridding algorithm parameters based on surface relief and data density in order to minimize DEM interpolation errors. A new addition to the program will quantify the uncertainty of interpolated elevations in DEMs using the range of interpolation errors from the various gridding algorithms at the DEM cell-scale. This will improve our understanding of the spatial variability of uncertainty introduced by gridding algorithms, and the propagation of that uncertainty into the modeling of tsunami inundation. The impacts on coastal inundation that result from tsunami modeling on divergent DEMs developed with various gridding algorithms will be assessed at Crescent City, Calif., using the historic 1964 tsunami event.

Milestone 3. Develop techniques and software to process raw Deep-ocean Assessment and Reporting of Tsunamis (DART) data with various time discretization and record lengths to produce high-quality data sets for climate and tsunami research.

During FY11, CIRES staff at the NGDC developed a set of programs for control, validation, processing and visualization of raw DART data. DART data are of two types: 1) high-resolution 15-second retrospective records and 2) irregularly sampled real-time transmitted data. The main purpose of DART data is early detection and warning of tsunamis in the open ocean. Their real-time use by the NOAA Tsunami Warning Centers improves the tsunami forecasts and refines the tsunami source parameters. In most of the cases, the tsunami signal is about 3-5 percent of the recorded amplitude, and high precision processing is required. The instruments are deployed on the ocean floor for up to 48 months at depths up to 6,000 meters. As with any scientific instrumentation, various instrument issues are identified and fixed throughout the data control and validation processing. The tidal signal that usually accounts for more than 90-95 percent of the variance of the DART records is removed by a redesigned and customized tidal fitting high-precision code. An additional filter is used to process the residuals that contain the tsunami signal.

More than 85 archived DART high-resolution records are processed and available on the NGDC website. This unique data set of long-term observations is used by researchers, hazard managers and many other users all over the world. We have also processed the real-time DART data from the Chilean Feb. 27, 2010, and Tohoku March 11, 2011, earthquakes and tsunamis, and posted them on the NGDC website.

Milestone 4. Enhance online and offline access and delivery of hazards data.

CIRES staff at the NGDC have improved data discovery and access to hazards data. New map services and interactive maps have been created using ArcGIS Server and the ArcGIS JavaScript API. The interactive maps feature

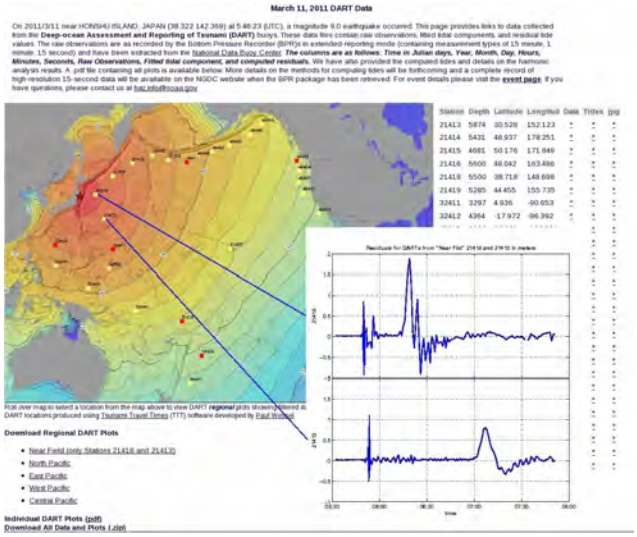


Figure 3: *Screen grab of interactive DART event page describing the March 11, 2011, Tohoku tsunami. Map depicts earthquake location, tsunami travel times and locations of DART buoys in the northern Pacific Ocean. Inset shows processed DART data for the two closest stations, with clear recordings of the earthquake (on left) and subsequent tsunami (to the right).*

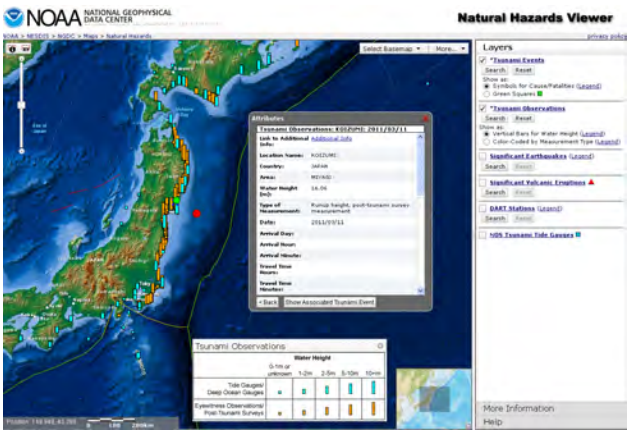


Figure 4: *The Natural Hazards Viewer, an ArcGIS Server interactive map provides access to NGDC's historical Natural Hazards database. Shown are observations of the March 11, 2011, tsunami along Japan's coast.*

increased usability, improved performance and enhanced cartography.

The NGDC Natural Hazards database can be explored using a powerful new interactive map interface (http://maps.ngdc.noaa.gov/viewers/hazards) that integrates historical tsunami events, tsunami observations, significant earthquakes, volcanic eruptions and water-level data from open-ocean buoys and coastal tide gauges.

Discovery of and access to coastal DEMs at NGDC (http://www.ngdc.noaa.gov/mgg/coastal/coastal.html) have also been enhanced using the Grails database framework. DEM search pages now include interactive maps depicting spatial coverage of the DEMs, along with shaded-relief visualizations. An RSS subscription feed announces the latest releases and updates.

The new map services are accessible via standard Open Geospatial Consortium (OGC) protocols such as WMS and WFS, which can be consumed by a variety of clients both inside and outside NGDC.

Offline access to the NGDC Natural Hazards database is available with TsuDig, a standalone GIS software package (based on uDig open source software). TsuDig allows searching and plotting historic data from the NGDC Natural Hazards database, as well as dynamic computation of tsunami travel times. TsuDig is currently being distributed on CD-ROM by the UNESCO International Tsunami Information Center (ITIC).

SWPC-03 Information Technology and Data Systems

FEDERAL LEAD: STEVEN HILL
CIRES LEAD: DAVID STONE

NOAA Goal 3: Weather and Water

Project 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) NOP series ground data system (GDS). Continue to enhance the GOES-NOP data processing systems and support GOES-N and GOES-O operationally used products. Provide analysis and technical support to algorithm development, instrument checkout and data verification for GOES-P as it completes post-launch testing. Facilitate planning for the transition of GOES-NOP GDS operations to the National Environmental Satellite, Data, and Information Service (NESDIS).

Successfully led and project managed a 13-person team of developers, administrators and scientists through both a six-month Post-Launch Test (PLT) and validation period, and through the deployment of the GOES P-series GDS to the Space Weather Prediction Center's (SWPC) National Critical Systems (NCS) operational environment. The NCS deployment required the team to enhance, test and document many different facets of the GDS's functionality within an unprecedentedly short time schedule. The deployment's scope additionally included integrating a Network-Attached Storage (NAS) system for the storage of Solar X-ray Imager (SXI) image files. The fact that the team was comprised of individuals from several different project teams required detailed, cross-branch coordination of deployment activities. In the end, the deployment occurred on schedule and with no disruptions to the lab, other operational projects or to the GOES GDS.

Expanded the GOES-NOP Preprocessor (PP) in support of operational and science requirements through a disciplined change control process that saw the completion of more than 78 documented change requests—150 percent more than the previous year. The Preprocessor is capable of subscribing to and ingesting high bandwidth telemetry into its component magnetometer, particle, extreme ultraviolet, X-ray sensor and SXI instrument raw data. It uses database-configurable logic to convert this data into space weather products for distribution to NOAA, NASA and the United States Air Force.

Milestone 2. Assist Space Weather Prediction Center (SPWC) 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. Improve legacy replacement systems that now exist and support new modernization projects as they are identified.

Technically lead the transition of the Wang-Sheeley-Arge (WSA)-Enlil model to operational status at the SWPC. This effort included modifying the overall system design; developing GUI-based (graphical user interface) tools for the analysis of Large Angle Spectrometric Coronagraph (LASCO) and Solar Terrestrial Relations Observatory (STEREO) coronagraph data; and making these tools suitable for use by forecasters in an operational context. The team also provided in-depth database support, including developing the fully normalized physical data models and required schema, and implementing the full set of database interface objects (stored procedures, views and user-defined functions) to support Enlil functions.

Provided technical oversight to contractors tasked to finish porting and modernizing software that processes International Space Environment Services (ISES) and Air Force coded messages utilized by SWPC to exchange space weather data. The project was completed and deployed ahead of schedule, and the legacy systems were decommissioned as planned.

Technically assisted NESDIS Center for Satellite Applications and Research (STAR) in their effort to port and assume operational responsibility for the software that processes telemetry from the Atmospheric Composition Explorer (ACE) satellite.

Helped decommission the Costello Solar wind model and replaced it with a new WingKp Solar wind model.

Prototyped the new GOES-R Solar Ultraviolet Imager (SUVI) Thematic Maps Generation requirements as specified by the GOES-R algorithm development team.

Supported the transition of the Real-Time Ground Magnetometer (RTGM) processing code to the latest relational database available in the lab (Microsoft SQL Server 2008).

SWPC-04 Space Environment Data Algorithm and Product Development

FEDERAL LEAD: STEVEN HILL
CIRES LEAD: MARY SHOULDIS

NOAA Goal 3: Weather and Water

Project Goal: Explore new techniques for analyzing and modeling Geostationary Operational Environmental Satellite (GOES) space environment data, and develop and validate new algorithms and products.

Milestone 1. Development of the algorithm and software tool for specifying satellite anomaly hazards from Geostationary Operational Environmental Satellite (GOES) energetic particle data shall be completed and put into operational test mode during the work plan timeframe. Research and development of five algorithms for phase two of the GOES-R Series project shall be completed in this time period. Research and development of the six phase three algorithms will be started and shall progress through preliminary design and into critical design in this time period.

The SEAESRT (Space, Environmental Expert System Real Time) algorithm to specify satellite anomaly hazards was developed and successfully tested before it was provided to the Space Weather Prediction Center (SWPC). It has not yet been put into operational test mode by SWPC because of other priorities. The National Geophysical Data Center (NGDC) may implement it into their system as a post-analysis tool.

Research, development and testing of five algorithms for Phase 2 of the GOES-R development project were completed and delivered to SWPC. These algorithms will be part of the suite of Level 2+ processing of GOES-R data to provide the forecast center with specification, analysis and forecast tools for the space environment. They include the magnetometer analysis tool that indicates when a magnetopause crossing has been detected at geostationary altitude by the GOES-R satellite. Two more of the algorithms were developed to use the energetic particle data to determine temperature and density moments and indicate spacecraft charging levels. The final two algorithms analyze the solar ultra-violet imaging data to produce thematic maps and coronal hole images of the sun.

Planning and requirements gathering for Phase 3 of the algorithms development project are underway.

Product: Loto'aniu, TM, and HJ Singer (2011), The GOES-R magnetopause crossing algorithm theoretical basis document, *NOAA/NESDIS Technical Publication*.

Loto'aniu, TM, L Mayer, and M Berguson (2011), The GOES-R magnetopause crossing algorithm implementation and users' guide, *NOAA/NESDIS Technical Publication*.

Loto'aniu, TM, L Mayer, and M Berguson (2011), The GOES-R delivery 2 test plan and results, *NOAA/NESDIS Technical Publication.*

Rodriguez, J (2011), GOES-R SEISS density and temperature moments and level of spacecraft charging algorithm theoretical basis document, *NOAA/NEDIS Technical Document*.

Rodriguez, J (2011), GOES-R SEISS density and temperature moments and level of spacecraft charging algorithm implementation and users' guide, *NOAA/NEDIS Technical Document.*

Rodriguez, J (2011,) GOES-R SEISS density and temperature moments and level of spacecraft charging algorithm test plan and results, *NOAA/NEDIS Technical Document.*

Rigler, EJ, and SM Hill (2011), SUVI thematic maps algorithm theoretical basis document, *NOAA/NEDIS Technical Document.*

GSD-07 High Performance Computing Systems

FEDERAL LEAD: SCOTT NAHMAN
CIRES LEAD: CRAIG TIERNEY

NOAA Goals 2: Climate

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

Milestone 1. Conduct technical study of latest hardware architectures to support future NOAA procurements.

NOAA has increased investment into new high-performance computing (HPC) systems over the last year for supporting both weather and hurricane modeling. While investment has increased, the research needs continue to outstrip resources. CIRES supported NOAA in the identification and acquisition of two major HPC platforms. Our goal in each case was to evaluate existing technologies and lend our own expertise to the architecture and implementation of these systems to maximize NOAA's investment. The first system was delivered at the end of summer 2010. This system, tJet, was a three-times performance increase over the previous system. This made the Earth System Research Laboratory (ESRL) the home to the largest NOAA-managed HPC resources.

The second system procured is a system whose purpose is to support weather and other modeling efforts for the entire NOAA program. The system is to be located in Fairmont, W. Va. CIRES provided assistance in the gathering of requirements, and made architectural recommendations to NOAA to help them maximize their investment. This system shall be operational by the end of 2011.

Milestone 2. Investigate tools to automate the use of Graphical Processor Units (GPU) co-processors within existing GSD codes.

While the use of HPC continues to increase in importance and expand to other disciplines, the users of this technology are starting to run into a performance wall. While the number of cores per central processing unit (CPU) socket continues to increase, the performance of individual cores is not increasing. Also, the power consumed on these systems is becoming a significant portion of the total cost of ownership of HPC systems. NOAA's Global Systems Division (GSD) is looking at new hardware technologies that can provide significant performance improvements while decreasing power consumption. Graphical Processor Units (GPUs) are one technology that appears to have the ability to meet this need, but effective use of these devices requires significant changes in programming models.

We have been supporting NOAA in the investigation of commercial and open-source tools that can help automate conversion of existing code to efficient code on the GPUs. Several vendors (Portland Group, Intel, Cray, CAPS) are taking different approaches to this problem. While most of the technologies are still immature, they are all showing promise. Comparisons of code generated by vendors' tools to handwritten code show tools are between 50 percent and 90 percent as efficient as handwritten code. Much work is still needed to assist the vendors with their programming tools to increase relative performance as close to 100 percent as possible.

Milestone 3. Support investigations of large, core-count model scalability in heterogeneous computing environments.

Due to time restraints and changes in NOAA priorities for the high-performance computing acquisition research area, we were not able to address this Milestone.

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
- GSD-06 Environmental Information Systems
- NGDC-03 Space Weather
- SWPC-01 Solar Disturbances in the Geospace Environment
- SWPC-02 Modeling the Upper Atmosphere

CSD-02 Chemical Transport Model Research

FEDERAL LEAD: MICHAEL TRAINER
CIRES LEAD: CHRISTINE ENNIS

NOAA Goal 3: Weather and Water

Project 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. Conduct a detailed study of the California ozone budget during the CalNex field study in the spring of 2010. Impact: This CIRES research will result in the first measurement-based tropospheric ozone budget for California. The findings will enable scientists and air quality mangers to quantify the contribution of baseline ozone to the exceedances of ozone air quality standards in California.

Since 1997, monitoring of tropospheric baseline ozone at the U.S. West Coast has been limited to the weekly ozonesondes from Trinidad Head, Calif. To explore baseline ozone at other latitudes, an ozonesonde network was implemented during spring 2010, with four launch sites along the California coast. Three inland sites indicated the impact of ozone production downwind of the baseline sites. Modeled North America pollution impacted the California coast primarily below 3 km, with no significant impact on the median coastal ozone profiles. Vertical and latitudinal variation in free tropospheric baseline ozone appears to be partly explained by polluted and stratospheric air masses that descend isentropically along the West Coast. Above 3 km, the dominant sources of ozone precursors were China and international shipping, while international shipping was the greatest source below 2 km. Approximately 8 percent to 10 percent of the baseline ozone that enters California in the 0-6 km range impacts the surface of the United States, but very little reaches the eastern United States. Within California, the major impact of baseline ozone that enters the state above 2 km is on the high-elevation terrain of eastern California. Baseline ozone below 2 km has its strongest impact on the low-elevation sites throughout the state. Compared to baseline sites, we found no increase in lower tropospheric ozone in the northern Central Valley, while ozone increases of 12 percent to 24 percent were found over the rest of the Central Valley. Enhancements above Joshua Tree National Park were similar, 16 percent

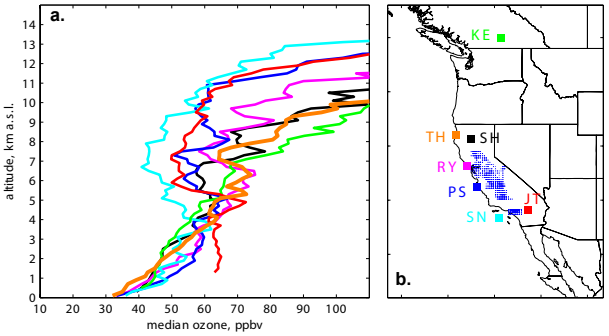


Figure 1: *a) Median ozone profiles above the IONS-2010 ozonesonde sites using all available profiles. Line colors correspond to the site label colors in panel b; b) Locations of the seven IONS-2010 ozonesonde sites. Also shown are the NOAA P-3 sampling locations (blue dots) of the measurements used in the Central Valley and L.A. Basin ozone composite profiles.*

to 21 percent, while the greatest ozone enhancements occurred over the Los Angeles Basin, 29 percent to 60 percent.

Product: Cooper, OR, SJ Oltmans, BJ Johnson, J Brioude, W Angevine, M Trainer, DD Parrish, TR Ryerson, I Pollack, PD Cullis, MA Ives, DW Tarasick, J Al-Saadi, and I Stajner (2011), Measurement of western U.S. baseline ozone from the surface to the tropopause and assessment of downwind impact regions, *J. Geophys. Res.*, in review.

Milestone 2. Use existing inventories, available field and satellite measurements, and models to improve the emission inventories for chemical transport models; and initiate a multiagency effort to coordinate U.S. research on emissions and enhance access to emission data sets and tools for their evaluation. Impact: These comparisons will provide an evaluation of the status of the most recent inventories and the temporal trends in emissions that have been seen over the last decade. The multiagency initiative will strengthen the research relationships between the inventory development, observations and modeling communities.

Task 1: We evaluated U.S. Environmental Protection Agency (EPA) 2005 National Emission Inventory (NEI2005) estimates of air pollution emissions. We focused on Houston and Dallas, Texas, which regularly violate Federal air-quality standards (Figure 2). We compared an atmospheric chemical-transport model to satellite and NOAA aircraft data of direct pollution emissions (nitrogen oxides, or NO_x, and two highly reactive organic compounds, ethylene and propylene) and the secondary pollutants (ozone and formaldehyde) formed by atmospheric chemical reactions of these emissions. We found that the NEI2005 provides reasonable estimates of 2006 Dallas and Houston motor vehicle emissions. The NEI2005 inaccurately represents NO_x, ethylene and propylene emissions from Houston's petrochemical industry and NO_x emissions from Houston's in-port commercial shipping. Reducing NEI2005 industrial and port NO_x emissions and increasing NEI2005 petrochemical ethylene and propylene emissions in Houston improved the model's ability to simulate secondary ozone and formaldehyde in the city's pollution plumes.

Task 2: The Community Initiative for Emissions Research and Applications (CIERA) was initiated through a partnership of the U.S. EPA, NOAA, the Federation of Earth Science Information Partners (ESIP), Department of Energy (DOE), International Global Atmospheric Chemistry (IGAC), NCAR, several academic institutions

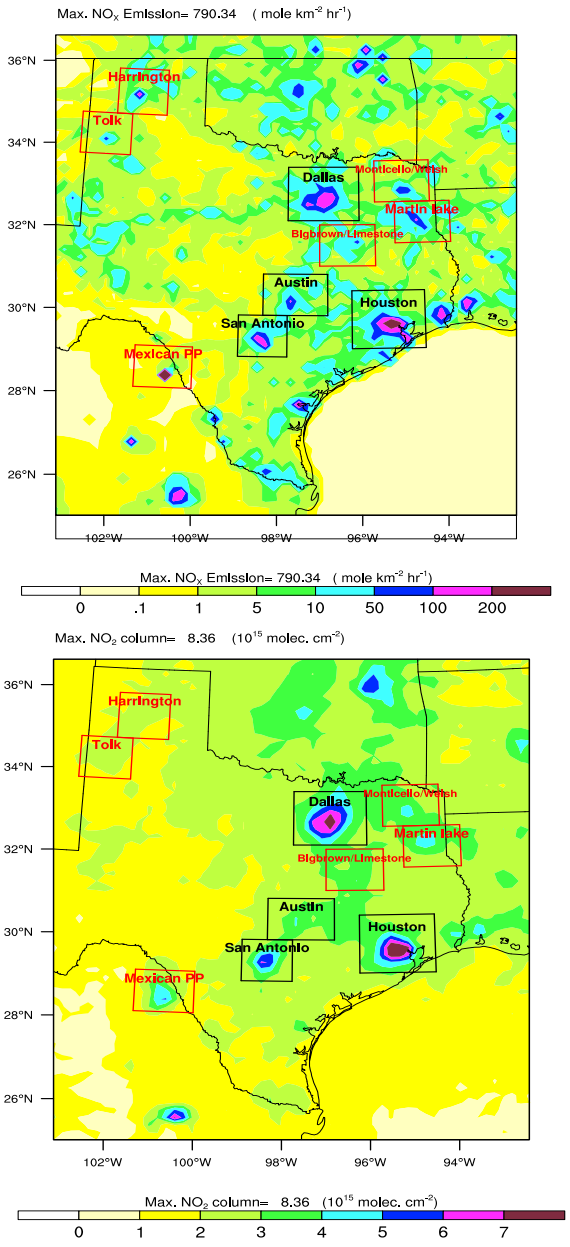


Figure 2: The spatial distribution of the U.S. EPA National Emission Inventory 2005 NO_x emissions (top) and NO_2 columns from the NASA OMI satellite (bottom) over the Texas domain used in this study.

and the private sector. CIERA envisions an international community to catalyze emissions research by facilitating 1) the consistent, timely and transparent development of emissions inventories at all scales; 2) evaluations and analyses of emissions data sets; and 3) the exchange and communication of emissions information. In FY2011, the vision for CIERA was formulated, CIERA sponsored emissions research sessions at two major scientific conferences and the CIERA web portal began development.

Product: Task 1: A manuscript describing the Texas emission study will be submitted to the journal *Atmospheric Chemistry and Physics Discussions* in July 2011.

Task 2: The CIERA web portal, http://ciera-air.org/, the virtual work space for CIERA activities, began development in FY11 and will continue to be built and expanded in the future.

Milestone 3. Use measurements of aerosols and their precursors made during the 2006 Texas Air Quality Study field mission in conjunction with a state-of-the-art air quality forecast model to assess recent developments in the treatment of secondary organic aerosol formation and their impact on particulate matter (PM2.5) aerosol forecasts. Impact: This CIRES research contributes to improved forecasts of aerosol within air quality models and directly supports NOAA's mission of having an operational national PM2.5 aerosol forecasting system by 2015.

Because particulate matter (PM2.5) aerosol are a public health concern, NOAA and the National Weather Service (NWS) have made it a mission to deploy an operational national PM2.5 aerosol forecast system, much like the national ozone forecast system currently in place within NOAA/NWS. Several forecast and research centers are developing PM2.5 forecast capabilities, such as the WRF/Chem (Weather Research and Forecast coupled with Chemistry) model within NOAA/ESRL. These models have undergone evaluation using observations from intensive field studies and surface PM2.5 network data, and have consistently demonstrated that forecasts of PM2.5 suffer from inaccuracies and biases that limit their usefulness. The most persistent forecast deficiency is the under-prediction of secondary organic aerosol (SOA).

This work incorporates recent laboratory and theoretical advances in SOA formation to an accepted and well-documented PM2.5 forecast model. A new SOA formation mechanism based on the Carnegie-Mellon Volatility Basis Set Approach is applied to the WRF/Chem model, and evaluated for summer 2006 using PM2.5 composition measurements from three national networks and observations from the Texas Air Quality Study. The results of this work were submitted as a report to NWS in March 2011, and the finished manuscript will be submitted in early August. Critical evaluations show the new SOA module compares well with available organic aerosol measurements and also improves PM2.5 forecasts. The model code will be submitted to the publicly accessible WRF model repository, and plans are in place to transfer the code to NWS for developmental testing at the national forecast center.

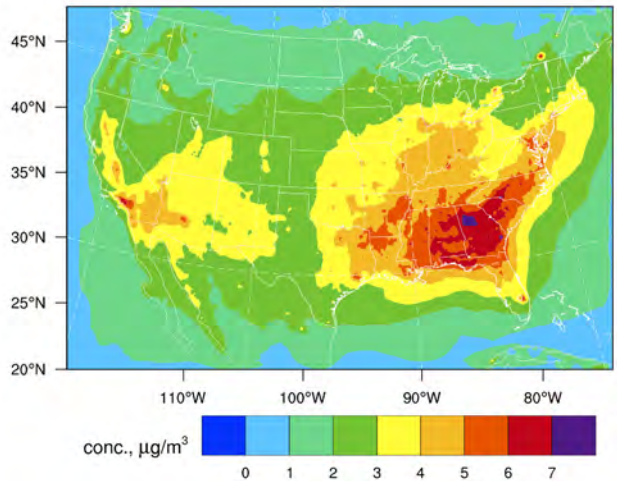


Figure 3: Average organic aerosol concentration between Aug. 1 and Sept. 30, 2006, using Volatility Basis Set Approach within the NOAA/ESRL WRF/Chem model.

PSD-16 Raindrop Size Distributions

FEDERAL LEAD: TIMOTHY SCHNEIDER
CIRES LEAD: CHRISTOPHER WILLIAMS

NOAA Goal 3: Weather and Water

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

Milestone 1. A vertical air motion estimation technique will be developed using collocated 50- and 920-MHz radar observations to isolate the vertical air motion resolved in the 50-MHz radar observations. These columnar dual-frequency vertical air motion estimates will provide reference measurements for simultaneous dual-Doppler scanning radar estimates.

A dual-frequency profiler retrieval technique was developed that estimates the vertical air motion within precipitating cloud systems. The technique relies on using the 'signal' in one radar to mask out the 'noise' observed in another. In particular, the 50-MHz profiler can simultaneously observe the vertical air motion and the raindrop motion when precipitating clouds pass directly overhead. But the 920-MHz profiler is only sensitive to the raindrop motion. By combining the two measurements, the 920-MHz profiler signal is used to mask out the raindrop motion in the 50-MHz profiler observation. The resulting filtered 50-MHz profiler observation contains only the vertical air motion information. The dual-frequency profiler retrieval technique was applied to observations collected during the Tropical Warm Pool–International Cloud Experiment (TWP-ICE). The vertical air motions have been and are still being used by international and domestic researchers studying the dynamics of precipitating cloud systems.

PSD-17 Environmental Monitoring and Prediction

FEDERAL LEAD: GARY WICK
CIRES LEAD: DARREN JACKSON

NOAA Goal 3: Weather and Water

Project 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 the representation of water vapor content and transport in the new Flow-following finite-volume Icosohedral Model during wintertime precipitation events along the U.S. West Coast using satellite observations, and compare with that of other operational models.

Efforts have focused on the development and validation of methods to compare the representation of water vapor content and transport between observations and model analysis and forecast fields. Atmospheric rivers are the primary manifestation of water vapor transport during wintertime precipitation events. An objective, automated tool for the identification and characterization of atmospheric river events in satellite observation and model forecast fields has been developed. The functionality of the technique was validated by comparing the objectively identified landfalling atmospheric rivers over five winter seasons with those identified visually in a climatology of landfalling events. The results demonstrated that the technique performed extremely well with a critical success index of 92.8 percent in identifying events. A publication describing the technique is now being completed. Initial application of the technique to comparisons of the frequency and intensity of atmospheric river events between observations and multiple forecast models suggest that the models do a good job in forecasting the occurrence of the events, but possibly overpredict their influence on land, particularly at longer lead times. Additional observations to directly assess the water vapor transport within three atmospheric river events were collected from the unmanned Global Hawk aircraft as part of the NOAA-led Winter Storms and Pacific Atmospheric Rivers (WISPAR) experiment.

GSD-01 Numerical Weather Prediction

FEDERAL LEAD: GEORG GRELL
CIRES LEAD: CURTIS ALEXANDER

NOAA Goal 3: Weather and Water

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

Milestone 1. Conduct and evaluate a summer 2010 and 2011 convection forecast exercise with other Aviation Weather Research Product Development Teams (Convective Weather, in particular), in which the High Resolution Rapid Refresh (HRRR) run at convection-resolving resolution over the conterminous United States plays a dominant role. The goal of this exercise is to evaluate the potential effectiveness of the HRRR in predicting high-impact aviation weather, particularly convection, 3–12 hours in advance.

The HRRR model output was used as a key input into a real-time automated convective weather forecast product known as CoSPA, which was used by the Federal Aviation Administration (FAA). During the summers of 2010 and 2011, the FAA conducted an operational performance evaluation of CoSPA to assess its impact on air traffic management decision-making. Additionally, the HRRR model forecasts have been provided to the Aviation Weather Center (AWC) for guidance in the production of a Collaborative Convective Forecast Product (CCFP).

Prior to the summer 2010 season, the HRRR forecast domain was expanded to include the entire conterminous United States; the underlying Weather Research and Forecasting (WRF) model version was updated to include the official version 3.2 release; and the forecast period was extended from 12 to 15 hours. Reliability of HRRR model runs has been maintained at about 95 percent for 2010/2011. Additional resources were implemented to improve the HRRR convective forecast guidance including an in-house multi-scale verification system and a parallel (shadow) HRRR model whereby impacts of model changes are assessed in both real-time and thru retrospective forecasts.

Prior to the summer 2011 season, the parent forecast model for HRRR initialization was changed from the Rapid Update Cycle (RUC) to the Rapid Refresh (RR) and includes a more advanced data-assimilation system known as Gridpoint Statistical Interpolation (GSI) along with a larger forecast domain covering North America. The larger domain reduces the negative impact of lateral boundaries and additional observations are now incorporated into the hourly RR analysis used by the HRRR.

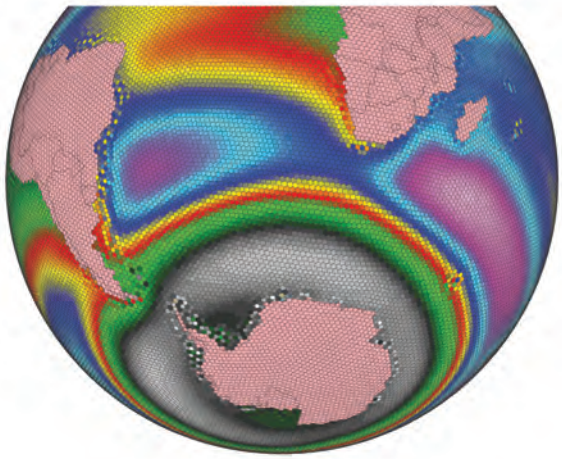


Figure 1: Sea surface height (SSH) simulated by the icosahedral ocean model OFIM. Grey/purple shades indicate lowest/highest SSH values. Surface currents tend to follow SSH contours. Dominant features are the Antarctic Circumpolar Current, flowing west to east, and the clockwise-rotating gyres in the South Atlantic and Southern Indian Ocean. Also shown are the grid cells of the icosahedral grid.

Milestone 2. Progress toward construction of an ESRL Earth system model by coupling an icosahedral formulation of the global Hybrid Coordinate Ocean Model (currently under development within ESRL) with the global Flow-following finite-volume Icosahedral atmospheric Model (FIM) on an identical horizontal grid. Test this coupled model on individual cases, and in real time if adequate computing resources and initial data are available.

Development of the icosahedral ocean circulation model OFIM (Oceanic Flow-following finite-volume Icosahedral Model) has reached a point where, when coupled to its atmospheric counterpart FIM, it produces acceptable global ocean state solutions on multiyear time scales. OFIM mimics FIM in using constant density layers in the ocean interior. Thermohaline coupling with the atmosphere is mediated by two nonisopycnic coordinate layers representing a turbulent mixed layer. With the two submodels sharing the same horizontal mesh, information exchange is straightforward. Emphasis at this point is on validation of air-sea fluxes calculated by FIM with an eye on drift in subsurface stratification. Among the ocean processes affecting global sea surface temperature—gyre-scale horizontal heat transport, surface mixed layer de- and entrainment and global meridional overturning ('conveyor belt')—our present focus is on the mixed layer and its role in properly maintaining the permanent thermocline. A milestone not yet reached is simulation of the ENSO (El Nino, La Nina) cycle. Soon to be added is a sea ice model to end the present dependence on observed ice coverage.

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

FEDERAL LEAD: JENNIFER MAHONEY
CIRES LEAD: ANDREW LOUGHE

NOAA Goal 3: Weather and Water

Project 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. Develop a verification plan for assessing the quality of the Graphical Turbulence Guidance Product version 3, and the Graphical Turbulence Guidance Product Nowcast.

Due to changes in priorities at the Federal Aviation Administration (FAA), the Graphical Turbulence Guidance (GTG) Product version 2.5 evaluation has been extended, while the GTG version 3 and GTG Product Nowcast evaluations have been pushed back. The GTG version 2.5 product incorporated a new observing platform (Eddy Dissipation Rate, EDR). As a result, in preparation for the evaluation, it was necessary to study the EDR reports and develop techniques for utilizing them in the evaluation. These new techniques were then incorporated into the evaluation of the GTG version 2.5 product. That evaluation has been completed, with the final presentation and publication of the official report to occur early in the next fiscal year.

Milestone 2. Provide assessment report summarizing the findings from an evaluation of the Current Icing Potential and the Forecast Icing Potential.

A verification plan for the Current Icing Potential (CIP) and Forecast Icing Potential (FIP) is underway. The plan focuses on a comparison of the current CIP and FIP algorithms run by the Aviation Weather Center (AWC) with new versions of CIP and FIP using the new Weather Research and Forecast model (WRF) Rapid Refresh. Additionally, new techniques are being developed to utilize satellite data for icing detection and verification. A report is forthcoming in late September 2011.

Milestone 3. Provide a comprehensive assessment of the Consolidated Storm Prediction for Aviation (CoSPA) forecast algorithm in support of the Federal Aviation Administration FY10 demonstration.

Completed the 2010 assessment of the real-time automated convective weather forecast product known as CoSPA and presented it to both the Convective Weather Product Development Team and to a Technical Review Panel from the Federal Aviation Administration. Two separate reports were written to support this effort. In addition, a winter 2010 assessment of CoSPA was completed, which used results from the summer 2010 study as a baseline. This was also presented to FAA management. A written report of the 2010 winter study will accompany the 2011 CoSPA Assessment.

GSD-05 Numerical Prediction Developmental Testbed Center (DTC)

FEDERAL LEAD: ZOLTAN TOTH
CIRES LEAD: LIGIA BERNARDET

NOAA Goal 3: Weather and Water

Project Goal: Transition new developments from research to operations in the Gridpoint Statistical Interpolator (GSI) data assimilation system and the Hurricane Weather Research and Forecasting (HWRF) modeling system through the Developmental Testbed Center (DTC).

Milestone 1. Upgrade the community Hurricane-Weather Research and Forecasting model (HWRF) code to contain new developments used by NOAA's National Centers for Environmental Prediction (NCEP) for the 2010 operational hurricane season and run extensive tests to assure that

the community HWRF is performing as well as operational HWRF, enabling a transition of the community code to NCEP for the 2011 hurricane season.

The community HWRF model has been upgraded to contain the capabilities of the 2010 operational model and of the 2011 operational baseline (a starting point for developing the 2011 operational model). Extensive tests have been conducted to show that the forecasts produced with the community model have similar average forecast skill as those generated at NOAA NCEP; an exact match is not expected due to differences in computer platform. The results from these tests have been made available at http://verif.rap.ucar.edu/eval/hwrf_hnr2_hr20/, where a final report is posted.

This extensive test, which employed 1,190 cases from 53 storms of the North Atlantic and Eastern North Pacific basins for the 2008, 2009 and 2010 seasons, was the first comprehensive hurricane test conducted by the DTC, and was also used to qualify DTC's functionally similar testing and evaluation infrastructure.

The community code has been transitioned to be used at NCEP for the 2011 hurricane season, indicating that the research and operational communities are now using the same code base, which facilitates the transition of new developments to operations.

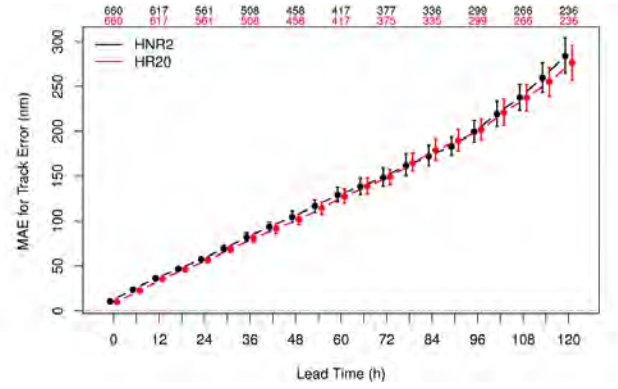


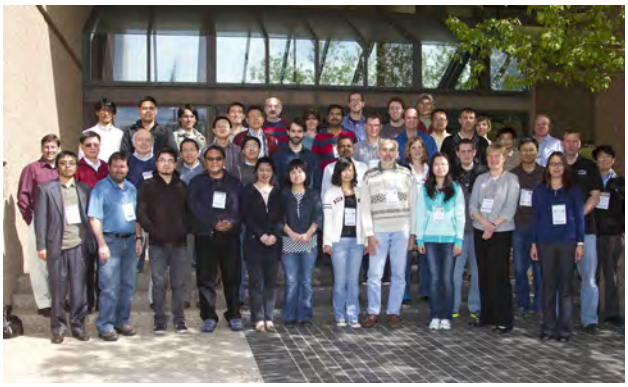
Figure 1: *Mean and 95% confidence intervals of tropical cyclone position errors (nautical miles) as a function of forecast lead time (hours) for two configurations of the 2011 baseline of the HWRF model. HNR2 (black) is configured from the community HWRF model and run by the DTC. HR20 (red) is a corresponding run done by NOAA/NCEP. Both configurations show that track errors increase linearly with time from near zero to over 250 nm at the five-day forecast. The forecasts from the two configurations are statistically indistinguishable, indicating that the operational model has been adequately ported to the community code repositories and qualifying the DTC functionally similar testing infrastructure.*

Milestone 2. Maintain the code repositories for Gridpoint Statistical Interpolation (GSI) and Hurricane-Weather Research and Forecasting model (HWRF) and provide user support for both codes (helpdesk, website, code distribution, and documentation).

During the last year, the DTC has provided user support for both the HWRF model and the GSI. GSI and HWRF have more than 300 and 170 registered users, respectively. Approximately 30 questions are answered by the email helpdesk for each system every month.

GSI v3 was released, and work has been done toward the HWRF v3.3a release planned for July 2011. The users' guide, websites (http://www.dtcenter.org/com-GSI/users/ and http://www.dtcenter.org/HurrWRF/users/), case studies and tutorial instructions were updated for both systems. Tutorials for the HWRF and GSI systems were offered in April and June 2011, respectively.

Maintenance of the community GSI and HWRF repositories continued to transition all operational upgrades to the community code and to incorporate the community code onto NOAA NCEP operations. This process ensures that the code used by the academic and operational communities remains connected, which facilitates transfer of new research to operations.



Students and instructors of the April 2011 Hurricane WRF Tutorial.

GSD-06 Environmental Information Systems

FEDERAL LEAD: PATRICIA MILLER
CIRES LEAD: LEON BENJAMIN

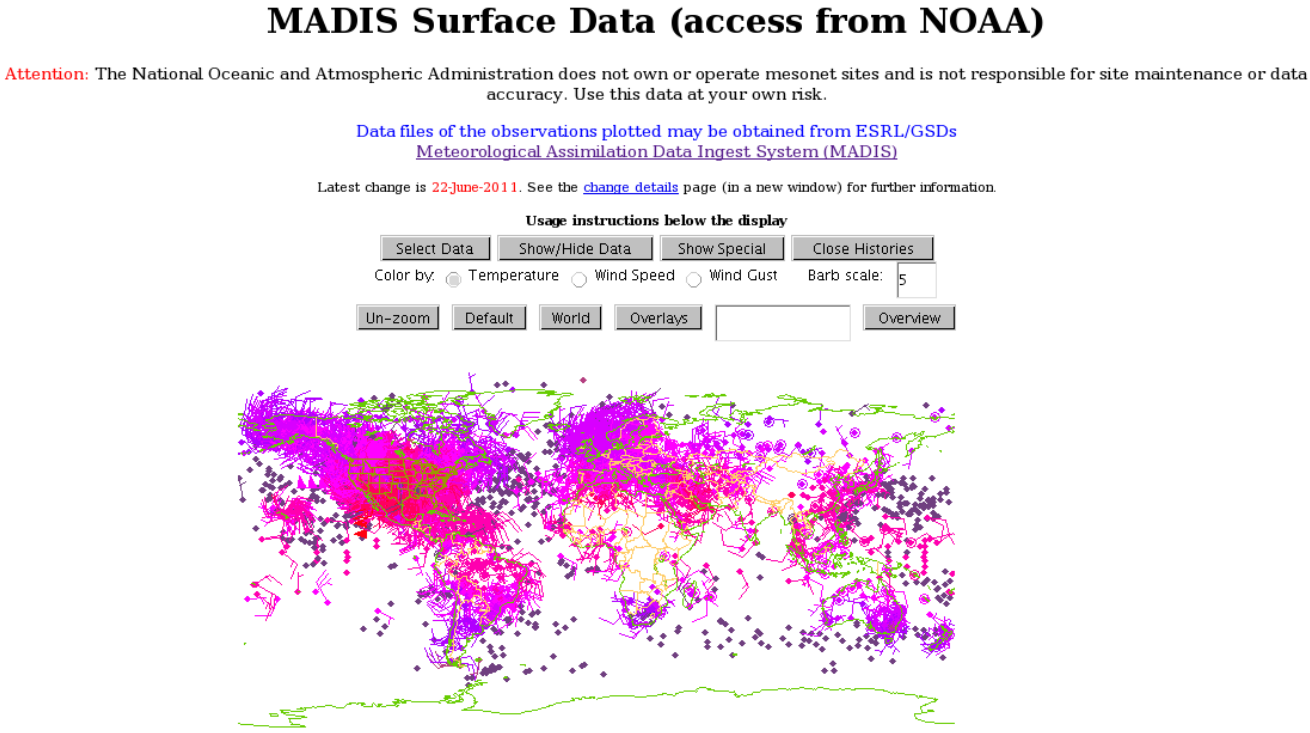
NOAA Goal 3: Weather and Water

Project Goal: Develop information systems that deliver atmospheric observation data and environmental products to users of weather, water and climate information.

Milestone 1. Complete Final Operating Capability of the Meteorological Assimilation Data Ingest System (MADIS) at the National Weather Service.

MADIS ingests data files from NOAA data sources and non-NOAA data providers, decodes the data and then encodes all of the observational data into a common format with uniform observation units and time stamps. Quality-control checks are conducted, and the integrated data sets are stored in the MADIS database with a series of flags indicating the quality of the observation from a variety of perspectives (e.g., temporal consistency and spatial consistency), or more precisely, a series of flags indicating the results of various quality-control checks.

The completion of the Final Operating Capability (FOC) of MADIS at the National Weather Service (NWS) is in progress. Transition to the NWS includes three major milestones: start of transition (Sept. 15, 2008), Initial Operating Capability (IOC) (completed Sept. 30, 2010) and Full Operating Capability (FOC). At IOC MADIS has a primary system



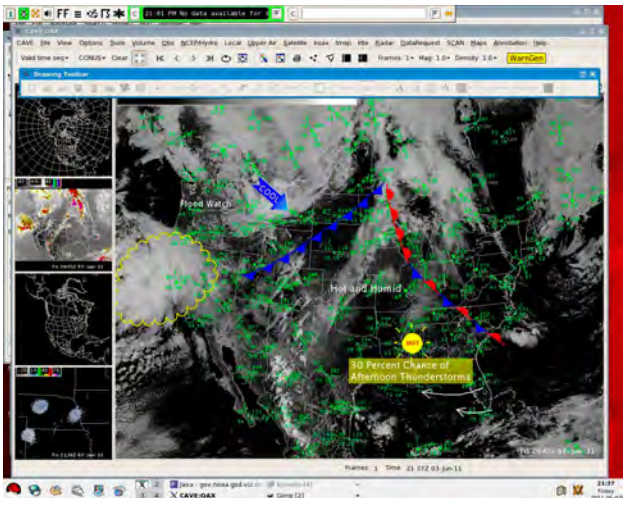
running at NWS and a backup at the Global Systems Division (GSD). The IOC system at NWS is a distributed MADIS architecture between the NWS Telecommunications Operations Center (TOC) and NCEP Central Operations (NCO). There is a supporting research-to-operations test and backup capacity at the Oceanic and Atmospheric Research's (OAR) GSD. OAR's Earth System Research Laboratory (ESRL) GSD office continues to sustain both the GSD MADIS and NWS systems throughout the transition phase in order to support NOAA customers.

Milestone 2. Port FX-Collaborate drawing tool software to AWIPS II.

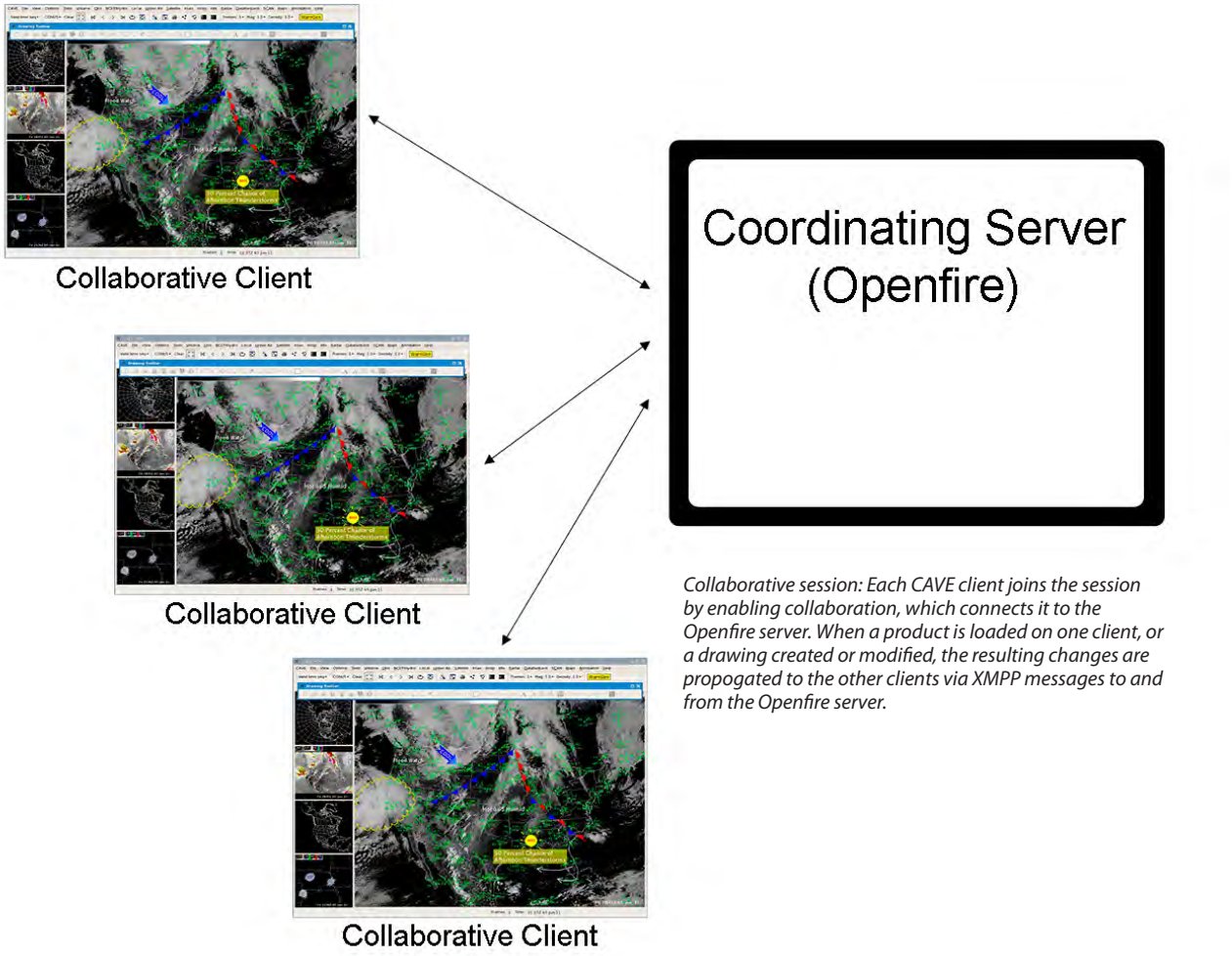
The port of FX-Collaborate (a weather collaboration program) functionality to the Advanced Weather Interactive Processing System II (AWIPS II) involves the addition of a drawing tool in order to allow weather forecasters the ability to produce annotated products. The latter might include, for example, a cold front line, text explaining various features, shaded shapes representing warning areas, etc. The previous-generation AWIPS system required that forecasters use another tool, FX-Collaborate, in order to create such annotated products. AWIPS II integrates the drawing capability into the core software.

In the last year, the previously existing rough prototype of the AWIPS II drawing tool was refined and rewritten to create a nearly production-ready application. This involved a number of steps, including ensuring that the drawing tool could handle various AWIPS II events (pane swapping, toggling the editable property, mouse-based input over the layer labels, etc.); fixing memory leaks that could cause slow performance or crashes; successive upgrades of the drawing tool to match new capabilities and limitations of new versions of the core AWIPS II software suite as the latter became available; the creation of a page of relevant options to the AWIPS II Preferences dialog box; and the addition of new editing actions (dynamic rotation of drawable objects, creation of configurable background rectangles for text, etc.)

The result is a CAVE (Common AWIPS Visualization Environment) plug-in providing nearly all the functionality of the FX-Collaborate drawing tool, as well as new enhancements, all integrated into the core AWIPS II software.



Screenshot of the CAVE drawing tool plug-in in action. The user has used the drawing tool to annotate weather products, such as the satellite image serving as a background. A yellow cloud shape, sun and arrow symbols, text and three fronts have been added.



Collaborative session: Each CAVE client joins the session by enabling collaboration, which connects it to the Openfire server. When a product is loaded on one client, or a drawing created or modified, the resulting changes are propogated to the other clients via XMPP messages to and from the Openfire server.

Milestone 3. Develop an AWIPS II collaboration prototype as part of the AWIPS II.

The NWS is investigating various approaches to meet the collaboration requirements for AWIPS II. The latter will allow real-time collaboration between weather forecasters at different sites by allowing them to share weather products, drawings and other data within the AWIPS II environment.

The last year has seen the design of a distributed architecture and the implementation of a basic system, to allow collaboration as a plug-in for CAVE. The system uses XMPP (Extensible Messaging and Presence Protocol) messages between participating CAVE clients and Openfire (an open-source server responsible for coordinating the session) to exchange information about products each client has loaded. Clients who are able to load products directly are only passed metadata indicating what products are to be loaded in order to remain synchronized with the collaborative session, whereas those who cannot load data are sent "screenshots" from connected clients of the same data, thus minimizing bandwidth usage. Screenshots are optimized for transmission and may be compressed substantially or not, depending upon the bandwidth requirements in that particular case.

Furthermore, the collaboration plug-in has been merged with a version of the AWIPS II drawing tool plug-in (Milestone 2) in order to enable collaborative drawing as well. This allows session participants to draw or modify cold fronts, weather symbols, etc. and have these changes appear on other clients' displays in near real-time. Development of the collaboration tool will continue in the coming year as NWS requirements evolve in order to provide a fully functional production-quality end product.

NGDC-03 Space Weather

FEDERAL LEAD: ERIC KIHN
CIRES LEAD: JUSTIN MABIE

NOAA Goal 4: Transportation

Project 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. Add new features to the Space Physics Interactive Data Resource (SPIDR), including the work flow system, data dashboard, and collaboration on new web service interface development with colleagues at the Russian Academy of Sciences, Geophysical Center.

Several new features were added to SPIDR as part of this effort. A downloadable desktop graphical application for creating and executing workflows, based off of the Kepler workflow system. The National Geophysical Data Center (NGDC) bundle includes the derivative application,

workflows that make use of SPIDR's Simple Object Access Protocol (SOAP) web services and workflows that combine data from different datasets within SPIDR and manipulate them, such as filtering. In addition to this front-end, user-centric system, the beginnings of a back-end workflow system were completed as well. http://spidr.ngdc.noaa.gov/worfklow

A RESTful (REpresentational State Transfer) web service interface was added to SPIDR allowing easier access to the web service middle ware for those less versed in web service development, including sample clients in Perl, Python, IDL and Matlab/Octave, bringing SPIDR's web services to a much larger community of science data customers. As a result of these new services, the SPIDR team received an NGDC customer service award and a NASA software award.

- http://spidr.ngdc.noaa.gov/spidr/servletGetData?describe
- http://spidr.ngdc.noaa.gov/spidr/tools.do

The data dashboard was completed for three widely used datasets, ionospheric, geomagnetic and cosmic ray data, and allows a data customer or scientist to see latency of receipt of SPIDR's holdings within those domains. This information better supports the use of these data so it is clear when they were received and from where.

- http://spidr.ngdc.noaa.gov/spidr/data_dashboard.do

Product: Poster presentation, 'Auroral Resources Toolkit (ART),' at the Space Weather Workshop, April 27, 2011.

Milestone 2. Develop an operational version of the D-Region Absorption Prediction (D-RAP) Modeling System on the NGDC website, which will generate model outputs that are available from, and archived at, NGDC.

This task is complete, and the data, model outputs and visualization are all available on the NGDC's Solar and Terrestrial Physics Division (STPD) website. There is an opportunity for continued development as well, to make or collaborate with another group to create an on-demand model run capability. This would be similar to what the NASA Goddard Space Flight Center Community Coordinated Modeling Center (CCMC) does, and as such, they would make a good partner for doing so. Discussions on this topic have been held, and the desire for a broader NGDC on-demand model run capability exists and was brought to light by said discussions.

This dynamic/on-demand aspect of D-RAP would be a subset of the wider NGDC effort, so it will not be pursued as part of this milestone, but will be considered for the wider NGDC on-demand capability as a follow-up effort, whether that is an in-house project or collaboration with an outside organization. D-RAP Modeling System outputs are available from the NGDC/STP website, and are being archived at NGDC as well.

- http://ngdc.noaa.gov/stp/iono/drap/index.html.

Milestone 3. Develop a 'Geomag Tracking Database' to track geomagnetic data holdings at NGDC in order to modernize the geomagnetic data stewardship program and provide a tool that will help correct past difficulties in data stewardship and dissemination.

The Geomag Tracking Database was developed and operates according to specification. This database ingests inventory data in XML format and handles a dynamic range of metadata fields. The database allows sorting of geomatic data and metadata in ways that were not before possible, providing a powerful new tool to the community and NGDC data managers.

Product: Database was presented at the meeting 'Artifical Intelligence in the Earth's Magnetic Field Study,' in Uglich, Russia, January 2011.

Milestone 4. Develop a 'MIRror of online MAGnetic data (MIRRMAG)' data ingest system that will ingest available, online geomagnetic data into NGDC databases. Once ingested, the system will perform any needed format processing, load the data into the SPIDR database, port the data to the NGDC FTP site, and port the data to the tape library ingest staging area.

MIRRMAG ingest system is fully functional. The system ingests, processes and disseminates data as designed. This system streamlines ingest and dissemination of geomagnetic observatory data, allowing for more efficient use of data manager time and limiting the potential problems that arise from more hands-on data management techniques. As an unforeseen benefit, this system has allowed for the geomagnetic data manager to take on an increased workload in a time when resources are limited. As a result, our customer service and data-handling practices are performing better in a more challenging environment.

SWPC-01 Solar Disturbances in the Geospace Environment

FEDERAL LEAD: VIC PIZZO
CIRES LEAD: ALYSHA REINARD

NOAA Goal 3: Weather and Water

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

Milestone 1. In collaboration, SWPC will modify and test the empirical relationship linking helicity and future flaring potential of a given active region, and will evaluate its potential as a forecasting tool for solar flares.

This project is just beginning. We have hired a postdoc, who began work in April. She has just started this effort, and we expect to have results to report on next year.

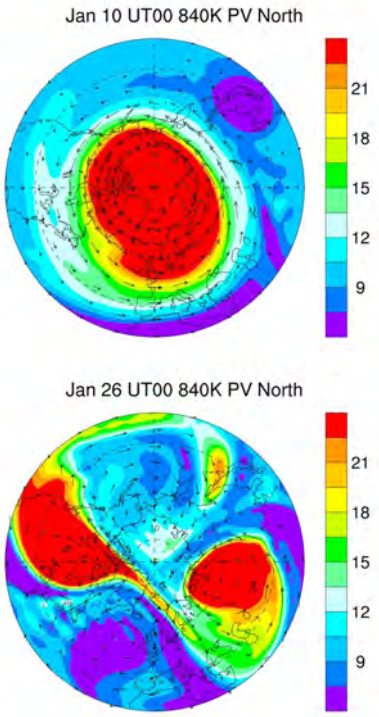
SWPC-02 Modeling the Upper Atmosphere

FEDERAL LEAD: MICHAEL CRUMLY
CIRES LEAD: TIMOTHY FULLER-ROWELL

NOAA Goal 3: Weather and Water

Project Goal: Quantify the impact of sudden stratospheric warmings (SSW) on the upper atmosphere. Recent observations suggest that SSW impact the dynamics and electrodynamics of the lower thermosphere, and change the diurnal variation of total electron, which is an important component of space weather. The recently developed Whole Atmosphere Model (WAM) simulates SSW naturally so will be used to quantify their impact on the thermosphere and ionosphere.

Milestone 1. Quantify the impact of sudden stratospheric warmings (SSW) on the upper atmosphere. Recent observations suggest that SSW impact the dynamics and electrodynamics of the lower thermosphere, and change the diurnal variation of total electron, which is an important component of space weather. The recently developed Whole Atmosphere Model (WAM) simulates SSW naturally, so will be used to quantify their impact on the thermosphere and ionosphere.



A whole atmosphere model has been used to simulate the changes in the global atmosphere dynamics and electrodynamics during the January 2009 sudden stratospheric warming (SSW). In a companion paper, it has been demonstrated that the neutral atmosphere response to the 2009 warming can be simulated with high fidelity and can be forecast several days ahead. The 2009 warming was a large event with the polar stratospheric temperature increasing by 70 K. The neutral dynamics from the whole atmosphere model (WAM) was used to simulate the response of the electrodynamics. The WAM simulation predicted a substantial increase in the amplitude of the eight-hour ter-diurnal tide in the lower thermosphere dynamo region in response to the warming, at the expense of the more typical semi-diurnal tides. The increase in the ter-diurnal mode had a significant impact on the diurnal variation of the electrodynamics at low latitude. The changes in the winds in the dayside ionospheric E region increased the eastward electric field early in the morning, and drove a westward electric field in the afternoon. The initial large increase in upward drifts gradually moved to later local times, and decreased in magnitude. The change in the amplitude and phase of the electrodynamic response to the SSW is in good agreement with observations from the Jicamarca radar. The agreement of the electrodynamics with observations serves to validate the whole atmosphere dynamic response. Since WAM can forecast the neutral dynamics several days ahead, the simulations indicate that the electrodynamic response can also be predicted.

Product: Fuller-Rowell, T, H Wang, R Akmaev, F Wu, T Fang, M Iredell, and A Richmond (2011), Forecasting the dynamic and electrodynamic response to the January 2009 sudden stratospheric warming, *Geophys. Res. Lett., 38,* L13102, doi:10.1029/2011GL047732.

AMOS-04 Observing Facilities, Campaigns and Networks

- GMD-02 Surface Radiation Network
- PSD-10 Cloud and Aerosol Processes
- PSD-11 Water Cycle
- GSD-04 Unmanned Aircraft Systems

GMD-02 Surface Radiation Network

FEDERAL LEAD: JOSEPH MICHALSKY
CIRES LEAD: GARY HODGES

NOAA Goal 2: Climate

Project 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.

View of the albedo tower located at Table Mountain, approximately 10 miles north of Boulder, Colo. Mounted on the tower is the head of an MFRSR. Other instruments are radiometers measuring reflected UV-B and reflected Photosynthetically Active Radiation (PAR).

Milestone 1. Using SURFRAD databases, complete and publish an analysis of spectral albedo at the Table Mountain, Colorado, SURFRAD station and present the results in conferences.

To determine surface spectral albedo requires measuring the incoming (downwelling) and reflected (upwelling) irradiance over a range of wavelengths. Reflected values are divided by the corresponding incoming values to give albedo. To measure the incoming data, we continue to operate a Multi-Filter Rotating Shadowband Radiometer (MFRSR) at our Table Mountain, Boulder, Colo., Surface Radiation Budget Network (known as SURFRAD) site. For the reflected data, we have mounted an MFRSR sensor head in the inverted position on a 10-m tower located approximately 100 feet north of the MFRSR. For accurate albedo calculation, it is important that both instruments undergo routine calibrations linked to a common source. Instrument calibrations are performed on a regular basis using a standard lamp.

We have presented spectral albedo results at three meetings: 1) The annual Atmospheric System Research Science Team Meeting in Bethesda, Maryland; 2) The biennial Baseline Surface Radiation Network meeting in Queenstown, New Zealand; and 3) the 13th Conference on Atmospheric Radiation in Portland, Ore.

Collecting the necessary data for determining spectral albedo at Table Mountain is part of an ongoing, long-term measurement program. These data have been attracting the interest of other researchers. Most recently, NASA has requested these data for use in validating the Moderate Resolution Imaging Spectroradiometer (MODIS), a key instrument aboard the Terra and Aqua satellites.

PSD-10 Cloud and Aerosol Processes

FEDERAL LEADS: TANEIL UTTAL AND TIM SCHNEIDER
CIRES LEAD: MATTHEW SHUPE

NOAA Goal 2: Climate

Project 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. Produce cloud macrophysical and microphysical data sets describing the clouds at Arctic atmospheric observatories. These data sets will include information on cloud occurrence, vertical distribution, boundaries, phase and microphysical properties.

There has been ongoing work to develop and evaluate techniques for deriving cloud macrophysical, microphysical and dynamical properties from remote sensor measurements in order to produce continuous data sets from ongoing Arctic observatory measurements and periodic observational campaigns. Many of these data sets are made available via public data archives supported by NOAA and other agencies. During the past year, two papers were published documenting some of these cloud data sets. The first paper documented cloud fraction measurements from long-term measurements (at least approximately one year in duration) from six Arctic atmospheric observatories, including a characterization of cloud boundaries, vertical distribution and persistence. The second paper looked in more detail at cloud phase occurrence at three of the observatories with more complete and complex instrument suites. These studies revealed important differences in the annual distribution and occurrence of clouds at different Arctic locations, which could be linked to processes that control cloud phase and ultimately to the larger-scale meteorological environment at these locations. Additionally, a new set of comprehensive cloud measurements has been started at Summit, Greenland, and will eventually lead to further cloud properties data sets.

Product: Shupe, MD, VP Walden, E Eloranta, T Uttal, JR Campbell, SM Starkweather, and M Shiobara (2011), Clouds at Arctic Atmospheric Observatories, Part I: Occurrence and macrophysical properties, *J. Appl. Meteor. Clim., 50,* 626-644.

Shupe, MD (2011), Clouds at Arctic Atmospheric Observatories, Part II: Thermodynamic phase characteristics, *J. Appl. Meteor. Clim., 50,* 645-661.

Milestone 2: Utilize ground-based, multi-instrument, remote-sensor measurements, aircraft in situ observations and high-resolution mesoscale models to study the role of cloud dynamical-microphysical processes in the Arctic cloud life cycle. Specific observations will come from various sites, including NOAA's Study of Arctic Environmental Change, SEARCH; the DOE's ARM sites, and the Surface Heat Budget of the Arctic, SHEBA; Arctic Summer Cloud Ocean Study, ASCOS; and Arctic Mechanisms of Interaction between the Surface and Atmosphere, AMISA, field campaigns.

Coordinated observational and modeling efforts have substantially enhanced our understanding of cloud microphysical and dynamical processes that are responsible for the persistence of Arctic stratiform clouds. Observationally, efforts have focused on deriving detailed information on in-cloud dynamical and microphysical properties and determining how these interact both within the cloud and the surrounding atmosphere. These observational analyses have led to a number of papers (in preparation or published) that document the observed cloud and boundary layer structure and suggest some ways in which aerosol properties constrain the formation of ice particles in mixed-phase clouds. The detailed observational data have also been used to evaluate nested Weather Research and Forecasting (WRF) model simulations, where the innermost nest is run at very fine scale resolutions of 50 meters or less. These high-resolution simulations, with proper large scale forcing, are able to well capture the evolution of a stratiform, mixed-phase cloud system, lending confidence in many of the internal model processes. The model has then been used to examine moisture and energy budgets within the cloud and atmosphere that cannot be directly observed. Thus, the model simulations have been a key tool for extending our understanding of processes like entrainment and mixing beyond observational capabilities. Much of this general understanding has been synthesized in a collaborative review article on persistent Arctic mixed-phase clouds that is currently under review.

Product: De Boer, G, H Morrison, MD Shupe, and R Hildner (2011), Evidence of liquid dependent ice nucleation in high-latitude stratiform clouds from surface remote sensors, *Geophys. Res. Lett., 38,* L01803, doi:10.1029/2010GL046016.

Lance, S, MD Shupe, G Feingold, CA Brock, J Cozic, JS Holloway, RH Moore, A Nenes, JP Schwarz, JR Spackman, KD Froyd, DM Murphy, J Brioude, OR Cooper, A Stohl, and JF Burkhart (2011), CCN as a modulator of ice processes in Arctic mixed-phase clouds, *Atmos. Chem. Phys. Discuss., 11,* 6737-6770.

Solomon, A, MD Shupe, POG Persson, and H Morrison (2011), Moisture and dynamical interactions maintaining decoupled Arctic mixed-phase stratocumulus in the presence of a humidity inversion, *Atmos. Chem. Phys. Discuss., 11,* 13469-13524.

Morrison, H, G de Boer, G Feingold, J Harrington, MD Shupe, and K Sulia (2011), Self-organization and resilience of Arctic mixed-phase clouds, *Nat. Geosci.,* submitted.

Milestone 3. Participate in the Northwest Tropical Atlantic Salmon, NTAS; PIRATA Northeast Extension, PNE; and CalNex research cruises in 2010. Deploy cloud radar, radiometer and flux systems to measure key surface marine boundary layer parameters, low cloud macrophysical, microphysical and radiative properties. Conduct initial analysis focused on the associations between low clouds and the boundary layer structure.

The CIRES-NOAA team participated in the PIRATA (Prediction and Research Moored Array in the Tropical Atlantic) Northeast Extension (PNE; also referred to as Aerose) cruise in May 2010. Data have been made available via the NOAA Earth System Research Laboratory / Physical Sciences Division data archive and ftp site. Analysis of the data has been delayed.

PSD-11 Water Cycle

FEDERAL LEAD: MARTY RALPH
CIRES LEAD: DAVID KINGSMILL

NOAA Goal 3: Weather and Water

Project Goal: Improve weather and climate predictions

through an increased knowledge of regional and global water cycle processes.

Milestone 1. Plan and execute the 2011 Hydrometeorology Testbed, HMT-West field campaign, an annual series of field efforts conducted in the northern California American River basin, located in the Sierra Nevada Mountains west of Lake Tahoe and east of Sacramento. CIRES investigators will be key participants and contributors to these activities.

The Hydrometeorology Testbed (HMT)-West 2011 field season was conducted from Dec. 1, 2010, to March 8, 2011, with a break from Dec. 22-27 (94 total days of operations). This deployment was unique due to significant contributions to the existing HMT-West infrastructure from the California Energy Commission (CEC) and the California Department of Water Resources (CADWR). The CEC is building on the existing HMT-West instrumentation network through CalWater (http://www.esrl.noaa.gov/psd/calwater/), a program complementary to HMT-West that aims to examine the role of aerosols in precipitation as well as to quantify the temporal and spatial variability of atmospheric rivers (ARs) and their representation in climate models. These objectives involve specialized monitoring of the Sierra Barrier Jet (SBJ), which profoundly affects transports of both water vapor and aerosols, and ultimately redistributes orographic precipitation and modifies AR conditions (each of importance to HMT). Observational assets deployed for HMT-West 2011 (Figure 1) included:

- SkyWater C-band radar at Lincoln;
- Supplemental upper air soundings at Lincoln;
- S-band precipitation profilers at Sugar Pine and Mariposa;
- Atmospheric River Observatory at Concord;
- GPS-met observations at Fort Bragg and Shasta

Overall there were seven SBJ-focused Intensive Operating Periods, with 295 hours of SkyWater radar operations, and 88 special radiosondes launched (71 by the Earth System Research Laboratory Physical Sciences Division from Lincoln, plus 17 supplemental soundings by the National Weather Service from Oakland or Reno). In addition, specialized HMT-West numerical model simulations were conducted in real-time, and daily forecasts and field team deployment decisions were made throughout the period.

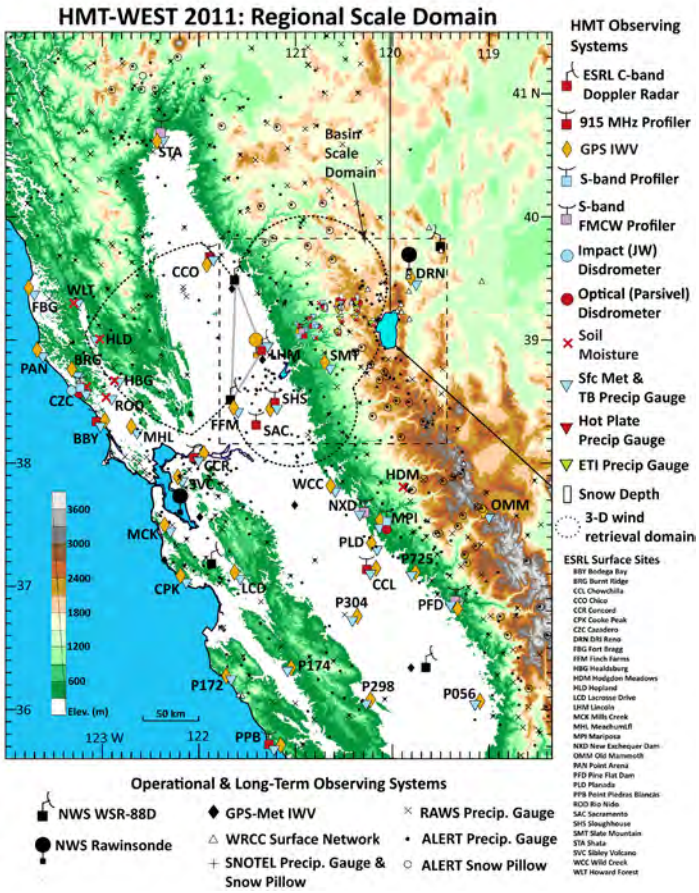


Figure 1: *Observational assets deployed for HMT-West 2011*

A remote sensing approach for simultaneous retrievals of cloud and rainfall parameters in the vertical column above the U.S. Department of Energy's (DOE) Climate Research Facility at the TWP Darwin site in Australia was developed. This approach uses vertically pointing measurements from Ka-band radar and scanning measurements from a nearby C-band radar pointing toward the TWP Darwin site. Rainfall retrieval constraints are provided by an impact disdrometer. The approach is applicable to stratiform precipitating systems when a separation between the liquid hydrometeor layer, which contains rainfall and liquid water clouds, and the ice hydrometeor layer is provided by the radar bright band. Absolute C-band reflectivities and Ka-band vertical reflectivity gradients in the liquid layer are used for retrievals of the mean layer rain rate and cloud liquid water path. Figure 2 shows a measurement example in a rain system. Different slopes of Ka-band radar reflectivity (MMCR) corresponds to different attenuation rates caused by differing amounts of liquid phase while C-band data (CPOL) used as a proxy for non-attenuated reflectivities show very little vertical variability.

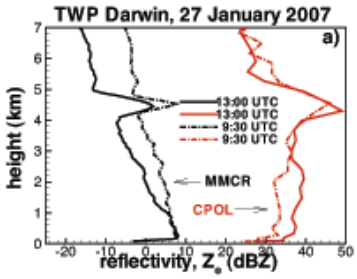


Figure 2: *A measurement example in a rain system*

Milestone 2. Develop and test an approach for a synergetic use of C-band scanning polarimetric radar (C-POL) and vertically pointing 8-mm wavelength radar (MMCR) for simultaneous retrievals of parameters in stratiform precipitating systems at the Tropical Western Pacific (TWP) Darwin Atmospheric Radiation Measurement (ARM) Climate Research Facility (ACRF). This remote sensing approach will aim to estimate liquid cloud water path and rain water path in the liquid hydrometer layer and simultaneously retrieve an ice water content profile and ice water path in the same vertical atmospheric column. In addition to measurements from radars that are currently available at the Darwin ACRF, the ground-based rain gauge and disdrometer data will be used to constrain retrievals. The suggested remote sensing approach will be tested using data from a number of experimental events. The retrieval uncertainties will be evaluated.

Milestone 3. Apply a CloudSat method for simultaneous retrievals of mean rain rate and ice water path in stratiform precipitating systems to multi-year data sets collected during the CloudSat overpasses in the vicinity of the ARM Southern Great Plains Climate Research Facility (ACRF). The CloudSat retrievals will be analyzed for possible correlations between parameters of the ice parts of precipitating systems (e.g., ice water path) and the resultant rainfall. The satellite retrievals will be also compared to the ARM retrievals, so a consistency between space-borne and ground-based estimates of hydrometeor parameters in precipitating cloud systems will be investigated.

A method to retrieve ice water path (IWP), mean rainfall rate and cloud liquid water path (CLWP) in the same vertical atmospheric column was developed and initially applied for stratiform-like precipitation events observed at the Southern Great Plains (SGP) site of the Atmospheric Radiation Measurement (ARM) Program. The retrieval method is based on multi-frequency radar measurements at W-, Ka and S-band. The radar measurements also provide a robust separation of the liquid, mixed and ice hydrometeor layers. Applying the method to case studies indicates that characteristic values of CLWP are about 300-400 g/m2, although values up to 1,000 g/m2 and higher are not uncommon. IWP, which represents the precipitating cloud part of the atmospheric column that is observed above the freezing level, usually significantly exceeds cloud liquid water path and can reach values of approximately 10,000 g/m2 and even higher. There is low-to-medium correlation between IWP and mean rain rate. On average, mean rainfall in the liquid layer, R, increases with an increase in ice mass observed above the melting layer. Figure 1 shows an example of retrievals.

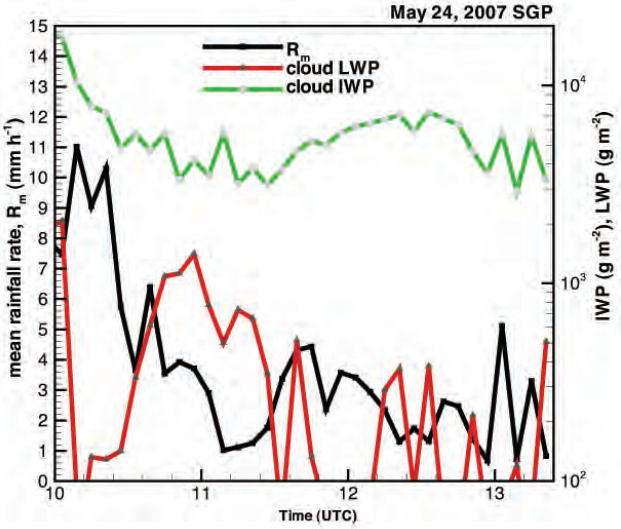


Figure 2: *Example of a retrieval.*

Milestone 4. Maintain configurations and web access to the real-time water vapor flux tool for use by researchers and weather forecasters to assess and monitor extreme precipitation events along the West Coast of the United States.

In support of the near-real-time water vapor flux tool, which is used by researchers and forecasters to help monitor and study extreme orographic precipitation events, automated software operations and configurations were maintained for 10 different NOAA and cooperative agency sites along the U.S West Coast. The maintenance and configuration of software to distribute the tool's numerical flux data was also performed. Lastly, monitoring of data and product quality as well as near-real-time availability was accomplished on a daily basis to support research and forecasting efforts during the NOAA HMT and CalWater campaigns.

Milestone 5. The CalWater experiment is a multi-year effort supported by NOAA and the California Energy Commission to study the impact of anthropogenic aerosols and climate change on precipitation and associated water supply in California. Aerosol and meteorological observing instruments will be deployed in key locations in California. Part of this effort will be to diagnose the vertical structure of the precipitating cloud systems in the context of collocated aerosol observations. Another part of this effort will entail analysis of meteorological observations to characterize the Sierra barrier jet, its modulation by atmospheric rivers and the resultant spatio-temporal distribution of precipitation.

During the first year of the CalWater experiment, a major accomplishment was the installation of NOAA radars and surface meteorological instruments at three field sites in California for the 2010-2011 winter season field campaign. The sites included Sugar Pine Dam, Mariposa airport and Lincoln airport. Researchers from the University of California at San Diego installed aerosol sampling instruments at all three sites. While the first year of CalWater focused on collecting data during the 2010-2011 winter season field campaign, next year will focus on analyzing and interpret-

NOAA instrumentation at the Mariposa airport during sunset. From left to right, the photo shows a vertically pointing S-band (2.8 GHz) profiling radar, a Parsivel disdrometer and an anemometer mounted on a 10-m tower.

A ribbon seal.

ing the collected data.

GSD-04 Unmanned Aircraft Systems

FEDERAL LEAD: SARA SUMMERS
CIRES LEAD: ELIZABETH WEATHERHEAD

NOAA Goal 3: Weather and Water

Project Goal: Analyze sea ice images collected from satellite to automatically identify ice seals and derive fractal ice characteristics.

Milestone 1. Evaluate measurements from unmanned aircraft systems (UAS) for their ability to measure sea ice characteristics and marine mammals.

More than 27,000 images have been collected through NOAA's Unmanned Aircraft Program. The analysis of these images, both to understand ice qualities and identify seals, is important to NOAA's mission of understanding and protecting the world's oceans. Techniques were successfully developed to automate analysis of images to describe the observed ice. Ice characteristics that are automatically described include: fraction of ice cover, amount of ice in each of the WMO classification of ice types and fractal dimensionality (edge-to-area ratio) of ice. Using a different set of programs, the images are also analyzed to help identify seals within an image. Successful development of seal identification can allow for future unmanned aircraft flights to be used to identify seals and, potentially, estimate seal populations should flight transects offer sufficient coverage. These capabilities did not exist prior to this effort. Efforts are proposed to make these image-analysis techniques operational and usable for future flights. The merging of information on ice characteristics and seal identification indicates that the seals show a distinct preference to certain types of ice. Further analysis will be needed to confirm this as a general tendency and may give insight into the fragility of seal habitats in the Arctic.

Product: Weatherhead, EC, Sea ice characteristics and ice seal behavior: New results from unmanned aircraft data, American Geophysical Union, Fall Meeting 2010, abstract #C43D-0574.

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

FEDERAL LEAD: SAMUEL OLTMANS
CIRES LEAD: IRINA PETROPAVLOVSKIKH

NOAA Goal 2: Climate

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

Milestone 1: Analyze ground-based, balloon and aircraft in situ ozone measurements for long-term trends in the troposphere and at the surface.

The 35-year record of surface ozone measurements at four of the NOAA Baseline Observatories (Barrow, Alaska; Mauna Loa, Hawaii; American Samoa; and South Pole) represents some of the longest continuous records of tropospheric ozone at background locations. At these sites, less than 5 percent of the data are influenced by nearby (less than 100 km) anthropogenic ozone precursor emissions. This data record is investigated for longer-term changes with an emphasis on the 30-year period 1980-2009. The three 10-year periods are compared with particular emphasis on possible changes in the seasonal pattern over this time. At each of these sites, strong seasonally dependent processes, such as the springtime boundary layer ozone depletion at Barrow, influence the year-to-year variability and can influence the longer-term changes. At several other regionally representative locations (Bermuda; Barbados; Iceland; and Niwot Ridge, Colo.), there are 20-plus years of observations, although in all cases there are multi-year gaps in the record. Earlier and more recent portions of the record are compared, again with emphasis on possible changes in the seasonal pattern over this time. Significant longer-term changes have taken place at Barrow and Mauna Loa. At Barrow this has been during the summer and winter months, while in Hawaii the change has been primarily during the seasonal minimum in the autumn and early winter. There is some suggestion of an increase over the Atlantic from the discontinuous records in Bermuda and Iceland that encompasses the entire year.

Product: Douglass, A, V Fioletov, S Godin-Beekmann, R Müller, RS Stolarski, A Webb, A Arola, JB Burkholder, P Burrows, MP Chipperfiel, R Cordero, C David, PN den Outer, SB Diaz, LE Flynn, M Hegglin, JR Herman, P Huck, S Janjaim, IM Jánosi, JW Krzyścin, Y Liu, J Logan, K Matthes, RL McKenzie, NJ Muthama, I Petropavlovskikh, M Pitts, S Ramachandran, M Rex, RJ Salawitch, BM Sinnhuber, J Staehelin, S Strahan, K Tourpali, J Valverde-Canossa, C Vigouroux (2010), Stratospheric ozone and surface ultraviolet radiation, *Scientific Assessment of Ozone Depletion: 2010*, World Meteorological Organization, 2011.

Milestone 2: Continue to assess and improve quality of column and profile ozone measurements for climate trend analysis and satellite validation.

The improvement of the Dobson and Brewer ozone profile retrieval algorithm has continued. The Umkehr data acquired in 2009-2010 by the NOAA Dobson and NEUBrew Brewer ozone ground-based network have been processed and archived. The new level 300 total ozone data are corrected for long-term drifts in instrumental degradation and are now used in the Umkehr ozone profile retrievals. The largest effect (about 5 percent) is in the lowermost tropospheric layers, and it reduces the previously found bias with respect to the co-located ozone-sounding data. Verification/quantification of the instrumental changes (caused 5 percent error in retrieved ozone at 40 km) found in the Dobson Umkehr retrieved ozone data at Mauna Loa (MLO), Hawaii, in 2005 were performed through the comparisons against the climatological data, and long-term time-series of co-incident measurements taken by lidar and microwave instruments at MLO, and ozone-sounding at Hilo, Hawaii. The work to apply corrections is underway. The study to assess the sensitivity of Dobson and Brewer Umkehr retrieved ozone profiles to the choice of the ozone absorption cross-section (Bass and Paur, 1985; Daumont, 1992), the out-of-band stray light (OOB) error and stratospheric temperature variability were assessed. It was found that ozone cross-section choice and its temperature dependence only minimally (within the retrieval accuracy) affect the Dobson and the Brewer Umkehr retrievals. Significantly larger errors are found when the OOB stray light contribution to the Umkehr measurement is not taken into account in the retrieval algorithm, but produces no statistically significant effect on long-term trends.

PSD-04 Decadal Climate and Global Change Research

FEDERAL LEAD: RANDALL DOLE
CIRES LEAD: PRASHANT SARDESHMUKH

NOAA Goal 2: Climate

Project 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 analysis 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 El Niño-Southern Oscillation-related (ENSO) variations contributed to the observed trends. 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 many studies, can lead to wrong conclusions. In a recently published study, we 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 sea surface temperature (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-year (1871–2006) HadISST (Hadley Centre Global Sea Ice and Sea Surface Temperature) data set. The analysis showed that previously identified multidecadal variations in the Pacific, Indian and Atlantic Oceans all have substantial ENSO components. The long-term warming trends over these oceans were also found to have appreciable ENSO components, in some instances up to 40 percent of the total trend. The ENSO-unrelated component of five-year average SST variations, obtained by removing the ENSO-related component, was interpreted as a combination of anthropogenic, naturally forced and natural coherent multidecadal variations. Two surprising aspects of these ENSO-unrelated variations were emphasized: 1) a strong cooling trend in the eastern equatorial Pacific Ocean and 2) a nearly zonally symmetric multidecadal tropical–extratropical seesaw that has amplified in recent decades.

Product: Compo, GP, and PD Sardeshmukh (2010), Removing ENSO-related variations from the climate record, *J. Clim.*, *23*, 1957-1978, DOI: 10.1175/2009JCLI2735.1.

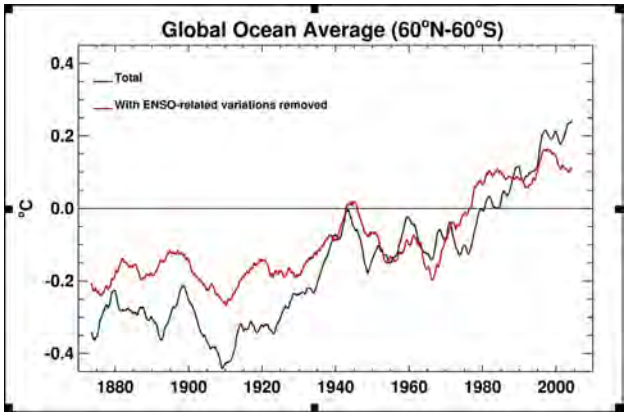


Figure 1: *Time series of the near-global ocean average surface temperature anomalies (black curve), and after their ENSO-related components are removed (red curve). A 10-year running mean has been applied to both time series. Anomalies are relative to a 1949 to 2004 average. Note that after removing the contributions associated with ENSO, the 1871 to 2006 trend of 0.5 K per century is reduced to 0.3 K per century, a 40% reduction. From Compo and Sardeshmukh (*Journal of Climate, *2010).*

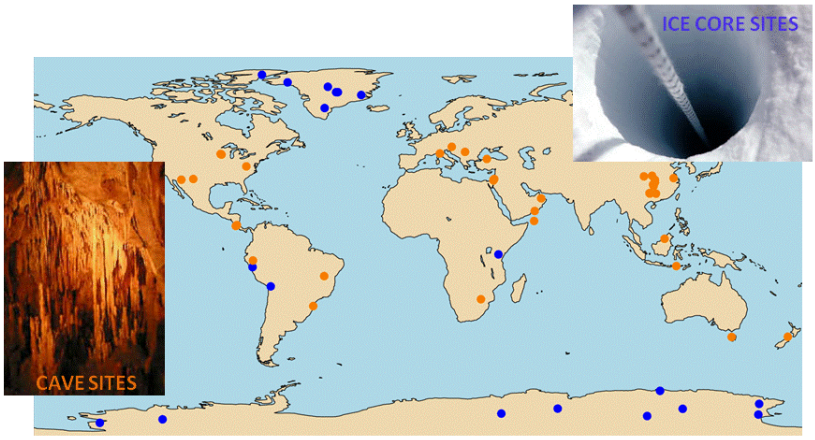


Figure 2: *Locations of cave (orange) and ice core (blue) records added to the data set of climate time series spanning the period between the Last Glacial Maximum and today.*

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

FEDERAL LEAD: DAVE M. ANDERSON
CIRES LEAD: CARRIE MORRILL

NOAA Goal 2: Climate

Project 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 data and information from the paleoclimatic record.

Milestone 1: Expand the database of transient climate change during the last 21,000 years to include terrestrial temperature reconstructions and stable isotope records from speleothems and ice cores. Also, add raw age model data to the database to allow users to generate new age models as dating and calibration methods are refined.

We added more than 100 marine and terrestrial records to the data set of climate time-series since the Last Glacial Maximum (21,000 years ago). The majority of these records came from cave deposits and ice cores and provided information about terrestrial temperature and hydrology. Refinements to our database structure and in standardizing variable names within and between proxy types permitted us to ingest these data into a common database. These advances allowed users for the first time to easily download consistently formatted data grouped into science-relevant themes. In addition, we gathered missing age model information, including raw radiocarbon dates, for more than 30 new and existing marine time-series. Incorporating this information into the database gave users the opportunity to recalibrate radiocarbon dates for each time-series and to eliminate discrepancies in age models caused by using different calibration methods. This research database of the last 21,000 years will enable extensive comparisons between climate models and paleoclimate data planned for the next Intergovernmental Panel on Climate Change (IPCC) assessment report.

Milestone 2: Expand the last millennium temperature database to include gridded climate reconstructions. These gridded reconstructions will complement the point reconstructions already included in the database and will provide a template for the eventual addition of climate model simulations.

We greatly expanded the holdings in our last-millennium temperature database (now called the last 2+ millennium paleoclimate network) through the inclusion of several gridded data products—including the National Centers for Environmental Prediction (NCAP) and the National Center for Atmospheric Research (NCAR) gridded temperature reanalysis data; selected variables from the 2010 millennium simulations of the Max Planck Institute for Meteorology Comprehensive COSMOS (Community Earth System Models) Earth System Model; and the HadCRUT3v combined global land and ocean surface temperature data. This has expanded the spatial coverage of the existing 92-point reconstructions and 1,209 site proxy data already in the network. It also increased the temporal coverage of the network and allowed linkages to be made between the paleoclimatic records and modern instrumental observations. Researchers and others interested in later-Holocene climate can now find a complete set of data tools needed to calibrate and make temperature reconstructions, and can compare these with the accumulated high-resolution reconstructions in NOAA-Paleoclimatology's archive.

CSV-02 Mechanism and Forcings of Climate Variability

- CSD-03 Chemistry, Radiative Forcing, and Climate
- CSD-12 Emissions and Atmospheric Composition
- CSD-13 Kinetics and Photochemical Studies
- 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

FEDERAL LEADS: SUSAN SOLOMON, THOMAS B. RYERSON, KAREN ROSENLOF, STEVEN BROWN AND DAN MURPHY
CIRES LEAD: CHRISTINE ENNIS

NOAA Goal 2: Climate

Project 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 influencing 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. Add ice habit information to cloud parcel modeling. Impact: Ice formation and growth is a critical and highly uncertain process for both precipitation and the radiative properties of clouds. A better description of ice habits will allow better calculations of both ice crystal growth and sedimentation.

The fundamental physical processes that maintain supercooled liquid in observed Arctic mixed-phase clouds are poorly constrained. To isolate the factors that control ice/liquid partitioning during the ascent of an air parcel, detailed model studies were performed with ice nucleation by deposition and immersion freezing and ice habit evolution. Effects on ice and liquid water evolution in an updraft were explored as a function of ice nucleus (IN) concentration and nucleation mode, updraft velocity, properties of cloud condensation nuclei and assumption about ice particle shape (habit). For most conditions, ice and liquid coexist and increase simultaneously, and only at high IN concentrations or low updraft velocities do ice particles grow at the expense of droplets. The impact of the ice nucleation mode on ice/liquid distribution depends on the temperature and supersaturation regime. The assumption of spherical ice particles instead of non-spherical habits leads to substantially smaller predicted ice masses. It is concluded that updraft velocity, IN concentrations and particle shape can impact ice/liquid distribution to similar extents. The work will be continued by exploring different hypotheses on freezing (stochastic versus singular) using literature data from laboratory studies within the same model framework.

Product: Ervens, B, G Feingold, K Sulia, and JY Harrington, The impact of microphysical parameters, ice nucleation mode, and habit growth on the ice/liquid partitioning in mixed-phase Arctic clouds, submitted to *J. Geophys. Res.*

Milestone 2. In the CalNex 2010 Field Campaign, survey a wide variety of different sources of directly emitted gas and aerosol species (e.g., carbon dioxide, methane, nitrous oxide, halocarbons and particle-phase soot) that affect atmospheric radiative forcing. Impact: The planned suite of measurements includes both short-lived and long-lived forcing agents, and will provide survey data for anthropogenic, agricultural, biogenic and geologic sources of these radiatively important trace species. These data will provide additional independent evaluation of newly developed greenhouse gas inventories in California and better define source sector emissions strengths for directly emitted greenhouse gases.

During CalNex 2010, the research vessel Atlantis and the NOAA WP-3D research aircraft were deployed to characterize emissions of climate forcing agents and their precursors. Particular attention was paid to commercial marine vessels, which have been identified by the California Air Resources Board as significant sources of greenhouse gas emissions (CO_2) and important climate-forcing aerosol species (e.g., black carbon). In cooperation with the Maersk Shipping Line, an experiment was conducted that examined the effect on ship emissions of switching to low-sulfur marine fuels and slow-steaming (traveling at slower speeds) when a large containership was outside of and then within 24 miles of the California coast. Figure 1 (from Lack et al., submitted in 2011) shows that the two regulatory strategies are very effective at reducing stack emissions from these vessels. A separate experiment with a much smaller vessel showed similar results (Cappa et al., submitted in 2011).

Research Vessel Atlantis was also deployed within California's harbors of Los Angeles, Long Beach, San Francisco and Oakland to survey the levels of important climate-forcing agents in these industrial regions with the goal of verifying current emission inventories. Similarly, the WP-3D research aircraft was flown on flight tracks

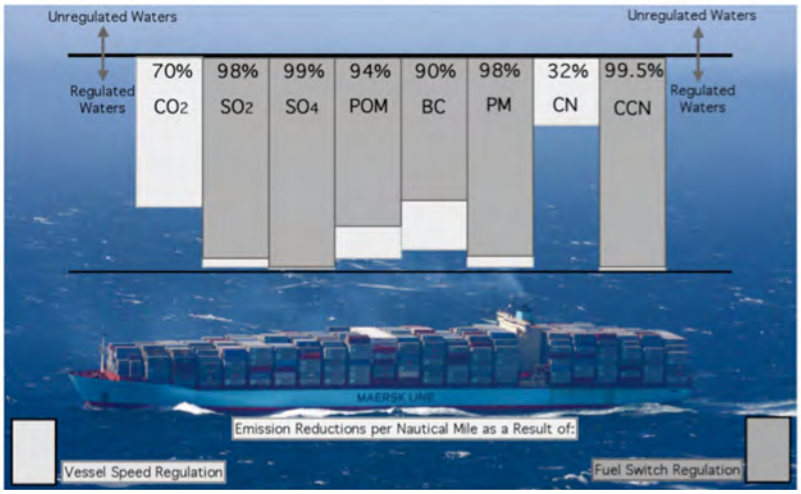


Figure 1: *Emissions reductions per nautical mile of travel from the Margrethe Maersk for all Species as a Result of the State of California fuel switch and vessel speed regulations. Contribution of the fuel switch regulation (vessel speed regulation) to emission reductions shown in dark grey (light grey).*

over urban, rural and agricultural regions throughout the South Coast Air Basin and extensively over the inland San Joaquin and Sacramento valleys. These flights were used to collect data that will be used in inverse modeling experiments to further improve emission inventories of climate-forcing agents such as CO_2 and CH_4.

Product: Lack, DA, et al., Observed changes in climate- and air quality–relevant shipping emissions due to vessel fuel quality and speed regulation, submitted to *Environ. Sci. Technol.*

Cappa, CD, et al., The influence of operating speed on gas and particle-phase shipping emissions: Results from the R/V Miller Freeman, submitted to *Environ. Sci. Technol.*

Milestone 3. Investigate the climate impact of changes in stratospheric ozone and water vapor concentrations using the National Center for Atmospheric Research (NCAR) Community Atmosphere Model (CAM) with the slab ocean component (SOM), using time slice simulations and sensitivity studies and making use of new and improved ozone and water vapor data sets. Impact: The experiments aim to quantify the importance of these gases to both the modeled stratospheric and tropospheric climates. Also, the results will show the effect of using improved ozone data as a model boundary condition, which will be of great use and interest to the global modeling community.

The final version of the National Institute of Water and Atmospheric Research (NIWA) ozone data set was released in January 2011, and a manuscript describing the regression fit to the observational data is currently being prepared (Bodeker, et al.). Several long CAM integrations have been completed, with the goal to investigate the dependence of the modeled climate response to late-20th-century ozone depletion to the ozone data set (comparing the NIWA data against the Intergovernmental Panel on Climate Change Fourth and Fifth Assessment Reports 'standard'). Results are being prepared for submission (Young, et al.), and they suggest that many of the signals of Antarctic ozone depletion (e.g., temperature and southern annular mode changes) are significantly stronger when using the NIWA data set, which will be of particular interest to the modeling community.

An ad hoc collaboration with Dr. Paul Kushner at the University of Toronto also has been initiated, using his expertise with analyzing dynamics in climate model output to investigate the model results in more depth. This extended analysis also will include an investigation of the possible role of the (slab) ocean in intensifying the ozone climate signal in the NCAR model. CAM simulations have been completed using imposed stratospheric water vapor (SWV) concentrations in the radiation code, investigating the potential role of the pre/post-2000 change in SWV in decadal scale climate variability. Early indications suggest the change did not yield a significant impact on modeled temperatures. It is planned to revisit this topic with a revised method and/or repeating the study with a newer model.

Products: Ozone dataset: "Combined vertical ozone profile database," available from Bodeker Scientific (http://www.bodekerscientific.com)

Bodeker, GE, B Hassler, et al., A vertically resolved, global, gap-free ozone database for assessing or constraining global climate model simulations, in prep.

Young, PJ, S Solomon, et al., Modeling the impact of late 20th century stratospheric ozone changes: Sensitivity to different ozone forcing data sets, in prep.

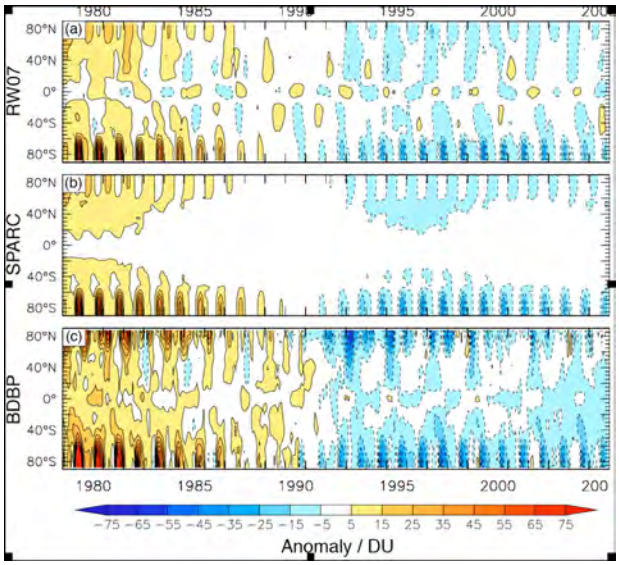


Figure 2: *Latitude-time plots of column (250-5 hPa) anomalies for the (a) Randel and Wu (2007), (b) SPARC (Cionni et al., 2011) and (c) BDBP-based (Hassler et al., 2009) climate model ozone data sets, in Dobson Units (DU). Anomalies are computed relative to the 1979-2005 climatology for each data set. Note the deeper blue colors at high latitudes in (c) indicating more ozone depletion in that data.*

CSD-12 Emissions and Atmospheric Composition

FEDERAL LEAD: SUSAN SOLOMON
CIRES LEAD: CHRISTINE ENNIS

NOAA Goal 2: Climate

Project Goal: Improve understanding of past and projected future anthropogenic and natural emissions of atmospheric trace gases that influence climate and climate variability.

Milestone 1. Evaluate anthropogenic and natural surface emissions of atmospheric chemical compounds during the past two decades by making detailed comparisons of available emissions inventories, and evaluate the consistency between global and regional emissions, and the impact on the composition of the atmosphere. Impact: This study will provide information used as inputs in climate models, focusing on the chemical compounds detected from space (CO, NO_2, ozone) and on hydrocarbons from natural and anthropogenic origins.

Several different inventories of global and regional anthropogenic and biomass burning emissions have been assessed for the 1980-2010 period. The species considered so far are CO, NO_x, SO_2 and black carbon. The Atmospheric Chemistry and Climate Model Intercomparison Project (ACCMIP) historical emissions developed in support of the simulations for the Intergovernmental Panel on Climate Change Fifth Assessment Report are also considered. Emissions from the Representative Concentration Pathways (RCPs) are also included. Large discrepancies between the global and regional emissions are identified, which shows that there is still no consensus on the best estimates for surface emissions. At the global scale, anthropogenic emissions of CO, NO_x and SO_2 show the best agreement for most years, although agreement does not necessarily mean that uncertainty is low. The agreement is low for BC emissions, particularly in the period prior to 2000. The best consensus is for NO_x emissions for all periods and all regions, except for China, where emissions in 1980 and 1990 need to be better defined. Emissions of CO need better quantification for all periods. The agreement between the different SO_2 emissions data sets is rather good for the United States, but better quantification is needed elsewhere. The comparisons show that the use of RCP 8.5 for the extension of the ACCMIP inventory beyond 2000 is reasonable, until more global or regional estimates become available. Biomass burning inventories agree within 50-80 percent, depending on the year and season. The large differences between datasets are due to differences in the estimates of burned areas from the different available products, as well as in the amount of biomass burned.

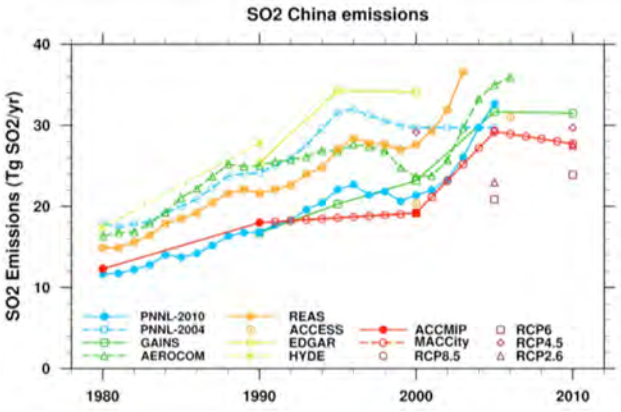


Figure 1: *Comparison of SO_2 emissions in China from 1980 to 2010 from different surface emissions inventories.*

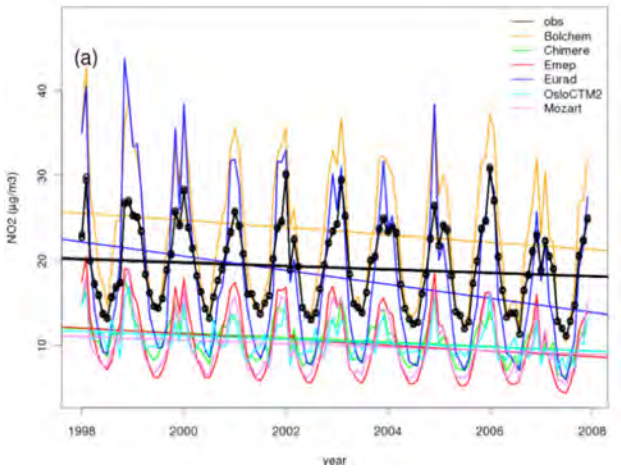


Figure 2: *European-wide composite of modelled and observed monthly means of NO_2 trend (µg/m³) at the air quality monitoring stations of background suburban and rural type. The straight line shows the best linear least square fit for each model results.*

Product: Granier, C, B Bessagnet, T Bond, A D'Angiola, H Denier van der Gon, G Frost, A Heil, J Kaiser, S Kinne, Z Klimont, JF Lamarque, C Liousse, T Masui, F Meleux, A Mieville, T Ohara, K Riahi, M Schultz, S Smith, A Thomson, J van Aardenne and G van der Werf (2011), Evolution of anthropogenic and biomass burning emissions at global and regional scales during the 1980-2010 period, *Clim. Change,* accepted for publication.

Milestone 2. Evaluate the evolution of the chemical composition of the atmosphere during the next two to three decades, using the different emissions scenarios developed in support of the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5) to assess different Representative Concentrations Pathways (RCPs). Impact: This research will support the IPCC AR5 report by determining the effects of different RCPs on the distribution of chemical species and on their deposition at the surface, which will enable improved understanding and modeling of the effect of atmospheric chemical composition on climate.

The proposed work has started with an evaluation of the capability of chemistry-transport models to reproduce past trends in air quality. Documenting these strengths and weaknesses on the basis of historical simulations is essential before the models can be used to assess future air-quality projections. Different regional and global models have been used to simulate the evolution of air quality during the 1997-2008 period. The analysis has so far focused on ozone and nitrogen dioxide, for which surface, as well as satellite, observations are available. A paper has been submitted in June 2011, which focuses on the results obtained for the European region. The analysis of the model results has shown that the year-to-year interannual changes in the distributions of the constituents are rather well reproduced, although capturing the more moderate trends of chemically produced species such as O_3 is more challenging. The modeled monthly variability is consistent with the observations but the year-to-year variability is generally underestimated.

A comparison of simulations where anthropogenic emissions are kept constant was also investigated. It was found that the magnitude of the emission-driven trends exceeds the natural variability for the chemical compounds considered in the study. It can, therefore, be concluded that emission-management strategies have had a significant impact over the past 10 years, hence supporting further emission-reductions strategies. Simulations for the 2010-2030 period are currently under way, using different sets of emissions scenarios, based on the emissions provided by the RCPs.

Product: Colette, A, C Granier, O Hodnebrog, H Jakobs, A Maurizi, A Nyiri, B Bessagnet, A D'Angiola, M D'Isidoro, M Gauss, F Meleux, M Memmesheimer, A Mieville, L Rouïl, F Russo, S Solberg, F Stordal, and F Tampieri, submitted to *Atmos. Chem. Phys*.

CSD-13 Kinetics and Photochemical Studies

FEDERAL LEAD: JIM BURKHOLDER
CIRES LEAD: CHRISTINE ENNIS

NOAA Goal 2: Climate

Project Goal: Determine the rates of climate-relevant processes and evaluate the lifetimes and radiative properties of atmospheric species (gases and particles) that influence climate.

Milestone 1. Measure rate coefficients for the chlorine monoxide self reaction (ClO + ClO + M) over a range of temperatures and pressures relevant to polar stratospheric photochemistry. Impact: This research will provide data needed to reduce uncertainties in atmospheric model calculations of polar ozone loss. This research has implications for stratospheric ozone chemistry and climate-chemistry coupling.

Halogen chemistry plays an important role in polar stratospheric ozone loss. The ClO dimer (ClOOCl) catalytic ozone destruction cycle accounts for the vast majority of winter/spring polar stratospheric ozone loss. A key step in the dimer catalytic cycle is the pressure- and temperature-dependent self-reaction of the ClO radical. The rate coefficient for the ClO self-reaction has been measured in previous laboratory studies but uncertainties persist, particularly at atmospherically relevant temperatures and pressures. In this laboratory study, rate coefficients for the ClO self-reaction were measured over a range of temperatures (200–296 K) and pressures (50–600 Torr, He and N2 bath gases). ClO radicals were produced by pulsed laser photolysis of Cl2O at 248 nm. The ClO radical temporal profile was measured using dual wavelength cavity ring-down spectroscopy (CRDS) near 280 nm. The absolute ClO radical concentration was determined using the ClO UV absorption cross sections, and their temperature dependence was measured as part of this work. The results from this work are in conflict with several previous studies that form the basis of current kinetic recommendations for use in atmospheric models. The impact of these differences on polar stratospheric chemistry and ozone loss will be evaluated in future work.

Milestone 2. Measure ultraviolet (UV) absorption cross sections of the long-lived ozone-sepleting and greenhouse gases nitrous oxide (N2O) and carbon tetrachloride (CCl4) as a function of temperature. Impact: UV photolysis is the key atmospheric loss process for these compounds. The laboratory data will be used as input for atmospheric models to better define the impact of these trace gases on stratospheric ozone and climate change.

The long-lived atmospheric species nitrous oxide (N_2O) and carbon tetrachloride (CCl_4) are ozone-depleting substances and potent radiative forcing agents. The abundance and atmospheric lifetimes of N_2O and CCl_4 are, therefore, important to understanding stratospheric ozone recovery and climate change as well as the linkage between these issues. This study measured properties of N_2O and CCl_4 that are key to determining the lifetime of these gases in the atmosphere. Absorption cross sections were measured at five atomic UV lines (ranging from 184.95 nm to 228.8 nm) at temperatures in the range of 210–350 K. In addition, UV absorption spectra of CCl_4 are reported between 200–235 nm as a function of temperature (225–350 K). The results from this work are critically compared with results from earlier studies. For N_2O, the results are in good agreement with the current recommended values, enabling a reduction in the estimated uncertainty in the N_2O atmospheric photolysis rate. For CCl_4, the cross section results are systematically greater than the current recommendation at the reduced temperatures most relevant to stratospheric photolysis. The new cross sections result in a 5–7 percent increase in the modeled CCl_4 photolysis loss, and a slight decrease in the stratospheric lifetime, from 51 to 50 years, for present-day conditions. The corresponding changes in modeled inorganic chlorine and ozone in the stratosphere are quite small. The data from this study will be used as input for atmospheric models to better define the impact of these trace gases on stratospheric ozone and climate change.

Product: Rontu Carlon, N, DK Papanastasiou, EL Fleming, CH Jackman, PA Newman, and JB Burkholder (2010), UV absorption cross sections of nitrous oxide (N_2O) and carbon tetrachloride (CCl_4) between 210 and 350K and the atmospheric implications, *Atmos. Chem. Phys., 10,* 6137–6149, doi:10.5194/acp-10-6137-2010, 2010.

Milestone 3. Develop and use a new laboratory apparatus to measure the Henry's Law solubility of key atmospheric trace species in aqueous solutions; and measure hydrolysis rate constants and product yields for reactive species. Impact: This research will evaluate the partitioning of trace species between the gas- and aqueous-phase and the possible significance of aqueous chemistry as an atmospheric loss process. This research has implications for both stratospheric ozone and climate-chemistry coupling.

A new experimental methodology for the determination of Henry's law constant and hydrolysis rate coefficient of compounds of atmospheric interest has been developed and tested thoroughly. The experimental setup is a closed-cycle recirculation temperature–controlled bubble apparatus connected in series with a Fourier transform infrared (FTIR) spectrometer to measure the fractional concentration change of a species in the gas-phase.

Henry's law solubility constants of many climate-sensitive atmospheric trace species with low solubility in water, such as HFC 227ea, NF_3, SF_6, CH_4 and HFC 134a, were determined as a function of temperature, in pure water and in buffered solutions of different pH. Hydrolysis rate coefficients were determined for perfluoro-2-methyl-3-pentatnone (PFMP), a new fire suppressant with atmospheric lifetime of approximately 15 days (degraded via UV pho-

tolysis) and global warming potential (GWP) of approximately 1. Hydrolysis is slow and produces HFC-227ea as the only gas phase product, a long-lived and potent greenhouse gas. Another co-product was C_2F_5COOH, which was highly soluble and did not show up in the gas phase. HFC-227ea has an atmospheric lifetime of 38.9 years and a GWP of 3580 (on a 100-year time horizon). Preliminary estimates indicate that although both the Henry's law constant and the hydrolysis rate are small, loss via hydrolysis in clouds and oceanic uptake can increase the effective climate forcing of PFMP significantly. Detailed measurements are in progress with other molecules of atmospheric interest. This project is scheduled to be completed and a paper to be submitted during the next year of this milestone.

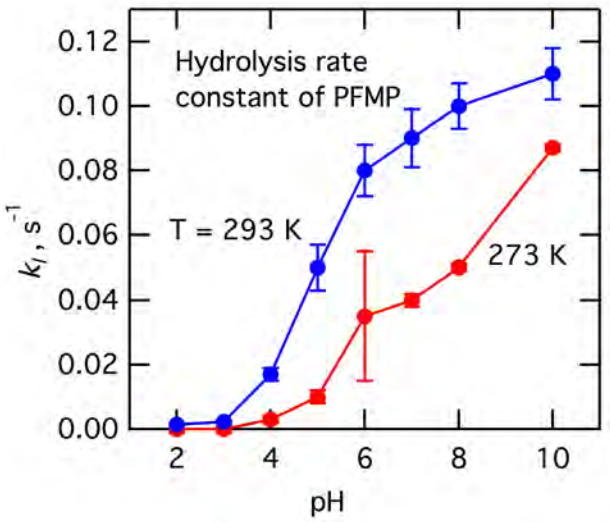


Figure 1: Hydrolysis rate coefficient (in units of per second) at two temperatures, 273 and 293 K in the buffer solutions of varying pH (acidity) relevant to tropospheric conditions.

PSD-01 Modeling of Seasonal to Interannual Variability

FEDERAL LEADS: RANDALL DOLE AND MARTIN HOERLING
CIRES LEAD: PRASHANT SARDESHMUKH

NOAA Goal 2: Climate

Project Goal: Understand how much predictability, especially outside the tropics, exists on seasonal to inter-annual 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. Determine the sensitivity of North American drought to tropical sea surface temperature (SST) changes at different locations, and identify the optimal anomalous tropical SST pattern for maximizing drought.

In a recently published study (Shin, Sardeshmukh, and Webb, *Journal of Climate,* 2010), the optimal anomalous sea surface temperature (SST) pattern for forcing North American drought was identified through atmospheric general circulation model integrations in which the response of the Palmer drought severity index (PDSI) was determined for each of 43 prescribed localized SST anomaly "patches" in a regular array over the tropical oceans. The robustness and relevance of the optimal pattern were established through the consistency of results obtained using two different models, and also by the good correspondence of the projection time series of historical tropical SST anomaly fields on the optimal pattern with the time series of the simulated PDSI in separate model integrations with prescribed time-varying observed global SST fields for 1920–2005. It was stressed that this optimal drought-forcing pattern differs markedly in the Pacific Ocean from the dominant SST pattern associated with El Niño–Southern Oscillation (ENSO), and also shows a large sensitivity of North American drought to Indian and Atlantic Ocean SSTs.

Product: Shin, SI, PD Sardeshmukh, and RS Webb (2010), Optimal sea surface temperature forcing of North American drought, *J. Clim.*, 23, 3907-3916, DOI: 10.1175/2010JCLI3360.1.

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

FEDERAL LEADS: JEFFREY WHITAKER AND RANDALL DOLE
CIRES LEAD: PRASHANT SARDESHMUKH

NOAA Goal 2: Climate

Project 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. Compare the week two and week three atmospheric circulation forecast skill of state-of-the-art global atmosphere-ocean coupled models with that of simple Linear Inverse Models (LIMs) based on lag-correlations of the northern hemispheric circulation and tropical convection fields. Assess the prospects for further skill improvement by performing a predictability analysis based on the relative magnitudes of the forecast signal and forecast noise.

Extending atmospheric prediction skill beyond the predictability limit of about 10 days for daily weather rests on the hope that some time-averaged aspects of anomalous circulations remain predictable at longer forecast lead times, both due to the existence of natural low-frequency modes of atmospheric variability and coupling to a medium with larger thermal inertia. In a recent study (Pegion and Sardeshmukh, 2011), the week two and week three forecast skill of two global coupled atmosphere-ocean models recently developed at NASA and NOAA was compared with that of much simpler Linear Inverse Models (LIMs) derived from observed time-lag correlations of atmospheric circulation anomalies in the northern hemisphere and outgoing long-wave radiation (OLR) anomalies in the tropics. The coupled models were found to beat the LIMs only slightly, and only if an ensemble prediction methodology was employed. To assess the potential for further skill improvement, a predictability analysis based on the relative magnitudes of forecast signal and forecast noise in the LIM framework was conducted. Estimating potential skill by such a method was argued to be superior to using the ensemble-mean and ensemble-spread information in the coupled-model ensemble prediction system. The LIM-based predictability analysis yielded relatively conservative estimates of the potential skill, and suggested that outside the tropics, the average coupled-model skill may already be close to the potential

skill, although there may still be room for improvement in the tropical forecast skill.

Product: Pegion, K, and PD Sardeshmukh (2011), Prospects for improving subseasonal predictions, *Mon. Wea. Rev.*, in press, doi: 10.1175/MWR-D-11-00004.1.

GMD-04 Climate Forcing

FEDERAL LEAD: JOHN OGREN
CIRES LEAD: ANNE JEFFERSON

NOAA Goal 2: Climate

Project 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. Use data from 12 high-altitude observatories to develop a climatology of free tropospheric aerosol radiative properties.

A climatology of aerosol radiative properties at 12 high-altitude observatories around the globe has been developed. The analysis shows that for the free troposphere measurements included here, aerosol loading increases from west to east (where west begins at the Mauna Loa site in Hawaii and east ends at the Mount Lulin site in Taiwan). Seasonal cycles in the aerosol properties suggested long-range transport (e.g., biomass burning and dust) has a strong influence on the variability of the aerosol at high altitude. The in-situ data are consistent with some recent remote sensing measurements such as CALIPSO (Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations) and some ground-based lidars. Systematic variability of aerosol properties with one another may be useful for identifying aerosol types at these sites.

Milestone 2. Establish one new tall tower site in the NOAA/ESRL Carbon America tall tower network to help reduce the uncertainty of carbon uptake by the North American continent and to better characterize regional terrestrial carbon flux estimates.

Milestone was completed and reported on in FY10 Annual Report.

Milestone 3. Complete development of a field-operational temperature/humidity/GPS system to augment current trace gas vertical profile measurements in the NOAA/ESRL Carbon America aircraft network (a prototype system exists and is in use currently at five network sites; the system allows for automated measurements of the ambient temperature and humidity and the position and altitude associated with each sample in a vertical profile).

Milestone was completed and reported on in FY10 Annual Report.

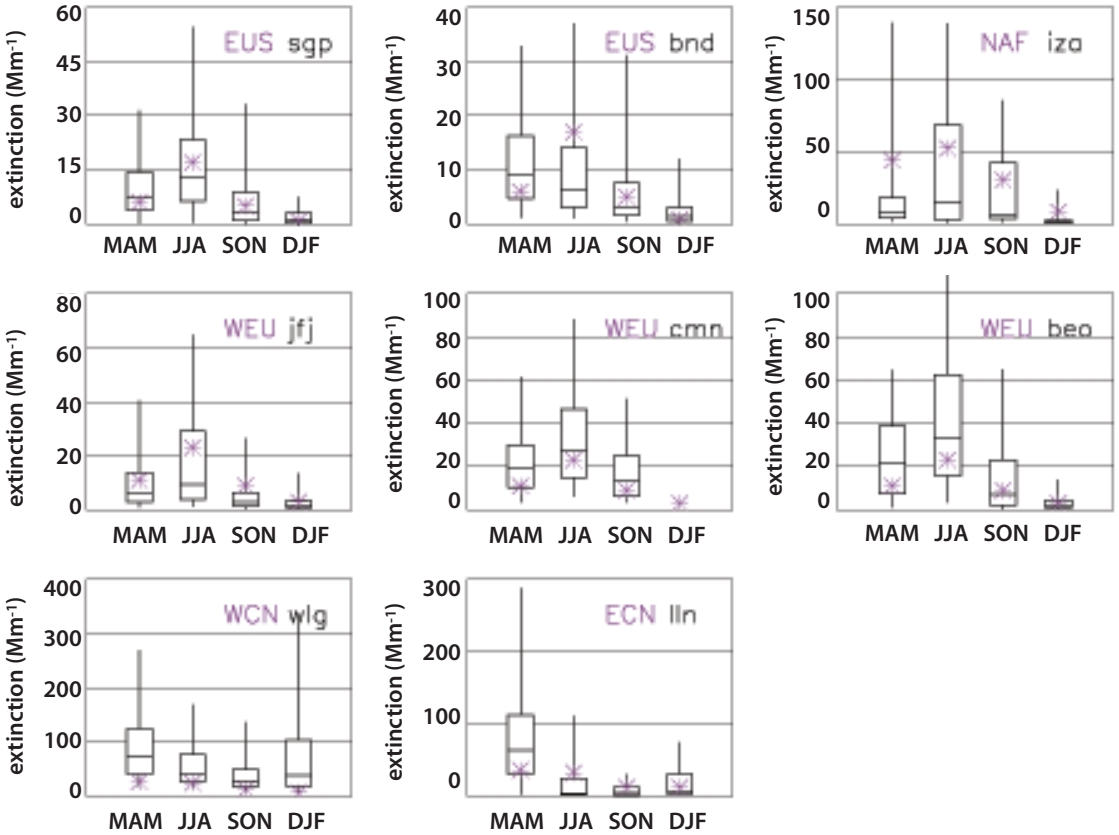


Figure 1: *Comparison of average seasonal CALIPSO ambient extinction values at 3 km (purple) 532 nm with seasonal in-situ extinction (at 550 nm, low relative humidity and standard condition for temperature and pressure). The BEO (Basic Environmental Observatory) plot shows scattering. CALIPSO values come from Yu, et al. (2010). EUS is eastern United States profile; NAF is northern Africa profile; WEU is western Europe profile; WCN is western China profile; and ECN is eastern China profile.*

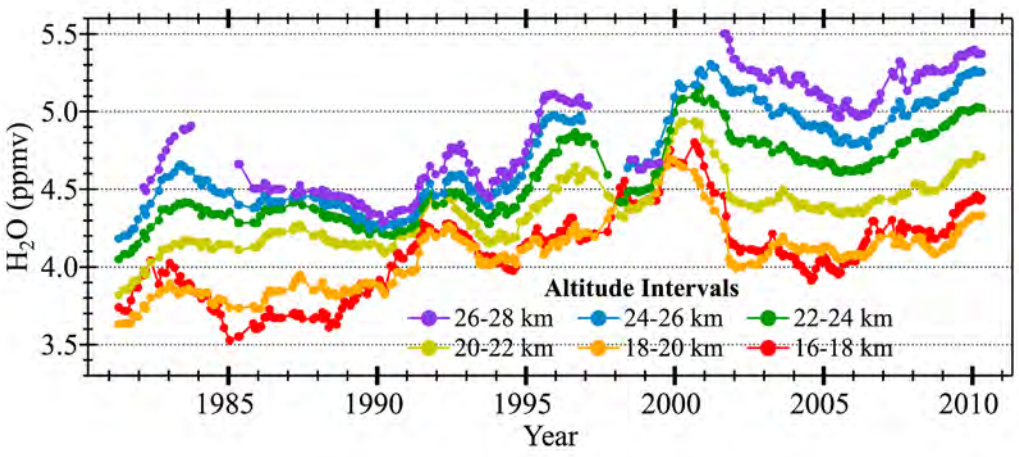


Figure 2: *Smoothed representation of the 30-year 'Boulder Record' of stratospheric water vapor mixing ratios. A net increase of 1.0±0.2 ppmv (27±6%) was determined for 1980–2010 [Hurst, et al., 2011].*

Milestone 4. Analyze balloon-borne measurements of water vapor in the UTLS to reveal multiple-year trends and attempt to attribute them to geophysical processes.

A statistical analysis of the 30-year record of stratospheric water vapor mixing ratios over Boulder, Colo., was performed to quantify multiple-year trends [Hurst, et al., 2011]. The record was compiled from more than 300 balloon flights carrying the NOAA frost point hygrometer. The long measurement record was divided into four distinct time periods (roughly 1980–1989, 1990–2000, 2001–2005 and 2006–2010) and analyzed for trends in 2-km altitude layers. Overall, stratospheric water vapor increased by 1±0.2 ppmv (27±6%) from 1980 to 2010. Net increases were found for all but the 2001–2005 period, when water vapor mixing ratios dropped precipitously due to a decline in tropical tropopause temperatures driven by increased tropical upwelling. Increased methane oxidation in the stratosphere during 1980–2010 can explain only 30 percent of the net water vapor increase. Attempts to find a long-term warming trend in tropical tropopause temperatures that would cause an increase in stratospheric water vapor have been unsuccessful. It has been suggested that a gradual widening of the tropics and/or increase in the strength of the Brewer-Dobson circulation during Northern Hemisphere summer would bring additional moisture from the troposphere into the stratosphere. Recent water vapor soundings over Boulder indicate that stratospheric water vapor mixing ratios had nearly recovered to pre-2001 values by the end of 2010 and continued to increase during the first half of 2011. Work continues to determine the causal mechanisms for these significant variations in midlatitude stratospheric water vapor abundance.

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

FEDERAL LEAD: KAREN ROSENLOF
CIRES LEAD: CHRISTINE ENNIS

NOAA Goal 2: Climate

Project 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. Use ozone data from flights of the National Center for Atmospheric Research HIAPER Gulfstream-V aircraft and the Global Hawk unmanned aircraft system to examine transport and photochemical processes in the upper troposphere and lower stratosphere. Impact: The data and intercomparisons with high-resolution models will offer new insights into how ozone can be used to constrain transport and photochemical processes in global models.

In situ measurements of ozone in the upper troposphere and lower stratosphere (UTLS) have been made in the past several years from the NCAR/NSF HIAPER G-V (High-performance Instrumented Airborne Platform for Environmental Research Gulfstream V) and the NASA Global Hawk UAS (Unmanned Aircraft System) in the Pacific Ocean and Arctic regions, spanning a latitude range from 85° N to 67° S. These measurements provide an excellent data set for comparison with satellite measurements and high-resolution models. To date, the data from one of the HIAPER Pole-to-Pole Observations (HIPPO) missions have been compared with output of the Real-time Air Quality Modeling System (RAQMS). RAQMS simulates ozone based on model physics and chemistry, Global Forecast System meteorology and constraints from assimilated Ozone Monitoring Instrument cloud-cleared total column ozone and Microwave Limb Sounder stratospheric ozone profiles from the NASA Aura satellite. Initial comparisons between the satellite-constrained RAQMS forecasts (2° x 2° grid) and in situ ozone measurements indicate that 1) the model does not fully reproduce the variability observed throughout the extratropical UTLS region and 2) the model exhibits a low bias in the high-latitude lower stratosphere. The model-measurement differences exceeded 40 percent for nearly one-third of the extratropical UTLS data. Some of these discrepancies are likely related to the systematic profiling of the G-V aircraft near the tropopause in the extratropics where the vertical ozone gradients are large and significant variations occur at scales not resolved by RAQMS.

Milestone 2. Using diagnosed proxies for tropical in-mixing based on meteorological analyses and satellite measured chemical species, examine changes in the width and isolation of the tropical pipe on seasonal, interannual and decadal time scales. Impact: Changes in the characteristics of mixing between the tropics and mid-latitudes in the lowermost stratosphere can affect residence time and possibly species distribution throughout the stratosphere.

Globally, air cycles into the stratosphere from the troposphere in the tropics, and out of the stratosphere at higher latitudes. The amount of time air spends in the stratosphere affects the distribution of trace gases that affect the ozone layer and play a role in climate change. An important quantity in this regard is the so-called mean age of stratospheric air. This quantity is determined in part by how fast air rises in the tropics, and how vigorously air mixes between the tropics and higher latitudes. The goals of this project are to evaluate long-term changes in mixing between the tropics and extra tropics, and study the implications of these changes for stratospheric age of air. To accomplish this, we calculated effective diffusivity using

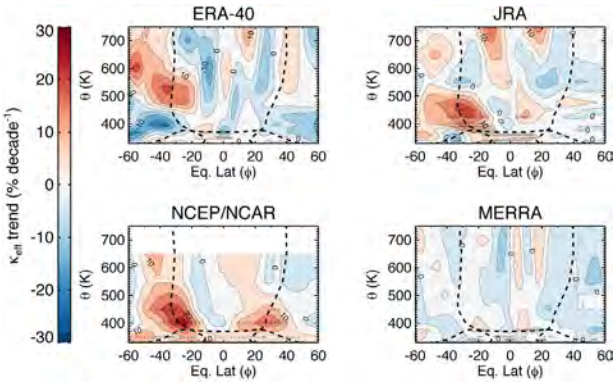


Figure 1: This figure shows decadal trends (% decade-1) in effective diffusivity from four reanalyses: the European Centre for Medium-Range Weather Forecasts reanalysis (ERA-40, upper left), the Japanese reanalysis (JRA, upper right), the National Centers for Environmental Prediction/National Center for Atmospheric Research reanalysis (NCEP/NCAR, bottom left), and the NASA Modern Era Retrospective-Analysis for Research and Applications reanalysis (MERRA, bottom right). Crosses show areas where the trends are statistically significant, vertical dashed lines show the latitudinal edge of the tropical upwelling region, and the horizontal dashed line shows the tropopause. Most reanalyses show an increase in effective diffusivity (i.e., increase in mixing) along the SH tropical edge, as indicated by the broad regions of red, although there are notable differences in the precise location and magnitude of the increase.

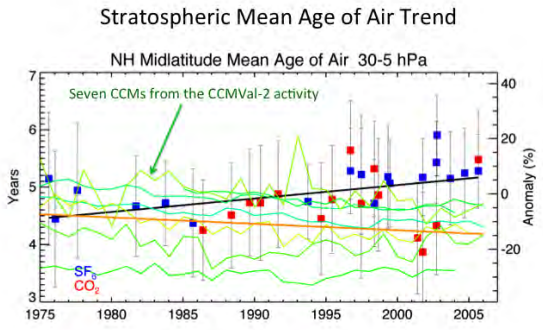


Figure 2: Decreasing mean ages caused by an increasing strength of the stratospheric circulation are consistent robust results in nearly all CCMs (green lines). Observed indicators of NH midlatitude mean age (blue and red squares) show the opposite trend over the past several decades.

wind fields from multiple reanalyses. This data was fit to a regression model to remove year-to-year variability and evaluate long-term trends. We found that the reanalyses exhibit a long-term trend toward greater mixing between the tropics and extratropics in the lower stratosphere. These trends were combined with trace gas observations in a simple model to investigate long-term changes in the stratospheric age-of-air. It was found that the long-term changes in stratospheric mixing have a potentially strong impact on age-of-air. These results may help explain why global climate models, which predict age-of-air decreases, and observations, which don't show age-of-air decreases, appear to be at odds regarding their long-term trends.

Product: Davis, SM, EA Ray, and KH Rosenlof (2011),Variability and trends in effective diffusivity in the stratosphere, and their implications for stratospheric circulation changes, AMS Spring Meeting, Seattle, WA.

Ray, EA, et al. (2010), Evidence for changes in stratospheric transport and mixing over the past three decades based on multiple data sets and tropical leaky pipe analysis, *J. Geophys. Res., 115,* D21304, doi:10.1029/2010JD014206.

Milestone 3. Examine stratospheric mean meridional circulation and mixing changes during recent decades with observations, reanalysis data, chemistry-climate model output and a simple stratospheric model. Impact: Understanding how the stratospheric circulation has recently changed will likely help us better understand how changes in the troposphere affect the stratosphere.

Changes in the mean meridional circulation and mixing in the stratosphere are important to understand since these changes are a direct result of changes in the tropospheric circulation and weather patterns. Since we don't have measurements of the stratospheric circulation or mixing, we used a combination of mean age of air estimates from in situ balloon observations, satellite ozone observations, mixing trends from reanalysis data and a simple model of the stratosphere to compare to a suite of chemistry-climate model simulations. We found that the simple stratospheric model could reproduce the observed mean age and ozone changes over the past several decades with a small strengthening of the mean circulation in the lower stratosphere, a moderate weakening of the mean circulation in the middle and upper stratosphere and a moderate increase in the horizontal mixing into the tropics. This circulation change profile does not compare well to that produced by chemistry-climate models, which tend to have a large strengthening of the circulation in the lower stratosphere and weak strengthening in the lower stratosphere. Mixing changes were not able to be determined from the chemistry-climate model simulations since the full resolution output was not saved in the archive. The differences between circulation changes inferred from observations and chemistry-climate model results are substantial. One of the main implications of our work is that mixing between the midlatitude and tropical stratosphere plays an important role in understanding the changes seen in observations of trace gases in the stratosphere.

Product: Ray, EA, et al. (2010), Evidence for changes in stratospheric transport and mixing over the past three decades based on multiple data sets and tropical leaky pipe analysis, *J. Geophys. Res., 115,* D21304, doi:10.1029/2010JD014206.

GMD-05 Ozone Depletion

FEDERAL LEADS: JAMES ELKINS, STEPHEN MONTZKA AND SAM OLTMANS
CIRES LEAD: FRED MOORE

NOAA Goal 2: Climate

Project Goal: Understanding the production and fate of ozone and the compounds that deplete it is a focal point of collaborative CIRES research with ESRL's Global Monitoring and Chemical Sciences divisions. *Stratospheric Ozone Measurements:* Measure ozone declines during the past two decades at northern hemispheric midlatitudes 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 characterize, understand and predict the atmospheric behavior of gases that cause ozone depletion. *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. From flask and in situ measurements of ozone-depleting substances around the globe, update the Ozone Depleting Gas Index for 2009 and 2010.

Measurements of long-lived substances that cause stratospheric ozone depletion were continued at remote sites during July 2010 through June 2011. A statistical technique was developed to combine measurements from flask and in situ programs spanning four decades for several gases (Figure 1).

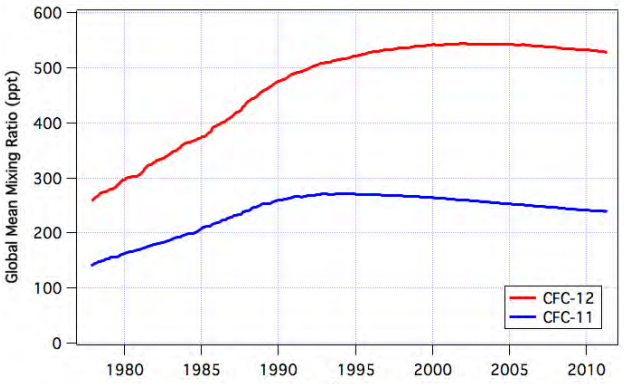


Figure 1: *Global mean mixing ratios of CFC-11 and CFC-12 from 1978 to 2011.*

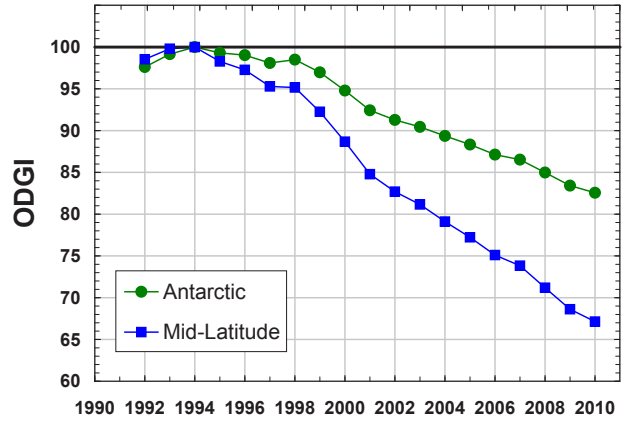


Figure 2: *NOAA annual "Ozone Depleting Gas Index" for Antarctic and mid-latitude regions from 1992 to 2010.*

These measurement data are used to update the Ozone-Depleting Gas Index (Figure 2). The index represents tropospheric trace-gas abundances weighted by different factors relevant for different regions of the stratosphere. Actual changes in the stratospheric abundance of ozone-depleting halogen will be less than the declines shown in this figure, owing to transport-related time lags. The index shows a continued overall decline in the tropospheric abundance of ozone-depleting substances.

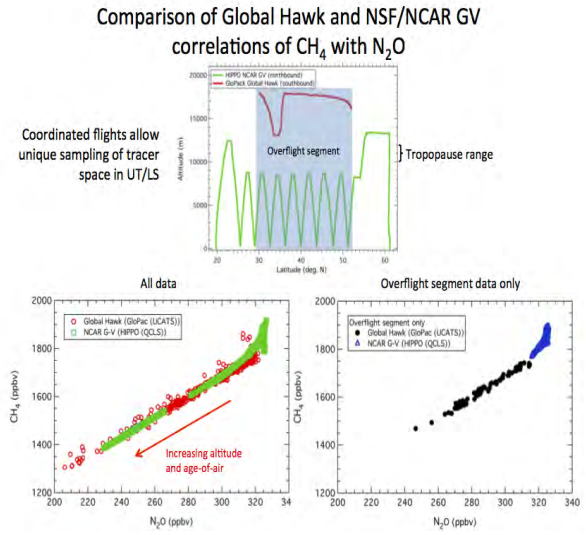
Trace-gas measurement data collected in this program were also used to draw conclusions about the interannual variability of certain loss processes. Results for methyl chloroform, in particular, suggest only small changes in global mean atmospheric hydroxyl radical (OH) concentrations (Montzka et al., 2011), in contrast to results from some earlier observational studies. Data for a number of other gases also suggest small interannual variability in global mean OH concentrations. Given the central role the atmospheric hydroxyl radical plays in global atmospheric chemistry, these results suggest that the atmosphere's ability to cleanse itself of many pollutants is fairly robust.

Product: http://www.esrl.noaa.gov/gmd/hats/combined/CFC11.html

http://www.esrl.noaa.gov/gmd/hats/combined/CFC12.html

Milestone 2. Report on the vertical profiles of ozone-depleting substances from the first three campaigns of the HIAPER Pole-to-Pole Observations of Greenhouse Gases mission (HIPPO) in 2010. Submit data to the HIPPO archive and report on the results at a scientific meeting.

HIAPER (High-performance Instrumented Airborne Platform for Environmental Research) Pole-to-Pole Observations—also known as HIPPO—involves the study of carbon dioxide and other greenhouse gases, aerosols and black carbon (soot) in the troposphere using the National Science Foundation (NSF)/National Center for Atmospheric Research (NCAR) Gulfstream V (GV) research aircraft. The flight path starts in Broomfield, Colo.; travels as far to the North Pole as possible from Anchorage, Alaska; and proceeds south across the Pacific to as far south as the South Pole from Christchurch, New Zealand, and back to Colorado. There will be five complete circuits during four seasons. As of June 2011, HIPPO/1, HIPPO/2, HIPPO/3 and HIPPO/4 have been completed. More than 120 profiles were taken of the whole troposphere



from above ground to the tropopause from pole-to-pole during each circuit. Final data are being submitted for the three circuits—HIPPO/2 through HIPPO/4. During HIPPO/3, the NCAR GV aircraft flew below the Global Hawk Unmanned Aircraft Systems during its Global Hawk Pacific (GloPac) experiment at about 40° N. A tracer-tracer plot of methane (CH_4) versus nitrous oxide (N_2O) shows the agreement of different instruments and altitudes for the two airborne platforms. An overview of the HIPPO/1 and some HIPPO/2 results was reported by Wofsy et al., 2011. A summary of the first three HIPPO circuit results was presented during the Global Monitoring Annual Conference in May 2011 in Boulder, Colo.

Milestone 3. Analyze ground-based and balloon ozone measurements for long-term trends in the upper troposphere and stratosphere.

The work on the 2010 World Meteorological Organization (WMO) Ozone Assessment included assessment of ozone trends derived from the ground-based Dobson data. With the addition of four more years in the ozone record, evaluation of the current state of the ozone layer continues to be of interest to the scientific community. The Ozone Assessment supported the conclusion that the long-term ozone decline over the midlatitudes had stopped and that ozone had stabilized since 1996. When extended to 2009, the ground-based and satellite data at northern middle latitudes show statistically significant increases in the middle stratospheric ozone (20–25 km) since 1996 in some locations, but not globally. At the same time, trends in the upper stratospheric ozone (35–45 km) over northern middle latitudes show approximately 2 percent increases, but uncertainties are large, and thus the attribution to ozone depleting substance (ODS) changes is not certain. The time series of well-established and calibrated ground-based Dobson Umkehr instruments (Boulder, United States; OHP [Observatoire de Haute-Provence], France; Arosa, Switzerland; and Belsk, Poland) were used to identify long-term changes in stratospheric ozone over Northern Middle latitudes since 1979. Collaborative work with Japanese scientists was conducted to assess Antarctic stratospheric ozone long-term variability and trends. The analysis of stratospheric ozone data recorded by Dobson Umkehr measurements since 1977 at the Syowa (69.0° S, 39.6° E), Antarctica, station show a significant decrease in ozone above 4 hPa during the 1980s and 1990s. Over the last decade the atmospheric chlorine levels begin to decline, while ozone is expected to recover. However, ozone values over Syowa remain low since 2001.

Product: Douglass, A, V Fioletov, S Godin-Beekmann, R Müller, RS Stolarski, A Webb, A Arola, JB Burkholder, P Burrows, MP Chipperfiel, R Cordero, C David, PN den Outer, SB Diaz, LE Flynn, M Hegglin, JR Herman, P Huck, S Janjaim, IM Jánosi, JW Krzyścin, Y Liu, J Logan, K Matthes, RL McKenzie, NJ Muthama, I Petropavlovskikh, M Pitts, S Ramachandran, M Rex, RJ Salawitch, BM Sinnhuber, J Staehelin, S Strahan, K Tourpali, J Valverde-Canossa, C Vigouroux (2010), Stratospheric ozone and surface ultraviolet radiation, *Scientific Assessment of Ozone Depletion: 2010*, World Meteorological Organization, 2011.

CSV-04 Climate Dynamics

PSD-06 Climate Dynamics

FEDERAL LEAD: CHRIS FAIRALL
CIRES LEAD: LESLIE HARTTEN

NOAA Goal 2: Climate

Project 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).

Milestone 1. Explore relationship between sea breezes along the West Coast of Mexico during the North American Monsoon (NAM) and precipitation along the western Sierra Madres Occidental. Submit publication on results.

Little progress was made on this milestone during the July 2010-June 2011 time period, due to pressing needs on other projects.

Milestone 2. Submit papers documenting the daily cycle of winds during the NAM and their longitudinal and year-to-year variability.

These manuscripts are in preparation; submission is planned during the July 2011-June 2012 time period.

PSD-03 Empirical and Process Studies

FEDERAL LEADS: KLAUS WEICKMANN AND RANDALL DOLE
CIRES LEAD: PRASHANT SARDESHMUKH

NOAA Goal 2: Climate

Project 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. Conduct a local and non-local feedback analysis of tropical sea surface temperature (SST) variations in observations and the IPCC climate models through Linear Inverse Modeling.

An important emerging issue in climate research is the degree to which a SST change in one tropical ocean basin affects the SST in other basins. In a recently published study (Shin, Sardeshmukh, and Pegion, 2010), the SST interactions among eight broadly defined regions of coherent SST variability in the tropical Pacific, Indian and Atlantic oceans were estimated using three observational and 76 climate model simulation data sets of the 20th century. The eight-dimensional SST feedback matrix was estimated separately using each data set by constructing a Linear Inverse Model based on the lag-covariance statistics of the 100-year monthly SST time series. The simulated feedback matrices were found to differ in several key respects from the observed matrices and also from one another. In particular, the influence of the eastern Pacific El Niño-Southern Oscillation (ENSO) region on other regions and of the other regions on the ENSO region was found to vary considerably from model to model. The representation of remote interactions with the Indo-Pacific Warm Pool region was also found to be highly variable. It was argued that these large errors/differences arise mainly from differences in the representation of the remote atmospheric teleconnective feedbacks, and to a lesser extent the local radiative-thermodynamic

feedbacks, on the SSTs in the models, whereas differences in the representation of the tropical oceanic wave dynamics are likely less important.

Product: Shin, SI, PD Sardeshmukh, and K Pegion (2010), Realism of local and remote feedbacks on tropical sea surface temperatures in climate models, *J. Geophys. Res., 115*, D21110, doi:10.1029/2010JD013927.

PSD-15 Surface Processes

FEDERAL LEAD: CHRIS FAIRALL
CIRES LEAD: OLA PERRSON

NOAA Goal 2: Climate

Project Goal: Combine state-of-the-art observations of surface fluxes, boundary-layer structure and mesoscale features with high-resolution numerical modeling. Current work focuses on boundary layers over ice/snow surfaces and the effects of terrain on coastal precipitation. High quality observations of surface turbulent, radiative and precipitation fluxes are combined with radar measurements and mesoscale model simulations. Parameterizations are being developed for stable surface-layer flux-profile relationships and linking terrain slopes and wind-vector profiles to spatial patterns of precipitation accumulations.

Milestone 1. Analyze data from Surface Heat Budget of the Arctic (SHEBA); Arctic Summer Cloud Ocean Study (ASCOS); Arctic Mechanisms of Interaction between Surface and Atmosphere (AMISA); and other field programs to understand the links between the clouds, atmospheric boundary layer, and surface processes over sea ice. Evaluate their respective contributions to the net surface energy fluxes

Analyses of the soundings, surface energy budget and surface temperatures at SHEBA and ASCOS and analyses of soundings and surface temperatures from Soviet drifting stations have provided insights into the processes producing the onset and end of melt over sea ice. A paper submitted for publication on describing the SHEBA melt transitions links the surface energy budget to free-troposphere synoptic variables, clouds, precipitation and in-ice temperatures.

The key results are 1) SHEBA melt-season transitions are associated with atmospheric synoptic events; 2) onset of melt clearly occurs on May 28, while the end of melt is produced by a sequence of three atmospheric storm events over a 28-day period producing step-like reductions in the net surface energy flux—the last one occurs on Aug. 22; 3) Melt onset is primarily due to large increases in the downwelling longwave radiation and modest decreases in the surface albedo; 4) decreases in the downwelling longwave radiation occur for all end-of-melt transition steps, while increases in surface albedo occur for the first two; 5) changes in downwelling shortwave radiation contributes only to the first end-of-melt transition step; 6) springtime free-tropospheric warming preconditions the atmosphere-ice system for the subsequent melt onset; and 7) melt-season transitions also mark transitions in system responses to radiative energy flux changes because of invariant melt-season surface temperatures. (See Figure 1.)

The last result is the reason that the length of the summer melt season has a large impact on the mass balance of the sea ice. Significant energy flux excess, and hence ice loss, can only occur when the surface temperature is fixed and unable to radiatively compensate for large positive energy fluxes. The extensive SHEBA observations enable an understanding

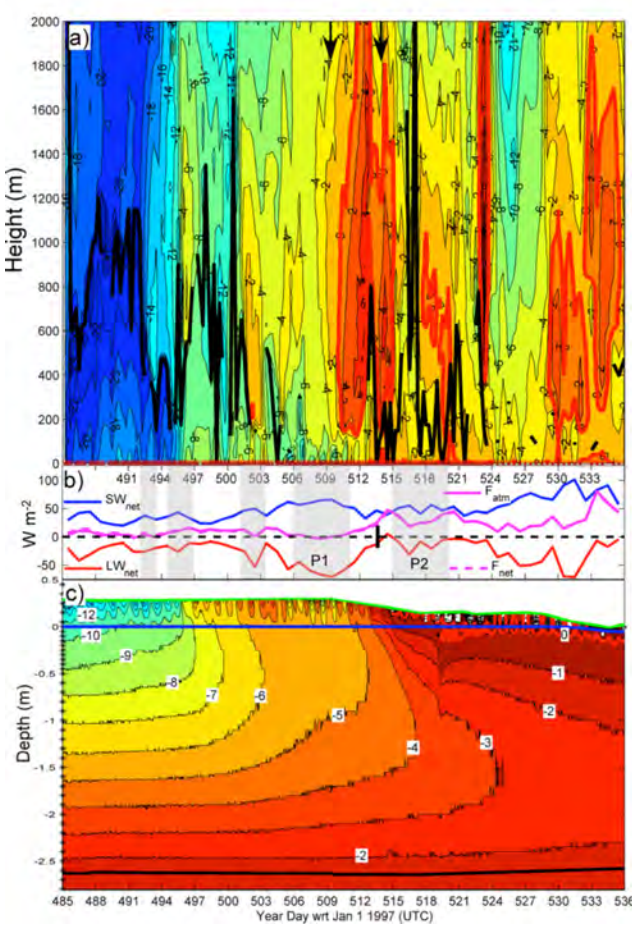


Figure 1: *Temperature in the a) atmosphere and c) snow and ice from April 30 (YD485) to June 20 (YD536), 1998 at SHEBA. Panel b) shows the daily mean net energy fluxes and the time of melt onset (vertical black bar). In a) and c), the 0°C isotherm is shown in bold red and the height of the maximum RHw for RHw > 95% is shown in bold black in a). In b), the times of springtime synoptic events discussed are shaded but unlabeled, while P1 and P2 are discussed in Table 3. In c), the snow surface is shown by the green line, the snow-ice interface by the blue line, and the ice bottom by the thick black line. Temperatures near the top of the snow may be biased by solar radiation*

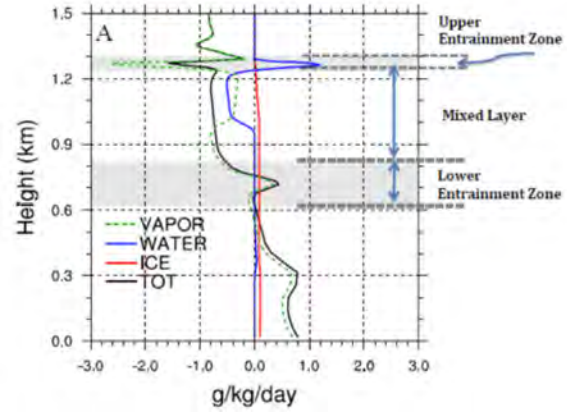


Figure 2: *Cloud water, vapor, ice and total water tendencies, in units of g kg-1 day-1. Gray dash lines denote boundaries of cloud top entrainment zone, mixed layer, lower entrainment zone. Positive (negative) indicates water gained (lost) by the layer.*

of the complex processes not available from other field program data. The analysis provides a basis for future testing of the generality of the results, and contributes to better physical understanding of multi-year analyses of melt-season trends from less extensive data sets. A paper describing the generality of the SHEBA results using the ASCOS observations and the Soviet data is in preparation.

Milestone 2. Using a Weather Research and Forecasting (WRF) or 1-D model, simulate select cases from SHEBA, ASCOS, AMISA and other field programs to a) evaluate the model representation of the observed physical processes and b) suggest improvements to related parameterizations when possible. Improvements to the parameterization of turbulent fluxes and surface albedo will be tried.

Simulations of a springtime Arctic stratocumulus cloud over sea ice near Barrow during the 2008 Indirect and Semi-Direct Aerosol Campaign (ISDAC) campaign were done using a large-eddy simulation configuration of the WRF model. Diagnostics of the dynamic and thermodynamic interactions within the cloud and the surrounding environment were carried out to understand the processes by which these types of clouds are able to maintain themselves. Features found to be key for this maintenance include a shallow upper entrainment zone acting as a moisture source for the cloud from a humidity inversion above cloud top; mall-scale cloud-top turbulence facilitating this moisture transport; and larger-scale convective cells encompassing the cloud and a sub-cloud region driven by cloud-top cooling. The moisture inversion coinciding with the temperature inversion at cloud top appears to be a feature unique to Arctic stratocumulus compared to subtropical ones. Moisture and energy transport from the surface was found to have minimal impact on the cloud formation and maintenance. A paper describing the results has been submitted. This milestone is also enhanced by contributions to an internationally collaborative paper validating surface energy fluxes in a regional climate model over East Antarctica.

Milestone 3. In collaboration with E. Andreas, use the SURFA global Numerical Weather Prediction (NWP) surface flux archive to examine the Arctic surface energy budget and its sensitivity to surface flux parameterizations

The Surface Flux Analysis (SURFA) data set was not used, and hence the sensitivity of the modeled surface energy budgets to surface flux parameterizations was not studied. However, work validating the surface energy fluxes in four reanalysis data sets over Arctic sea ice was completed, and this work revealed significant sensitivity of the various terms of the surface energy budget to the representation of cloud, surface and turbulent processes. In this study, meteorological parameters, turbulent fluxes, cloud properties, radiative fluxes and the surface energy budget from ERA-40 (the European Centre for Medium-Range Weather Forecasts [ECMWF] 40-Year Re-analysis), ERA-Interim, National Centers for Environmental Predication/Department of Energy (NCEP/DOE) and JRA-25 (Japanese 25-year reanalysis) reanalyses are compared to observations from the Surface Heat Budget of the Arctic Ocean (SHEBA), one of very few year-long measurement programs on the Arctic sea ice measuring surface fluxes and cloud properties. Seven-day running means of reanalysis and observational data were compared to understand how well the reanalyses represent the basic meteorological parameters and the processes producing the energy fluxes to the sea ice. All reanalyses represent basic atmospheric state variables well, with annual mean errors of 3.3-3.6% for ECMWF products and 5.3-5.4% for JRA-25 and NCEP/DOE. However, they have trouble simulating turbulent and radiative fluxes. Individual flux terms have larger biases than net components, indicating the presence of compensating errors (i.e., net fluxes are realistic for the wrong reasons). RMS (root-mean-square) errors of individual fluxes are 5.7-7.1 Wm-2 for the NCEP products, 13.6 Wm-2 for JRA-25 and 21.5 W m-2 for NCEP/DOE. All reanalyses produce negative mean biases for the annual surface energy balance, with three of the reanalyses indicating a net gain of surface sea ice during a year for which observations showed a loss of 76 cm of ice. Hence, improved representations are needed of relationships between basic meteorological parameters, cloud properties and individual components in the surface energy budget. During 2010-2011, these results are described in the University of Colorado master's thesis of Cassandra Wheeler, and a manuscript describing these results is being prepared for publication.

CSV-05 Climate Research Database Development

■ NSIDC-01 Digitization of Analog Cryospheric Data Under the Climate Database Modernization Program

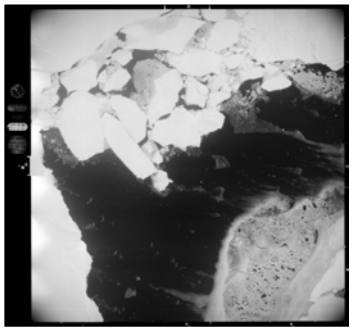
■ NSIDC-03 World Data Center for Glaciology, Boulder—Current Programs

NSIDC-01 Digitization of Analog Cryospheric Data under the Climate Database Modernization Program

FEDERAL LEAD: CARL GROENEVELD
CIRES LEAD: JANE BEITLER

NOAA Goal 2: Climate

Project Goal: Scan and make available online data from NSIDC's analog collections so that it is more easily located, browsed and obtained by users.



Clockwise, from top left: *Bird's-eye aerial ice reconnaissance imagery taken in 1973; Wilkes Station, Antarctica, 1958, as photographed by John T. Hollin during the International Geophysical Year; Muir Glacier, as photographed by Frank LaRoche in 1893. From the Glacier Photograph Collection, National Snow and Ice Data Center.*

Milestone 1. Add additional glacier photograph or other analog material to the collections to the Analog Collection in collaboration with NOAA NGDC and the NOAA CDMP program.

The National Snow and Ice Data Center (NSIDC) has been digitizing analog cryospheric material as part of the NOAA Climate Data Modernization Program (CDMP), which ends this year. CMDP began in 2002 with one project, the Glacier Photo Digitization Project; 13,478 glacier images are now available online. In 2004 a second project began to digitize Dehn Ice Charts. More than 7,000 charts were digitized and more than 4,000 are available online.

More photographs of glaciers were scanned and added this year to the Glacier Photograph Collection (http://nsidc.org/data/g00472.html). Photographs of glaciers in the McMurdo Dry Valleys region of Antarctica have been added as well, not through scanning, but in a collaborative Data Conservancy project with Johns Hopkins University. While the valleys themselves are notably ice-free, a number of glaciers terminate in the valleys, some acting as outlets to the East Antarctic Ice Sheet.

NSIDC-03 World Data Center for Glaciology, Boulder—Current Programs

FEDERAL LEAD: CARL GROENEVELD
CIRES LEAD: JANE BEITLER

NOAA Goal 2: Climate

Project Goal: Improve understanding of recent and unexpected changes in polar regions including lower sea-level atmospheric pressure, increased air temperature over most of the Arctic, lower temperatures over eastern North America, reduced sea ice cover, thawing permafrost and changes in precipitation patterns.

Milestone 1. Maintain and update existing research data sets (e.g., the Sea Ice Index). Publish new data sets and improve data-visualization tools, including Google Earth. Make research information available, acquire and catalog cryospheric materials in the NSIDC library, and maintain NSIDC's analog datasets.

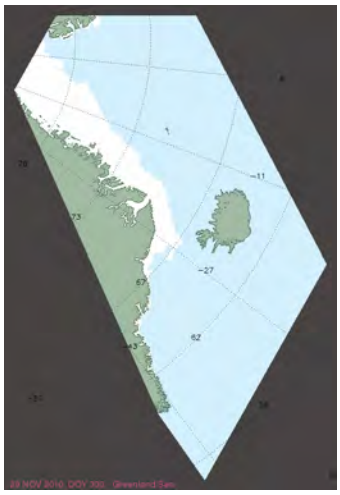


Figure 1. *This image from MASIE of the Greenland Sea on Nov. 29, 2010, shows the location of the sea-ice edge with more precision than other sea-ice products. MASIE images are compiled from sea-ice charts and other data sources, and are available daily in an easy-to-use format.*

NOAA@NSIDC has developed and will maintain a data inventory for the Science Ice Exercise (SCICEX) program—a U.S. Navy Submarine Arctic Science Program that utilizes nuclear submarines to collect scientific data about the Arctic Ocean. NOAA@NSIDC also published a new data set relevant to developing year-round transportation capabilities in the Arctic Ocean: Arctic Marine Transportation Program 1979–1986. The U.S. Maritime Administration sponsored this multi-year program to define environmental conditions in the Bering, Chukchi and Beaufort Seas; to obtain data to improve design criteria for ice-worthy ships and offshore structures; and to demonstrate the operational feasibility of commercial icebreaking ships along possible future Arctic marine routes.

NOAA@NISDC published a new data set inventorying the network of boreholes equipped for long-term permafrost temperature observations. The data set, IPA-IPY Thermal State of Permafrost (TSP) Snapshot Borehole Inventory, Version 1.0, consists of an inventory of boreholes established during the International Polar Year (IPY) 2007–2009 by the International Permafrost Association (IPA) under the Thermal State of Permafrost (TSP) Project #50.

NOAA@NSIDC published a new data set that provides measurements of mass balance, surface velocity and surface elevation of the South Dome of Barnes Ice Cap. The data set, Barnes Ice Cap South Dome Trilateration Net Survey Data 1970–1984, contains survey measurements of a network of 43 stakes along a 10-km flow line on the northeast flank of the south dome of the Barnes Ice Cap.

NSIDC and the U.S. National Ice Center (NIC) collaborated on a new daily sea ice analysis product: The Multisensor Analyzed Sea Ice Extent–Northern Hemisphere (MASIE-NH). Working with NIC, NSIDC developed MASIE-NH to meet a need for a more accurate daily product that is easy to use like the Sea Ice Index. MASIE lets you view and download Northern Hemisphere–wide sea-ice coverage for latest day and the last four weeks; sea ice coverage by region; and a file of sea-ice extent in square kilometers for the entire Northern Hemisphere and by region for the last four weeks, updated daily.

In cooperation with the International Arctic Research Center (IARC) at the University of Alaska, NOAA@NSIDC is providing an access point and standard metadata for the Sea Ice Experiment: Dynamic Nature of the Arctic (SEDNA) project. The SEDNA data collection is unique in that several ice-thickness data sets were inter-calibrated and coordinated with monitoring of the ice pack strain-rate (horizontal deformation) and measurements of internal ice stress.

CSV-07 Climate Services

- PSD-05 Experimental Regional Climate Services
- PSD-07 Experimental Climate Data and Web Services

PSD-05 Experimental Regional Climate Services

FEDERAL LEADS: ROGER PULWARTY AND ROBERT WEBB
CIRES LEADS: JOSEPH BARSUGLI , XIAOWEI QUAN AND KLAUS WOLTER

NOAA Goal 3: Weather and Water

Project Goal: Couple enhanced observations and research in regions of strong climate variability and societal impact with analysis of past data and improved modeling. Determine factors influencing the occurrence of extreme events. Improve the diagnosis, modeling and prediction of the regional consequences of climate change and variability on timescales of days to decades on hydrological variables of relevance to society.

Milestone 1. Examine the transitional probability of drought/pluvial conditions over the United States at different phases of sea surface temperature (SST) evolution in the tropical Pacific Ocean based on observational data and multi-model ensemble simulations.

Two sets of analyses are carried out with focus on the predictability at seasonal timescale. First, the transitional probability of drought/pluvial conditions is examined at various regional scales for observations; AMIP-type (Atmospheric Model Intercomparison Project) ensemble simulations from multiple atmospheric global circulation models (AGCMs) forced with observed evolution of global sea-surface temperature (SST); and the ensemble forecasts/hindcasts from a fully coupled forecast system with realistic initializations. The transitional probability in the dynamic model's simulations/forecasts are compared to the transitional probability seen in the observations. A diagnostic/forecast tool is developed for probabilistic forecast of seasonal drought/pluvial conditions. Our initial test indicates that this tool, built upon a larger number of ensembles of dynamic model output, is capable of producing more stable and realistic probability forecasts than other existing forecasts that have smaller ensemble size.

The second set of the analyses focuses on the predictability of change of an existing meteorological drought condition. A method is developed to combine forecasts with the measures of existing conditions to form a universal drought index, which gives an objective estimate on the severity of future drought and allows for quantitative verification. Further analyses are being pursued in collaboration with scientists at the International Research Institute for Climate and Society (IRI) and the Climate Prediction Center (CPC).

Milestone 2. Evaluation of statistical and dynamical down-scaled climate projections for the Colorado River Basin, including data from North American Regional Climate Change Assessment Program (NARCCAP), particularly as it relates to hydroclimatic processes and variability. Work with stakeholders through Western Water Assessment, WWA, in evaluating needs and approaches for applying regional climate change information to water and land resource management.

Hydrologic-model runs comparing statistical and dynamical downscaling NARCCAP methods were completed. Work with Bureau of Reclamation researchers to complete runs of the reservoir-operations model continues. Additionally, scientific study to clarify some confusing modeling results found in Reclamation's Colorado River Basin Study were designed, and sources of model bias are being isolated.

A project with The Nature Conservancy and University of Washington was initiated to calibrate Variable Infiltration Capacity (VIC) hydrologic model for the purposes of better modeling flows relevant to ecological applications. NARCCAP temperature and precipitation data over the Upper Colorado River Basin and the San Juan Mountains were analyzed (publication has been submitted). The team participated in the Gunnison Basin Climate Vulnerability Group, and climate information to assist a species- and habitat-based vulnerability assessment was provided.

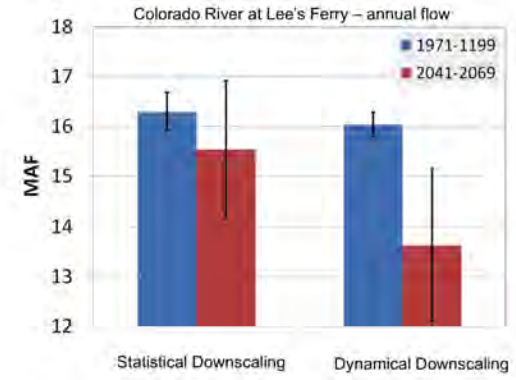


Figure 1

Milestone 3. Continue programmatic development and impact assessments of climate, weather and water services in conjunction with the National Integrated Drought Information Service (NIDIS) and other programs.

The Colorado Water Availability Task Force, as well as the Colorado Water Conservation Board (CWCB), Colorado Basin River Forecast Center (Salt Lake City) and Upper Colorado Assessments (NIDIS Pilot), were briefed on seasonal to two-year expectations regarding runoff prospects in Colorado. This was partially funded through CWCB. Figure 2 illustrates two-year runoff behavior for naturalized annual streamflow during long-lasting La Niña events, as a possible scenario for the current La Niña situation. Water managers in the southeastern U.S. (Apalachicola-Chattahoochee-Flint basin: ACF NIDIS pilot) were briefed on developing drought situation and linkages to La Niña. Work continues on an ongoing project with the Department of Water Resources in California to predict seasonal climate in that state, with a particular focus on the Sacramento and San Joaquin river basins. Additionally, a project with the Bureau of Reclamation to help with its seasonal-prediction efforts was initiated.

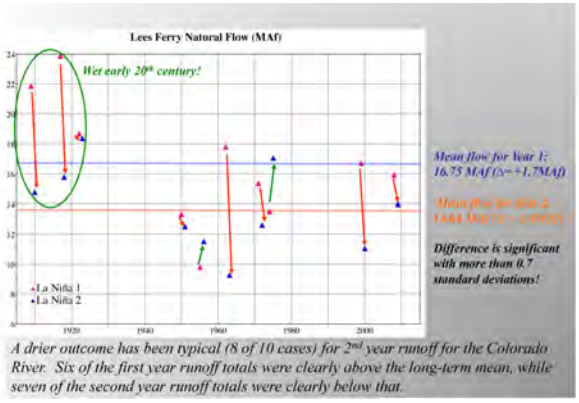


Figure 2

Several climate-monitoring products created by the Physical Sciences Division.

PSD-07 Experimental Climate Data and Web Services

FEDERAL LEADS: NICK WILDE AND RANDALL DOLE
CIRES LEADS: PRASHANT SARDESHMUKH AND CATHERINE SMITH

NOAA Goal 2: Climate

Project 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. Improve PSD's visualization and analysis of climate data to support experimental monitoring and explanation of current and evolving climate conditions, and to advance understanding of the climate system through imaging and animation.

The Physical Sciences Division (PSD) has created a number of products that make it easier to monitor the current climate and the processes that affect the climate. One research topic was looking at the factors affecting hurricane formation and maintenance. Web pages were developed to monitor the 2010 Atlantic hurricane season, presenting current and historic wind shear and sea surface temperature (SST) plots. An analysis of the 2010 Russian Heat Wave was presented on the climate attribution (CSI) page, incorporating an interactive map and plots of climate model simulations.

The PSD maproom website, which is an ongoing collection of climate/weather monitoring plots, has been revamped with a new look and better graphics. Interactive, animated visualizations are displayed continuously in the Climate/Weather Visualization Lab (see photo) for real-time monitoring of climate conditions.

Web applications for plotting maps and time series have been developed for the 20th Century Reanalysis to allow comparison of past and present climate. PSD has also generated Science-on-a-Sphere animations of this data set. Experimental web pages include an updated tropical SST forecast page and a page forecasting outgoing long-wave radiation (OLR) for tropical weather prediction. Significant updates to our climate monitoring data sets this past year include the 20th Century V2 Reanalysis, the NOAA merged SST and the NOAA high-resolution SST and ice data set.

Product: Dole, R, M Hoerling, J Perlwitz, J Eischeid, P Pegion, T Zhang, X Quan, T Xu, and D Murray (2010), Was there a basis for anticipating the 2010 Russian Heat Wave?, *Geophys. Res. Lett., 38,* L06702, doi:10.1029/2010GL046582.

GEODYNAMICS

GEO-07 Geophysical Data Systems

■ NGDC-05 Improved Integration and Modeling of Geomagnetic Data

NGDC-05 Improved Integration and Modeling of Geomagnetic Data

FEDERAL LEAD: SUSAN McLEAN
CIRES LEAD: HEINRICH MAUS

NOAA Goal 4: Transportation.

Project 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.

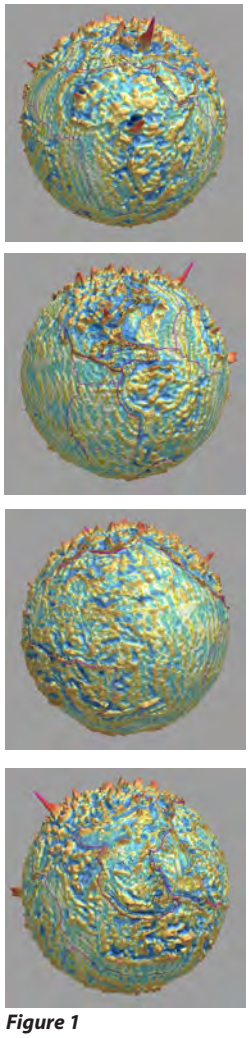


Figure 1

Milestone 1: Satellite-derived crustal magnetic field model: Using the latest measurements from the CHAMP satellite (CHAllenging Minisatellite Payload), develop a global crustal magnetic field model to spherical harmonic degree and order 150 and integrate it into NGDC/CIRES magnetic reference products for navigation and heading.

Satellites in low-Earth orbit (LEO) provide an effective means of mapping the long wavelengths of the magnetic field caused by the magnetization of the Earth's crust. The MF7 model was produced using CHAllenging Microsatellite Payload (CHAMP) measurements from May 2007 to April 2010. It resolves the crustal magnetic field to spherical harmonic degree 133, corresponding to a half-wavelength resolution of 150 km.

Figure 1 shows the vertical component of the crustal magnetic field at an altitude of 100 km above the Earth's surface. Magnetic anomalies are generally stronger over continents than over the oceans. They also increase with age and thickness of the crust. Linear features in the oceans are due to sea floor spreading, while strong anomalies over subduction zones are thought to be caused by metamorphic processes in and above the down-going slab.

PLANETARY METABOLISM

PM-02 Biosphere-Atmosphere Interactions

■ CSD-07 Biosphere-Atmosphere Exchange

■ CSD-14 Tropical Ocean Productivity

■ NGDC-07 Anthropogenic Remote Sensing

CSD-07 Biosphere-Atmosphere Exchange

FEDERAL LEADS: JIM BURKHOLDER AND JIM ROBERTS
CIRES LEAD: CHRISTINE ENNIS

NOAA Goal 3: Weather and Water

Project Goal: Improved understanding of how the exchange of gases between the surface and the atmosphere shapes regional climate and air quality.

Milestone 1: Continue studies to measure reaction rate coefficients and evaluate the atmospheric degradation mechanisms of key biogenic species. Impact: This research will provide information needed to quantitatively evaluate the role of biogenic compounds in regional ozone production and secondary organic aerosol formation. This research has implications for regional air quality.

Laboratory kinetic studies were performed to investigate the gas-phase reactivity of two classes of biogenic species. Rate coefficients, k, for the gas-phase reaction of the OH radical with (Z) 3 hexen 1 ol (Z) $CH_3CH_2CH{=}CHCH_2CH_2OH$ (k1), 1 penten 3 ol ($CH_3CH_2CH(OH)CH{=}CH_2$) (k2), (E) 2 penten 1 ol ((E) $CH_3CH_2CH{=}CHCH_2OH$) (k3) and (E) 2 hexen 1 ol ((E) $CH_3CH_2CH_2CH{=}CHCH_2OH$) (k4)—unsaturated alcohols that are emitted into the atmosphere following vegetation wounding and, thus, impact regional air quality—were measured. Rate coefficients were measured using pulsed laser photolysis (PLP) to produce OH radicals and laser induced fluorescence (LIF) to monitor the OH temporal profile. The obtained rate coefficients were independent of pressure with negative temperature dependences. The results of this study provide information that is necessary to evaluate the impact of these naturally emitted compounds on the oxidation capacity of the troposphere and regional air quality.

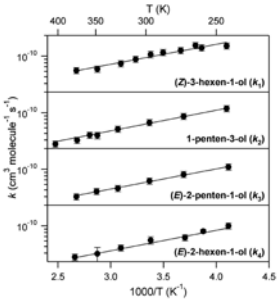


Figure 1: *Measured rate coefficients for the OH radical reaction with several unsaturated "green leaf" alcohols.*

In the second study, rate coefficients for the gas-phase reaction of CH_3COCHO (methylglyoxal) with the OH and NO_3 radicals and $(CHO)_2$ (glyoxal) with the NO_3 radical were measured. Methylglyoxal and glyoxal are abundant oxygenated species that are primarily formed in the atmosphere in the degradation of natural and manmade compounds that are emitted into the atmosphere. The results from this study reduce the uncertainty in the rate coefficient for the OH + methylglyoxal reaction, which is a critical step in the

atmospheric removal of methylglyoxal, and demonstrated that reaction with the NO_3 radical represents a minor atmospheric loss process for methylglyoxal and glyoxal.

Product: Davis, ME, and JB Burkholder (2011), Rate coefficients for the gas-phase reaction of OH with (Z) 3 hexen 1 ol, 1 penten 3 ol, (E) 2 penten 1 ol, and (E) 2 hexen 1 ol between 243 and 404 K, *Atmos. Chem. Phys., 11,* 3347-3358.

Talukdar, RK, L Zhu, KJ Feierabend, and JB Burkholder (2011), Rate coefficients for the reaction of methylglyoxal (CH_3COCHO) with OH and NO_3 and glyoxal $(HCO)_2$ with NO_3, *Atmos. Chem. Phys. Disc., 11,* 18211-18248.

Milestone 2: Initiate laboratory investigation of switch grass emissions to quantify volatile organic compounds emitted by different switch grass species, and to prepare for a summer 2011 field study of agricultural switch grass emissions. Impact: This CIRES research will provide information needed to assess the environmental impact of a large-scale production and use of alternative fuels produced from biofuel crops. Emissions of volatile organic compounds from vegetation can play a significant role in the formation of ozone and aerosol in polluted atmospheres.

Work continued on the characterization of volatile organic compound (VOC) emissions from biofuel crops. In addition to the measurements of VOCs from different switchgrass cultivars, field measurements of VOCs from switchgrass and corn were made in an agricultural field in Fort Collins, Colo. VOC emissions from switchgrass were determined in units of kilograms of carbon per hectare. In combination with industry numbers on the amount of switchgrass required per fuel volume produced, these results allow the environmental effects of biofuel use to be assessed in more detail than previously possible. Switchgrasses are found to be very low emitters of oxygenated species and monoterpenes. The growing of these species for biofuel production will have a much smaller impact on atmospheric composition than for other biofuel crops such as hybrid poplar. In 2011, a more detailed field study to measure the VOC emissions from corn will be conducted in collaboration with colleagues from Colorado State University in Fort Collins.

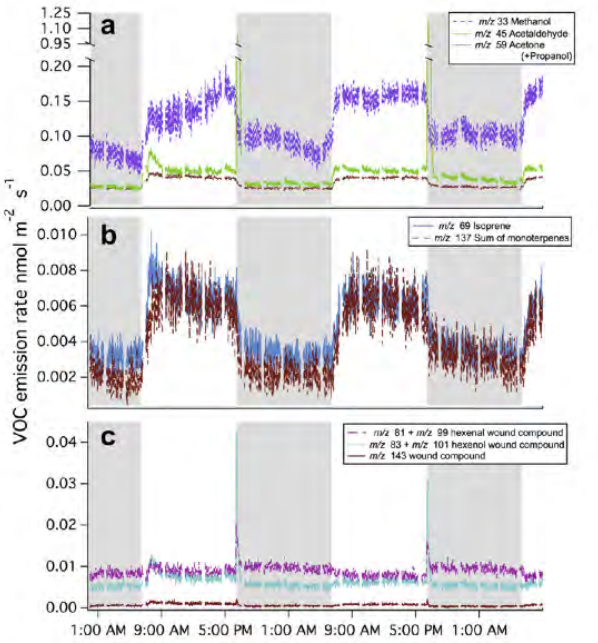


Figure 2

Products: Eller, ASD, K Sekimoto, JB Gilman, WC Kuster, JA de Gouw, RK Monson, M Graus, E Crespo, C Warneke, and R Fall (2011), Volatile organic compound emissions from switchgrass cultivars used as biofuel crops, *Atmos. Environ., 45,* 3333-3337.

Graus, M, A Eller, R Fall, B Yuan, Y Qian, P Westra, J de Gouw, and C Warneke, VOC exchange of C4 biofuel crops, in preparation.

Milestone 3. Develop and test the Acid chemical ionization mass spectrometry (CIMS) system for measuring organic and inorganic acids in the atmosphere. Impact: The Acid CIMS will enable measurement of a large number of organic and inorganic acids, rapidly and with high sensitivity. This capability can be applied to research as diverse as ecosystem fluxes, emissions from combustion sources and the participation of organic acids in secondary organic aerosol formation.

A CIMS instrument based on acetate ion chemistry was developed and used at a ground site in Pasadena, Calif., during the CalNex field study in 2010. The instrument worked very well during its first field deployment and provided quantitative measurements of a series of organic (formic, acrylic, methacrylic, propionic and pyruvic acid) and inorganic acids (nitrous, nitric and isocyanic acid and hydrogen chloride). It was found that most of these gases were formed efficiently by photochemical production from urban emissions. For the organic acids, these findings are not understandable in terms of known gas-phase chemical reactions. However, these reactions are important to understand as organic acids represent a significant fraction of the mass of organic carbon emissions. In summer 2010, the acid CIMS was used to sample emissions from the Fourmile Canyon Fire near Boulder, Colo. These measurements confirmed earlier laboratory findings of the importance of isocyanic acid (HNCO) as an emission from biomass burning.

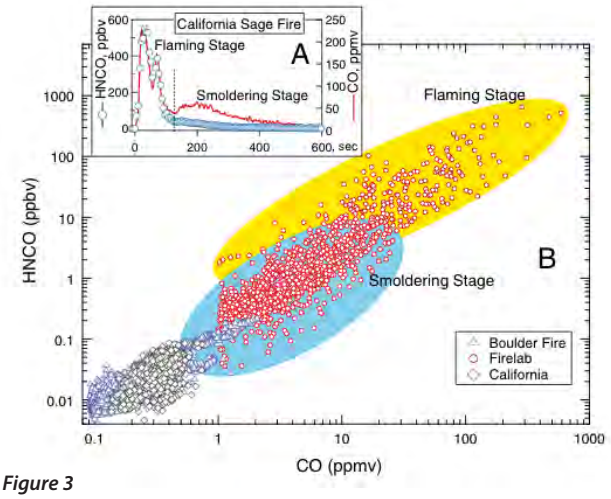


Figure 3

Product: Burling, IR, RJ Yokelson, DWT Griffith, TJ Johnson, P Veres, JM Roberts, C Warneke, SP Urbanski, J Reardon, DR Weise, WM Hao, and J de Gouw (2010), Laboratory measurements of trace gas emissions from biomass burning of fuel types from the Southeastern and Southwestern United States, *Atmos. Chem. Phys., 10,* 11115–11130.

Veres, P, JB Gilman, JM Roberts, WC Kuster, C Warneke, IR Burling, and J de Gouw (2010), Development and validation of a portable gas phase standard generation and calibration system for volatile organic compounds, *Atmos. Meas. Tech.*, *3*, 683-691.

Veres, P, JM Roberts, IR Burling, C Warneke, J de Gouw, and RJ Yokelson (2010), Measurements of gas-phase inorganic and organic acids from biomass fires by negative-ion proton-transfer chemical-ionization mass spectrometry (NI-PT-CIMS), *J. Geophys. Res.–Atmos.*, *115*, D23302, doi:10.1029/2010JD014033.

Roberts, JM, PR Veres, AK Cochran, C Warneke, IR Burling, RJ Yokelson, B Lerner, J Gilman, W Kuster, R Fall, and J de Gouw (2011), Isocyanic acid in the atmosphere and its possible link to smoke-related health effects, *Proceedings of the National Academy of Sciences*, *108*, 8966-8971.

Veres, PR, JM Roberts, AK Cochran, JB Gilman, WC Kuster, JS Holloway, M Graus, JH Flynn, B Lefer, C Warneke, and J de Gouw (2011), Efficient photochemical production of organic acids in urban atmospheres, submitted to *Geophys. Res. Lett*.

Warneke, C, JM Roberts, P Veres, J Gilman, WC Kuster, I Burling, R Yokelson, and JA de Gouw (2011), VOC identification and inter-comparison from laboratory biomass burning using PTR-MS and PIT-MS, Int. *J. Mass Spectrom.*, *303*, 6-14.

CSD-14 Tropical Ocean Productivity

FEDERAL LEAD: JAMES CHURNSIDE
CIRES LEAD: CHRISTINE ENNIS

NOAA Goal 3: Climate

Project Goal: Understand the effects of changes in temperature, vertical mixing and aerosol fertilization on primary productivity in the tropical ocean.

Milestone 1: Identify the temporal and spatial scales of the processes that link chlorophyll concentration in tropical ocean waters to aerosols and temperature. Impact: This research will help identify the processes leading to the recently observed expansion of the tropical ocean. These processes are important to predicting the rate of CO_2 uptake by the ocean of the future.

Thirteen years of satellite observations of ocean color were used to investigate trends in surface chlorophyll-a concentration in the mid–Pacific Ocean away from direct terrestrial influence. Statistically significant decreases in chlorophyll-a concentration were observed over broad extra-equatorial regions in both the northern (10–40˚ N) and southern (15–40˚ S) hemispheres. In the northern hemisphere, the decrease is related to a decrease in aerosol optical depth, and the most likely mechanism seems to be a reduction in iron fertilization. In the southern hemisphere, the cause is less clear, but multi-annual climate processes appear to be more important than aerosol trends.

Product: McCarty, BJ, and JH Churnside, Latitudinal trends of chlorophyll-a concentration and aerosol optical depth in the mid-Pacific Ocean, submitted to *Earth Interact*.

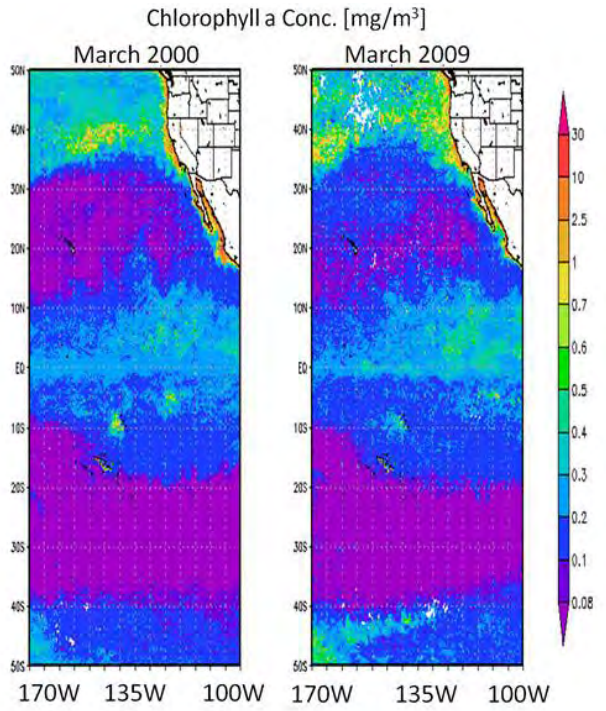


Figure 1: *Satellite observations of monthly chlorophyll-a concentration, March 2000 and 2009. The decline in chlorophyll-a concentration is clearly depicted between 30–40˚ N.*

PM-03 Response of Natural Systems to Perturbations

■ NGDC-07 Anthropogenic Remote Sensing

NGDC-07 Anthropogenic Remote Sensing

FEDERAL LEAD: CHRIS ELVIDGE
CIRES LEAD: BENJAMIN TUTTLE

NOAA Goal 4: Support the nation's commerce with information for safe, efficient and environmentally sound transportation.

Project 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: Complete a radiance calibrated Defense Meteorological Satellite Program Operational Linescan System (DMSP OLS) nighttime lights product for the year 2010 using satellite F16.

A Radiance Calibrated product was developed using the Fixed Gain data collected by the DMSP satellite F16 for the year 2010. This product is able to solve the vexing problem of saturation in the operational Stable Lights data set. By blending in low-gain data with the operational data, bright urban cores are resolvable. This product has already been used in studies of economics, stocks of metals and carbon emissions. A paper was published for the Asia-Pacific

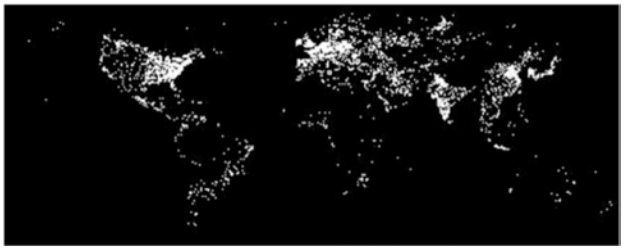


Figure 1: *Global image of the Radiance Calibrated Nighttime Lights from 2010 DMSP F16*

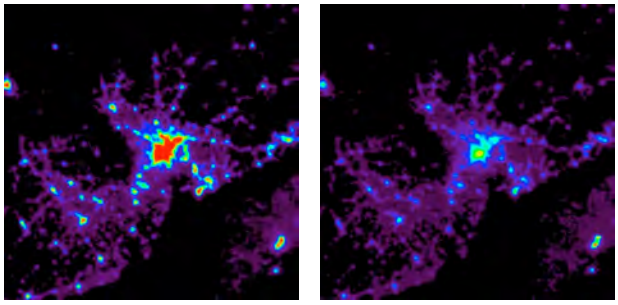


Figure 2: *Ho Chi Min City, Vietnam. The first image shows the Operational Stable Lights data where the urban core is saturated. The second image is the Radiance Calibrated data where the urban core is resolved. The radiance of the brightest pixels is measured to be a factor of about 12 larger than the saturated values.*

Advanced Network (APAN) conference proceedings. In order to create this product, a generalized method was created for processing other years.

Product: Ziskin, D, KE Baugh, FC Hsu, T Ghosh, and CD Elvidge (2010), Methods used for the 2006 radiance lights, Asia-Pacific Advanced Network conference.

Milestone 2: Develop a methodology for determining gain settings on DMSP OLS operational data for satellites F16 and F18.

Due to the fact that the gain settings are not stored in the DMSP Operational Linescan System (OLS), smooth resolution visible band data has been a barrier toward intercomparability of the OLS data. This work was the first step toward the goal of OLS data calibration (see Milestone 3).

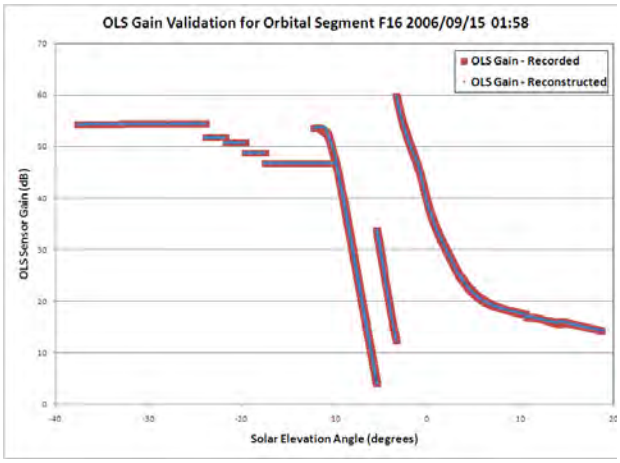


Figure 3: *Comparison of the recorded OLS visible band gain values and the software-reconstructed values for the last sample in each scanline of an F16 fine-resolution orbital segment.*

Software was created to reconstruct the DMSP-OLS gain settings for any orbital swath of data from satellites F16 and F18. The software is a recreation of the onboard along-scan gain control algorithms that the OLS uses to set the visible band gain. Onboard constants to the gain algorithm are modified weekly via Payload Activation Messages (PAMs). The PAMs were obtained and converted into a temporal database of gain constants that is accessed by the gain reconstruction software. The OLS fine-resolution datastream records the gain for the last sample in each scanline. This sample of recorded gains was used for software validation.

Milestone 3: Development of a robust and effective calibration method for the DMSP OLS time series based on reflected moonlight from desert surfaces for satellites F16 and F18.

Moonlight reflected off of desert surfaces was measured with the DMSP F16 and F18 satellites. The satellite gain settings were estimated for each overpass (see Milestone 2). This allowed us to determine the instrument's response and calculate an 'uncalibrated radiance.' We also modeled the expected radiance using an advanced radiative transfer model (MODTRAN). The comparison between the uncalibrated radiance from the instrument and the modeled radiance has yielded a compelling relationship. Work along this promising line will continue with the goal of developing an absolute calibration of the OLS.

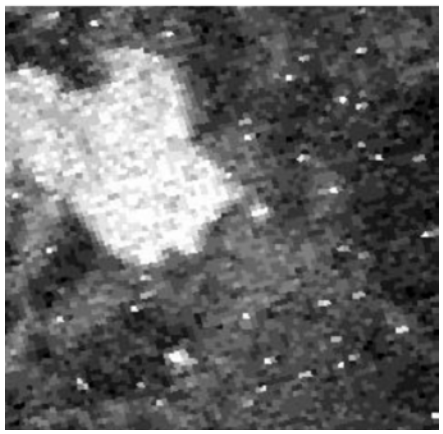


Figure 4: *The Uyuni Salt Flats in Bolivia in full moonlight.*

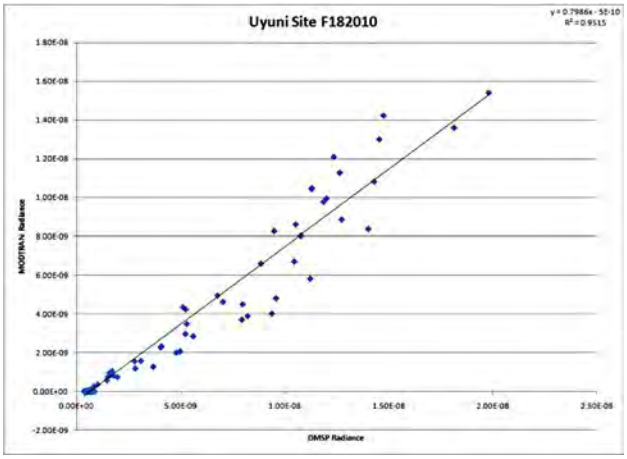


Figure 5: *The radiance that the DMSP F18 satellite observed is simulated by the MODTRAN radiative transfer model.*

REGIONAL PROCESSES

RP-02 Surface/Atmosphere Exchange

■ PSD-12 Air-Sea Interaction

PSD-12 Air-Sea Interaction

FEDERAL LEAD: CHRIS FAIRALL
CIRES LEAD: ANDREY GRACHEV

NOAA Goal 2: Climate

Project Goal: Perform cutting-edge micrometeorological and climatological research over the open ocean aboard research vessels, sea-based towers and buoys.

Milestone 1. Complete construction of synthesis data set for VOCALS-REX data.

The VAMOS (Variability of the American Monsoon Systems) Ocean-Cloud-Atmosphere-Land Study Regional Experiment—known as VOCALS-REX—was added to the 2001-2007 synthesis data set.

Product: DeSzoeke, SP, CW Fairall, DE Wolfe, L Bariteau, and P Zuidema (2010), Surface flux observations in the southeastern tropical Pacific and attribution of SST errors in coupled ocean-atmosphere models, *J. Clim., 23,* 4152-4174.

Milestone 2. Submit papers on parameterization of sea spray as part of the NOAA hurricane studies.

Two papers were submitted and are either accepted or are in print (see Product).

Product: Bao, J-W, CW Fairall, SA Michelson, L Bianco (2011), Parameterizations of sea-spray impact on the air-sea momentum and heat fluxes, to appear in *Mon. Wea. Rev.*

Bianco, L, JW Bao, CW Fairall, and SA Michelson (2011), Impact of sea spray on the surface boundary layer, *Bound.-Layer Meteorol.,140,* DOI: 10.1007/s10546-011-9617-1.

Milestone 3. Analyze flux and gas transfer observations from NOAA's Southern Ocean Gas Exchange Experiment (GasEx III) field program. Submit publication on results.

Analysis was completed, and five papers were submitted to the GasEx III special issue.

Product: Fairall, CW, M Yang, L Bariteau, JB Edson, D Helmig, W McGillis, S Pezoa, JE Hare, B Huebert, and B Blomquist (2011), Implementation of the COARE flux algorithm with CO_2, DMS, and O_3, to appear in *J. Geophys. Res.*

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

FEDERAL LEAD: SAMUEL OLTMANS
CIRES LEAD: ANNE JEFFERSON

NOAA Goal 2: Climate

Project Goal: Study intercontinental transport events to better understand their effects on overall air quality and its impacts on public health.

Milestone 1. An aerosol measurement system will be deployed to India's Ganges Valley to study the effect of aerosol on radiation, convection and cloud formation. The study will span the pre- to post-monsoon seasons.

The aerosol equipment as part of the Ganges Valley Aerosol eXperiment (GVAX) was installed in June 2011. The site is located in the foothills of the Himalayas above Nainital, India, and will examine transport from the Ganges Valley as well as long-range transport from China, the Arabian Peninsula and Pakistan. Comparisons will be made with an ancillary site of similar measurements located in the Ganges Valley to evaluate changes in the aerosol and cloud properties as the air mass moves up the mountain slope.

DOE Atmospheric Mobile Facility deployment in the Himalayan foothills of India as part of the Ganges River Valley Aerosol Experiment (GVAX).

PSD-13 Air Quality

FEDERAL LEAD: ALLEN WHITE
CIRES LEAD: SARA MICHELSON

NOAA Goal 2: Climate

Project 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. PSD engineers will deploy three wind

profiling radars with radio acoustic sounding systems and surface meteorology towers at three key locations in southern California for the CalNex field campaign in the upcoming spring and summer (2010). Meteorological observations collected at these sites will be accessed, displayed, and archived and quality controlled.

The data sets were used heavily both during and after the CalNex (Research at the Nexus of Air Quality and Climate Change) field campaign.

Milestone 2. Develop, operate and maintain a wind profiler trajectory tool for the CalNex field campaign. The tool is used by scientists to document transport pathways for air pollution and to help plan aircraft missions. Starting this year, the trajectory tool will be maintained by the PSD Water Cycle Branch, the same group responsible for operating and maintaining the wind profilers.

The trajectory tool was implemented with quality-controlled wind profiler data collected during CalNex.

Milestone 3. Execute the surface flux, boundary layer, and cloud observations for the CalNex cruise. Process and analyze the CalNex data set from the NOAA Ship Ronald H. Brown cruise, including turbulent fluxes of momentum, sensible heat and latent heat, down-welling radiative fluxes, cloud radar statistics, ceilometer observations, radio-soundings for boundary layer structure, microwave radiometer observations of cloud liquid water and column integrated water vapor, etc.

A preliminary analysis was done, and the results were presented at the CalNex-Atlantis Data Workshop at the University of California Davis, Jan. 11-13, 2011. All data have been archived under ftp://ftp1.esrl.noaa.gov/psd3/cruises/CALNEX_2010/Atlantis/Scientific_analysis/flux/.

Milestone 4. Deploy systems on the Gulf of Mexico oil platform for the Minerals Management Service observational program. Data include fluxes of sensible heat, latent heat, momentum and sea surface temperature.

Meteorological and flux instruments are currently deployed on the platform. A qualitative evaluation of the instruments was performed. Comparison of bulk estimates with eddy covariance air sea fluxes is ongoing.

CSD-08 Regional Air Quality

FEDERAL LEADS: DAVID PARRISH, JIM BURKHOLDER AND MICHAEL HARDESTY
CIRES LEAD: CHRISTINE ENNIS

NOAA Goal 2: Climate

Project 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 enhances air-quality prediction and forecasting.

Milestone 1. Measure the reactivity and optical properties of compounds that are replacements for ozone-depleting substances, and evaluate their global warming potentials. Impact: The determination of the atmospheric loss processes and atmospheric lifetimes of replacement compounds is critical decision-support information. This research has implications for regional air quality, stratospheric ozone and climate change.

In order to determine the impacts of the potential replacement compounds, we are studying the reactivities of these species toward OH, Cl and O_3. The atmospheric lifetimes of the hydrofluorocarbons (HFCs) due to loss by OH reaction were estimated. The rate coefficients for the OH reaction were measured as a function of temperature (211–374 K) and pressure (20–200 Torr, He, N_2) using a pulsed laser photolysis – laser induced fluorescence (PLP – LIF) technique, and at 296, 345 and 375 K using a relative rate technique at pressures between 100 and 300 Torr (He). The rate coefficients for the Cl reactions were measured using a relative rate method. We also measured the infrared and UV absorption cross sections of HFCs. The infrared absorption measurements were used to determine global warming potential (GWP) of these species. We have several compounds, which need to be assessed. A manuscript on atmospheric chemistry of (Z) $CF_3CH{=}CHCF_3$ is in preparation and about to be submitted. One of the samples is a mix of five or more structurally similar hydrofluoroethers. We have three samples with different mixing ratios, which will allow us to determine the reactivities of the individual isomers better. This is work in progress.

Milestone 2. In the CalNex 2010 field campaign, use surface, airplane-, ship- and satellite-borne sensors to survey a wide variety of sources of directly emitted gas and aerosol species that impact atmospheric air quality via ozone and secondary organic aerosol formation. Impact: This CIRES research will investigate the distribution and source strengths of precursors to pollution, leading to an improved understanding of anthropogenic, agricultural, biogenic and geologic sources of pollutant species. The study will also investigate the daytime and nighttime chemical transformations and pollutant transport in the atmosphere. These data and analyses will provide the State of California with the scientific foundation for their efforts to develop plans to bring several areas of the state into compliance with federally mandated National Ambient Air Quality Standards for ozone and particulate matter.

A principal focus of the 2010 CalNex study was on emissions of species that affect air quality and the chemical and physical processes that determine the fate of those species. CIRES research contributed significantly to verifying and quantifying these emissions and to understanding the transformation processes that the emitted species undergo. Three examples are provided here.

1) Nitryl chloride ($ClNO_2$) is a species formed at night from the reaction of oxides of nitrogen, ozone and chloride-containing wet aerosols and may contribute to early-morning chemistry that produces photochemical smog. It is produced from a sequence of chemical reactions and intermediate species that need certain environmental conditions to be met. During CalNex, $ClNO_2$ was observed over a large range of mixing ratios from research vessel Atlantis and the NOAA WP-3D aircraft. The cause of this variability is under investigation but will likely be verified from currently understood chemistry and from the environmental conditions (e.g., temperature, relative humidity) in which that chemistry happened.

2) At the Pasadena, Calif., ground site, measurements of a wide spectrum of organic compounds were made, which will provide information not only on emission sources, but also on chemical oxidation pathways that indicate the type of oxidation chemistry (e.g., hydroxyl radical) occurring, the

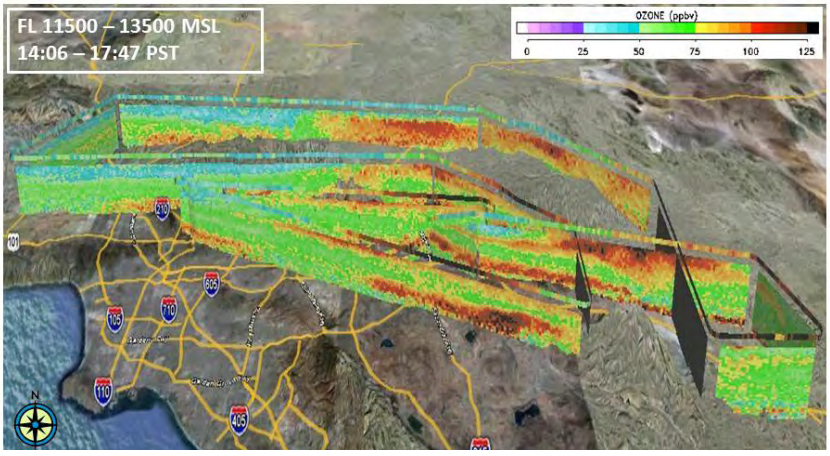
extent (i.e., chemical age) of that chemistry and possible fates (e.g., secondary organic aerosol formation or growth) of the species.

3) Measurements from Atlantis demonstrated that sulfur dioxide emissions from commercial marine vessels were within regulatory limits, which was of considerable interest to the California Air Resources Board (CARB).

Product: Results from CIRES research conducted during the 2010 CalNex field mission were presented during a workshop at the CARB headquarters during May 2011. The agenda and links to the presentations are available at http://www.arb.ca.gov/research/calnex2010/calnex2010.htm.

Milestone 3. Co-deploy airborne ozone and Doppler wind lidars during the 2010 CalNex air quality study to investigate transport processes of air pollutants. Impact: The combination of airborne ozone and Doppler lidars will allow us to measure simultaneously ozone concentration and wind speed and direction at high resolution and thus enable us to characterize and quantify transport processes of air pollutants in California on local and regional scales. The information will be scientific input for air quality decision makers in the state of California.

During the CalNex experiment from May through July 2010, we co-deployed NOAA's airborne Tunable Optical Profile for Aerosol and Ozone (TOPAZ) lidar and the University of Leeds scanning Doppler wind lidar on a Twin Otter aircraft. We flew 46 missions over the state of California, totaling approximately 200 flight hours and focusing primarily on the Los Angeles Basin and Sacramento areas. The downward-looking lidars provided highly resolved measurements of ozone concentration, aerosol backscatter and wind speed and direction in the boundary layer and lower free troposphere. We have used these data to characterize transport of pollutants on local, regional and continental scales for a number of cases. In particular, we have identified important ozone transport pathways between air basins in southern California. This included characterizing the role of flow patterns in complex terrain, such as gap flows and orographic lifting and venting along mountain slopes, in redistributing ozone in southern California. We have also consistently observed layers of high ozone concentrations at a few kilometers altitude above ground level. While some of these layers are caused by lofting of locally produced ozone, trajectory analysis revealed that in a number of cases, the ozone aloft was associated with transport of pollutants from Asia or downward transport of ozone from the stratosphere during stratospheric intrusion events. We have presented these results at the 2010 American Geophysical Union Fall Meeting and at a CalNex data analysis workshop in spring 2011, during which we communicated our findings to scientists and regulators from CARB.



O_3 distribution over the Los Angeles Basin and Mojave Desert measured with NOAA's TOPAZ ozone lidar on July 2, 2010.

GSD-02 Regional Air Quality Prediction

FEDERAL LEAD: GEORG GRELL
CIRES LEAD: STEVEN PECKMAN

NOAA Goal 3: Weather and Water

Project Goal: Design and evaluate new approaches for improving air-quality prediction.

Milestone 1. Test and evaluate the global FIM-Chem (Flow-following finite-volume Icosahedral Model) currently under development in ESRL and containing chemistry modules from the GOCART (Goddard Chemistry Aerosol Radiation and Transport) model, together with global wildfire definition and global anthropogenic emissions data. Run FIM-Chem in real time at the highest affordable resolution to predict multi-day global transport of aerosol and impact on weather forecasts.

The GOCART aerosol modules have been successfully included into FIM, and evaluation continues to be performed. An emissions processor from the Weather Research and Forecast–Chemistry model (WRF–Chem) was modified for use with the FIM to provide global wildfire emissions and anthropogenic emissions. Additionally, volcanic ash from volcanic eruptions was included both in the FIM and the emissions preprocessor. The resulting "FIM-Chem-ash" was run in real time twice a day following the major volcanic eruption in Iceland in April, and results from the forecasts are being evaluated.

Milestone 2. Continue to coordinate worldwide development of WRF-Chem (Weather Research and Forecasting Model) as an air-quality prediction tool and support the growing user community.

CIRES' leadership role in the development of this modeling system continues. WRF-Chem version 3.3 was released in April 2011 with many new additions, including additional coupling between chemistry and physics modules as well as new additions to chemical mechanisms (provided by the National Center for Atmospheric Research, the Pacific Northwest National Laboratory and the Earth System Research Laboratory's Chemical Sciences Division). In addition, significant improvements have been made to the data input/output (I/O) streams, which should enhance the overall performance of WRF-Chem.

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

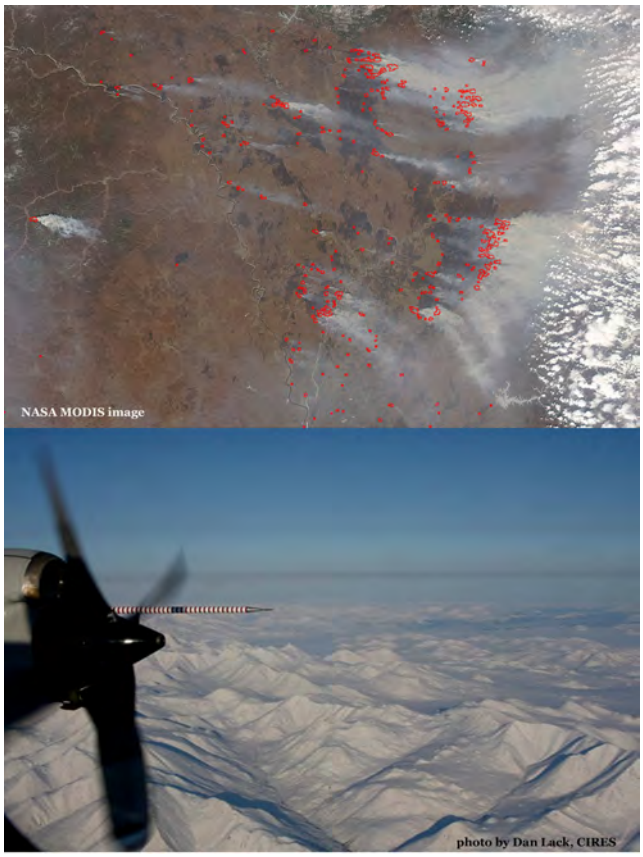
FEDERAL LEADS: TOM RYERSON AND STEVEN BROWN
CIRES LEAD: CHRISTINE ENNIS

NOAA Goals 2 and 3: Climate and Weather and Water

Project Goal: Carry out modeling studies and airborne and surface measurements of chemical species to elucidate processes involved in the intercontinental transport of photochemical pollution.

Milestone 1. Analyze the long-range transport of aerosols in the Arctic by using data from aircraft flights and other sources to provide chemical characterization of the aerosols. Impact: Aerosol particles, especially black carbon, have large climate effects in the Arctic. This CIRES research will analyze aerosols in the Arctic free troposphere, polluted Arctic regions, biomass burning plumes in the Arctic, and the air just above the pack ice, all of which are potentially subject to long-range transport.

Aerosol data obtained in spring 2008 in the Arctic surface layer as well as in the free troposphere have been analyzed for their chemical composition characteristics in order to understand sources of aerosols reaching the Arctic air, their fate and the impact they have on cloud formation. By combining in-situ measurements of gas and aerosol phase species with a long-range-transport model, we determined that biomass burning (BB) activities in southern Russia and southeastern Siberia contributed significantly to springtime Arctic aerosol properties. In addition to the BB plumes, plumes with characteristics of fossil fuel combustion were observed in the free troposphere. These plumes aloft were superimposed on a polluted background of aged European wintertime emissions, in contrast to the cleaner air at lower altitudes as seen by Arctic surface measurement stations. The long-range transport of pollutants across the continents resulted in enhanced loadings of aged organic species in the aerosol phase. Cloud condensation nuclei measurements along with aerosol chemistry data indicate that, regardless of the sources, most of the aerosols observed in the Arctic activated at super saturations greater than 0.1% to form clouds. The enhanced aerosol concentrations from BB plumes suppressed ice formation within mixed phase clouds. Black carbon mass was enhanced in biomass burning plumes by up to a factor of five compared to the background air. Black carbon was depleted in the Arctic surface layer, and the depletion was anti-correlated with ozone, indicating surface deposition as the mechanism for the depletion.



The satellite image (top) shows Russian fires that were the source of dense biomass burning plumes observed in the Arctic Atmosphere by (bottom photo) CIRES investigators aboard the NOAA P-3.

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

FEDERAL LEADS: DAN MURPHY, RU-SHAN GAO, DAVID FAHEY AND GRAHAM FEINGOLD
CIRES LEAD: CHRISTINE ENNIS

NOAA Goals 2 and 3: Climate and Weather and Water

Project Goal: Carry out airborne, ship-based and ground-based experiments that characterize the chemical composition of radiatively important aerosols in the upper troposphere and at Earth's surface.

Milestone 1. Use data from the Hiaper Pole-to-Pole Observations (HIPPO) mission deployments to examine the mixing state and optical size of individual black-carbon particles as well as black carbon mass loadings in remote regions. Impact: Black carbon is an important component of anthropogenic climate forcing in the Arctic region. These measurements will provide a basis to evaluate the treatment of black carbon in global aerosol models and to characterize the contribution of black carbon to global radiative forcing.

Complete analysis of the three completed HIAPER (High-Altitude Instrumented Airborne Platform for Environmental Research) Pole-to-Pole Observations (HIPPO) deployments was presented at the American Geophysical Union Fall Meeting in 2010. The results suggest that these measurements can be used to provide a single "typical remote" black carbon (BC) mass distribution for comparison to global models. Additionally, even in very different remote air masses, the estimated impact on BC absorption of shortwave solar radiation by dry coatings on BC cores was found to be fairly uniform, and to lie in good agreement with previous lower-stratospheric results. In the exceptionally clean Southern Hemisphere, measurements made in the third HIPPO deployment revealed two populations of BC-containing aerosol distinguished by the amount of dry coatings associated with the BC cores. This observation may provide a strong constraint on the absolute and relative aging of BC-containing aerosol and its transport timescales in global models.

At present a manuscript presenting these analyses and results is in preparation for publication in *Geophysical Research Letters.*

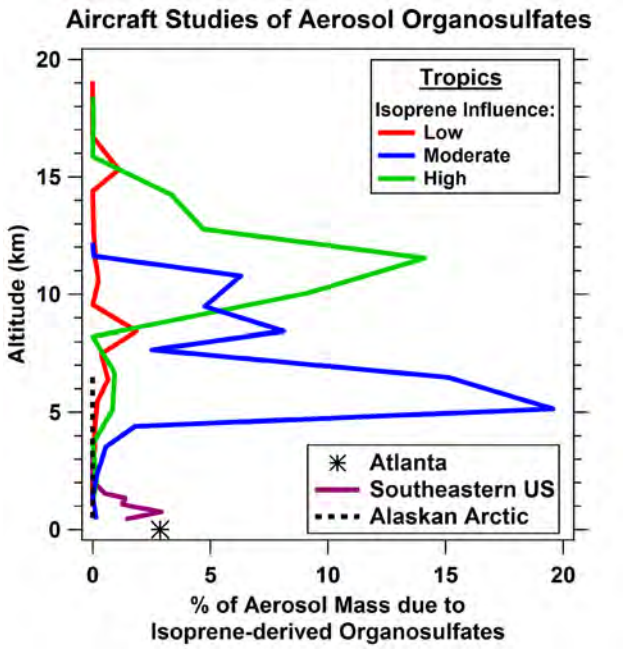
J. P. SCHWARZ

The NSF/NCAR GV research aircraft used for the HIPPO mission with a backdrop of the mountains of American Samoa.

Milestone 2. Examine organosulfate molecules in atmospheric aerosols. Impact: Organosulfate molecules can be formed when reaction products of isoprene and other biogenic organic products encounter acidic sulfate particles. Laboratory calibrations and a review of more than 10 years of field data will allow an assessment of the importance of these compounds in many atmospheric situations, including the Amazon boundary layer and the free troposphere over the United States.

Organosulfate compounds have recently been identified within aerosol particles in laboratory smog chamber studies. Organosulfate compounds form when isoprene oxidation products react with acidic sulfate aerosol particles. Gas-phase isoprene emitted from broadleaf vegetation constitutes an enormous flux of organic material into the atmosphere, and converting a small fraction of this emitted mass to condensed phase species would add dramatically to atmospheric aerosol loadings. Isoprene-derived organosulfates have not been previously observed in the real atmosphere.

For this project, organosulfate compounds were detected in free tropospheric aerosol by an airborne single particle mass spectrometer instrument. Laboratory calibrations enabled estimations of organosulfate aerosol mass loadings for a variety of atmospheric regions including the Arctic, continental midlatitudes and the tropics. Organosulfate loadings were highest in tropical and midlatitude air masses situated downwind of strong isoprene sources such as the Amazon and the southeastern U.S., where isoprene-derived organosulfates contributed from 1-20% of total aerosol mass regionally. This research provides new evidence on how urban and industrial emissions of sulfur compounds combine with typical biogenic emissions to generate substantial aerosol mass on regional and global scales. These results were published in the *Proceedings of the National Academy of Science* and presented at the American Association for Aerosol Research and American Geophysical Union annual meetings.



Milestone 3. Use data from the 2010 CalNex Air Quality Study to investigate secondary organic aerosol (SOA) formation in the urban Los Angeles area. Impact: This CIRES research will enable us to quantify the anthropogenic source of SOA to the atmosphere, which is currently not well understood. By combining the results from multiple measurements, we will investigate how the budget of organic carbon in the gas and aerosol phases changes as a function of the degree of photochemical processing. The results will be used to estimate the global source of SOA derived from anthropogenic volatile organic compounds and other urban precursors.

Work has started on the analysis of gas- and aerosol-phase organic carbon species obtained during the CalNex (Research at the Nexus of Air Quality and Climate Change) field study in 2010, with a special focus on the production of secondary organic aerosol (SOA). Initial analyses focused on the emissions characterization of volatile organic compounds, the chemical formation of glyoxal and other reaction intermediates and on the weekend-weekday effect in the production of SOA. First results were presented at the CalNex workshop in Sacramento, Calif., in May 2011. A detailed analysis of glyoxal measurements made at the ground site in Pasadena, Calif., was performed with the help of box-model calculations, and the manuscript is currently under review. This study found that the production of several reaction intermedi-

ates can be understood by production from the measured hydrocarbon precursors. Loss processes of glyoxal to the aerosol phase were quantified and were found to represent 0-13% of the observed SOA formation.

Product: Washenfelder, RA, CJ Young, SS Brown, WM Angevine, EL Atlas, DR Blake, DM Bon, MJ Cubison, JA de Gouw, S Dusanter, J Flynn, JB Gilman, M Graus, S Griffith, N Grossberg, PL Hayes, JL Jimenez, WC Kuster, BL Lefer, IB Pollack, TB Ryerson, H Stark, PS Stevens, and MK Trainer, The glyoxal budget and its contribution to organic aerosol for Los Angeles, California, during CalNex 2010, submitted to *J. of Geophys. Res.–Atmos.*

Instrumented trailers and sampling towers at the ground site on the campus of Caltech University in Pasadena, Calif., during the CalNex study in 2010.

INTEGRATING ACTIVITIES

IA-01 Science and Society

- CSD-10 Scientific Assessments for Decision Makers
- Policy-01 Science Policy Lecture Series
- DIR-01 Science Communications for Diverse Audiences

CSD-10 Scientific Assessments for Decision Makers

FEDERAL LEAD: A.R. RAVISHANKARA
CIRES LEAD: CHRISTINE ENNIS

NOAA Goals 2 and 3: Climate and Weather and Water

Project 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: Organize and oversee the international peer review of the United Nations Environment Programme/ World Meteorological Organization 2010 scientific state-of-understanding assessment of the ozone layer for the U.N. Montreal Protocol; complete the editing and publishing of the final report; and deliver the report to the Montreal Protocol decision makers and the worldwide scientific community. Impact: This CIRES research supports the decision making of the more than 190 nations that are Parties to the United Nations Montreal Protocol on Substances that Deplete the Ozone Layer.

At the end of December 2010, the international scientific state-of-understanding assessment report on the ozone layer was delivered to the United Nations Environment Programme (UNEP). The report was prepared for the nations that are Parties to the Montreal Protocol, the United Nations agreement that protects the Earth's stratospheric ozone layer (all nations are now signatories to that agreement). Updated every four years, the ozone assessment describes the latest scientific findings related to the ozone layer and informs decisions made under the Montreal Protocol to protect the ozone layer from depletion by chlorofluorocarbons (CFCs) and other ozone-depleting substances. More than 300 international scientists authored and reviewed the 2010 report, which is prepared under the auspices of UNEP and the World Meteorological Organization and with leadership by NOAA, NASA and the European Commission. CIRES scientists played key roles in coordinating, authoring, reviewing and editing the report, as well as preparing it for printing and distribution worldwide. Among the major findings of the 2010 report is that climate change and the ozone layer are intricately coupled, and that climate change will become increasingly important to the future ozone layer as ozone-depleting substances diminish in the atmosphere.

Product: *Scientific Assessment of Ozone Depletion: 2010,* World Meteorological Organization Global Ozone Research and Monitoring Project, Report No. 52, 516 pp., Geneva, Switzerland, 2011.

Covers of the full assessment report, its Executive Summary and the companion document answering frequently asked questions about the ozone layer and ozone depletion.

Policy-01 Science Policy Lecture Series

CIRES LEAD: ROBERTA KLEIN

NOAA Goals 2 and 3: Climate and Weather and Water

Project Goal: Provide useful information that will help improve the relationship between societal needs and science and technology policies.

Milestone 1. Organize a fall noontime seminar series focused on decision making under uncertainty, in conjunction with other units of CIRES.

Fall 2010:

"Climate change impacts on infrastructure: A global look at predicted changes and effects," Paul S. Chinowsky, CU Department of Civil, Environmental, & Architectural Engineering

"Integrating science and policy: Climate change assessments and water resources management," Christine Kirchhoff, Center for Science and Technology Policy Research (CSTPR)

"Arctic sea changes: Prospects for increased marine traf-

fic with unpredictable sea ice conditions," Mark Serreze, National Snow and Ice Data Center (NSIDC)

"Declaring a climate emergency: Geo-engineering and the doctrine of last resort," Bill Travis, CSTPR

"Producing useful scientific information for policy: How scientists perceive the likely utility of their research," Elizabeth McNie, Purdue University

"How climate models gain and exercise authority," Mike Hulme, University of East Anglia

"Observing and understanding changes in ice sheets: The sea level wild card," Waleed Abdalati, CIRES

"Media and climate-related responsible behavior," Gesa Lüdecke, Leuphana Universität Lüneburg

"Improving communication of weather forecast uncertainty to aid decisions," Rebecca Morss, National Center for Atmospheric Research (NCAR)

Spring 2011:

"Reports card for the environment: 1c, 3bs, 1a and 1 incomplete," Michael Glantz, Consortium for Capacity Building

"Quantification of the treatment of uncertainty by the IPCC AR4," Roger Pielke, Jr., CU-Boulder Environmental Studies Program (ENVS) and CSTPR

"Enhancing the resilience of small high-latitude fishing communities to climatic and marine-ecosystem change," James McGoodwin, CU Department of Anthropology

"Global earthquake fatalities: Nature vs. human nature," Roger Bilham, Geological Sciences and CIRES

"Dryness and desperate measures: Ranching, land tenure, and drought coping in the Rocky Mountain West," Kristin Gangwer, CU Department of Geography and CSTPR

"Inundation or ignorance? Public perception of storm surge," Jeffrey Lazo, NCAR

Milestone 2. Revise and update website.

In July 2010 the Center for Science and Technology Policy Research released its new website. The new site has an updated look as well as improved content and functionality, making it easy to find information about Center research, events, publications and other activities.

Product: The Center website is located at http://sciencepolicy.colorado.edu/

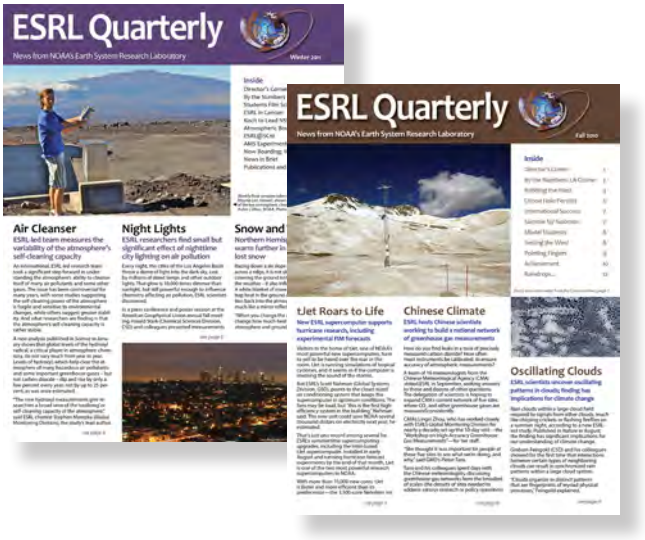
Milestone 3. Continue to upgrade newsletter and briefing, and expand readership.

Subscriptions to the Center's newsletter, *Ogmius*, have increased from 345 to 426 over the past year. The mailing list for the Center's briefing, sent primarily to Washington, D.C., decision makers, was updated to reflect changes in the Administration and now includes almost 4,000 recipients.

Product:

Ogmius: http://sciencepolicy.colorado.edu/ogmius/

Briefing: http://sciencepolicy.colorado.edu/outreach/cstpr_briefings.html



DIR-01 Science Communications for Diverse Audiences

CIRES LEAD: KATHLEEN HUMAN

NOAA Goals 1, 2, 3 and 4: Ecosystem, Climate, Weather and Water, Commerce and Transportation

Project Goal: Convey the importance of NOAA and CIRES research to diverse audiences, from the general public and Congressional staffers to real and potential scientific collaborators.

Milestone 1. Publish a quarterly science news magazine for NOAA's Earth System Research Laboratory (ESRL), and re-purpose articles for other outlets, especially Climate-Watch, NOAA World, NOAA.gov, CIRES web, ESRL web, CIRES Annual Report, and CIRES *Spheres* magazines.

Three issues of the *ESRL Quarterly* were completed before staff assigned to this task moved into a federal NOAA communication position. The majority of *ESRL Quarterly* stories published in these three editions were rerun elsewhere, from the CIRES website and *Spheres* to Climate Watch and NOAA.gov theme stories.

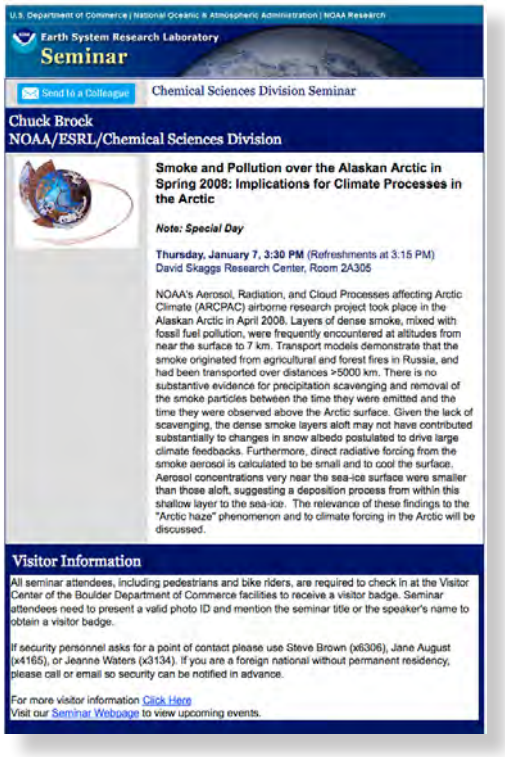
Product: *ESRL Quarterly* summer 2010, fall 2010 and winter 2010–2011.

Milestone 2. Collaborate on other communication projects with colleagues across NOAA and the CI system, primarily the CIRES Annual Report, but also informational 'two-pagers,' annual accomplishment writeups for NOAA Congressional Analysis and Relations Division, and various other programmatic and scientific documents.

CIRES' Annual Report was produced and submitted on time and approved at all levels, from internal CIRES to NOAA administration. Several two-pagers and other write-ups were produced, with topics ranging from successes in CIRES' Innovative Research Program to recent missions involving unmanned aircraft systems. Staff completed the annual update of ESRL's two-pager for NOAA's Congressional Analysis and Relations Division; spent several weeks editing the NOAA Climate Services Vision and Strategic Framework; and also edited an early draft of NOAA's Strategic Energy Report.

Milestone 3. Maintain a constituent database for the Earth System Research Laboratory, to be used for distributing newsletters, print publications, invitations to events and seminars, and for other purposes.

This database was updated regularly through Constant Contact. Staff assigned to this task not only updated several distribution lists monthly (all-NOAA, ESRL, *ESRL Quarterly* and local constituents), but trained colleagues to use the application. Constant Contact is now widely used to distribute internal NOAA announcements, from seminars and retirements to major workshops and conferences, and to organize and communicate with external constituents as well.



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

FEDERAL LEAD: ROBIN WEBB
CIRES LEADS: KRISTEN AVERYT, ERIC GORDON AND BRADLEY UDALL

NOAA Goal 2: Climate

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

Milestone 1: The WWA education goal for coming years is to develop a suite of process-oriented frameworks for improving the climate literacy of different users with distinct informational needs.

Western Water Assessment (WWA) work over the past year included presenting the NOAA Colorado Basin River Forecast Center (CBRFC) Water Resources Outlook tool at a user workshop to help identify differences in the user populations and determine changes in the Water Resources Outlook product that might be necessary for a different suite of users. In 2010, WWA and the CBRFC hosted a workshop in Grand Junction, Colo., where we tested the usability of the new RFC Water Resources Outlook online tool. During the workshop, researchers evaluated the climate literacy of participants and assessed the utility of the tool using decision gaming. The information gathered fed directly back to the developers who intend to use the information to improve the online product. WWA also held a workshop in January 2011 at the AMS Meeting in Seattle, Wash., in conjunction with a short course on water resources (http://www.cbrfc.noaa.gov/shortcourse/agenda.htm). This workshop introduced a gaming exercise that involved forecasted flows and reservoir schedules. A planned workshop in Salt Lake City has been postponed until late summer 2011 due to flooding events in the area, which required significant attention from potential workshop attendees.

Milestone 2. WWA will continue to partner with the Center for Snow and Avalanche Studies in Silverton, Colo., to investigate the impacts of dust deposition on snow on Colorado River runoff.

Hydrologic modeling was used to understand the influence of dust deposition and climate change on snowmelt and runoff in the Colorado River Basin. In September 2010, *Proceedings of the National Academy of Sciences* published "Response of Colorado River Runoff to Dust Radiative Forcing in Snow," a summary of WWA work on the impacts of dust on snowpack in the Colorado River Basin. WWA team members Tom Painter, Jeff Deems and Brad Udall collaborated with Chris Landry of the Center for Snow and Avalanche Studies and two other coauthors on the paper. This research used the Variable Infiltration Capacity (VIC) model to show that dust deposition is not only causing early spring runoff, but also may be responsible for evaporative losses equivalent to 800,000 acre-feet, or nearly 5 percent of the total river flow. The study is being updated to incorporate data from 2009 and 2010, and

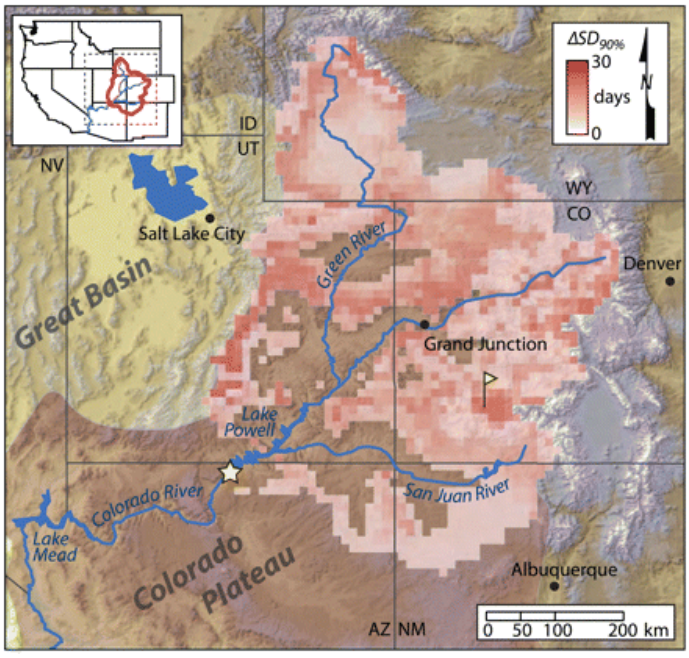
to incorporate future climate projections.

Product: Painter, TH, JS Deems, J Belnap, AF Hamlet, CC Landry, B Udall (2010), Response of Colorado River runoff to dust radiative forcing in snow, *Proceedings of the National Academy of Sciences, 107*(40), 17125-17130.

Milestone 3. WWA proposes to increase availability and use of paleohydrologic data in Utah during the next three to five years by coordinating methods proven successful elsewhere, beginning with scoping of Utah stakeholder needs for new paleohydrologies (gauge reconstructions) with one or two workshops in 2010, followed by an assessment of existing tree-ring data network for reconstructing those gauges, and development of new gauge reconstructions.

In summer 2010, WWA began engaging with a newly established group of researchers at Utah State University (USU), Brigham Young University and the Bureau of Reclamation, whose interest in using tree rings to reconstruct streamflow in the Wasatch Front and elsewhere in Utah coincided with the objectives of this milestone. Because of the emergence of this USU/BYU/Reclamation group, WWA's role shifted to one of technical advisor, helping that group establish an effective stakeholder-oriented research program modeled along the paleohydrology work conducted by WWA in Colorado between 2003 and 2009. WWA Team member Jeff Lukas assisted the USU group with grant applications to Reclamation research funding programs, participated in two project workshops held at USU in September 2010 and March 2011 and provided input on strategies for study design, fieldwork, analysis and stakeholder outreach. The USU-led group is conducting fieldwork and analyses in summer 2011, and should be developing new gauge reconstructions for northern Utah in fall and winter, with continued guidance from WWA.

Also, WWA has advanced two related paleohydrology efforts during the past year. First, a WWA-led project to reconstruct paleo-flows for the Lower Colorado River Basin commenced in September 2010. The scope of the project includes a portion of southwestern Utah within the Virgin River and Kanab Creek basins. Second, WWA continued to lead the updating and maintenance of the TreeFlow web resource for tree-ring paleohydrology (http://treeflow.info), which will ultimately archive the Utah data produced by the USU group and by the Lower Colorado River Basin paleohydrology project.



WWA-02 Climate Products

FEDERAL LEAD: ROBIN WEBB
CIRES LEADS: KRISTEN AVERYT, ERIC GORDON AND BRADLEY UDALL

NOAA Goal 2: Climate

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

Milestone 1. WWA will continue to publish the Intermountain West Climate Summary (IWCS), a compact Web-based package that includes the latest climate observations and forecasts for Colorado, Wyoming and Utah. This package will be produced seven to eight times each year.

In the past year, Western Water Assessment (WWA) continued on its schedule of producing six web-based issues of the IWCS, whose release is announced to a list of 400 stakeholders. All of the Feature and Focus articles in the past year were written expressly for the IWCS, with the Feature articles highlighting WWA research on hydrologic impacts of dust-on-snow and El Niño/Southern Oscillation-based streamflow forecasts; the WWA-led Colorado Climate Preparedness Project; WWA workshops on the water impacts of bark beetle infestation; and the National Integrated Drought Information System (NIDIS) Upper Colorado River Pilot. The release of each issue of the IWCS continues to be announced on the homepages of NOAA National Weather Service forecast offices throughout the region and other partner organizations.

Product: Wolter, K, and J Lukas (2010), ENSO and intermountain west water supply: A review of WY 2010 and outlook for WY 2011, Intermountain West Climate Summary, 6 (User input status: Published).

WWA-03 Climate and Water Affairs

FEDERAL LEAD: ROBIN WEBB
CIRES LEADS: KRISTEN AVERYT, ERIC GORDON AND BRADLEY UDALL

NOAA Goal 2: Climate

Project Goal: Increase decision makers' level of 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. WWA research is positioned to inform decision-making. WWA will continue facilitating conversations, discussions and interactions within the WWA stakeholder network of 100 organizations and 250 individuals, while assessing the impacts of such outreach activities.

Western Water Assessment (WWA) continued to bolster its longstanding reputation with

stakeholders and decision makers as a trusted source of climate information by participating in numerous stakeholder meetings and workshops. Collectively, WWA researchers gave more than 35 public talks and seminars since July 1, 2010, and were cited, quoted or interviewed by the media more than 50 times. The WWA research team produced 16 articles and book chapters. In addition, WWA staff served as members of many committees and organizations and continued efforts to expand climate literacy by hosting sponsored workshops across the Intermountain West. WWA staff organized numerous workshops to facilitate interactions between researchers and stakeholders, including a December 2010 meeting of Front Range water providers, an April 2011 science symposium focused on water-related impacts of bark beetle infestations and the June 2011 Colorado River Basin workshop on adaptive capacity. This activity helps fill gaps in science translation and provides us with additional information on the utility of WWA interactions and the need for future regionally based climate services and access to information.

Milestone 2. WWA researchers will, over the next two years, identify, engage and support research, scientists and stakeholders affected by decisions made at the interface of the water-energy nexus. In collaboration with energy-focused university and governmental researchers (including those from the National Renewable Energy Laboratory and the National Energy Technology Laboratory) and WWA's existing network of water professionals, WWA plans to identify salient issues and researchers approaching the energy-water nexus from either sector.

In August 2010, WWA hosted a workshop at NOAA entitled "Integrated Water-Energy Modeling Efforts & Reconciling Water Requirements for Electricity Generation." The results of the meeting were presented at the American Geophysical Union 2010 Fall Meeting. The consensus around the water requirements for energy (which leveraged WWA efforts to improve the University of California-Santa Barbara's database) is reflected in a National Renewable Energy Laboratory (NREL) report released in April 2011. At the workshop, WWA's parallel effort with NREL was recognized and subsequently merged into a single effort led by NREL. WWA will be working with the Union of Concerned Scientists to host a meeting with a similar theme, but focused on the collaboration with University of California-Santa Barbara, in late Summer 2011. In addition, WWA researchers submitted a manuscript entitled The Water-Energy Nexus in the Western United States. This book features contributions from 24 authors drawn from a network of water-energy-climate change researchers and decision makers whom we have cultivated over the past two years. The book is scheduled for publication in October 2011 by Edward Elgar Publishing.

Product: Averyt, K, D Kenney, R Wilkinson (Ed.) (2010), The Coal Conundrum, in *The Water-Energy Nexus in the Western US* (User input status: In press).

WWA-04 Management

FEDERAL LEAD: ROBIN WEBB
CIRES LEADS: KRISTEN AVERYT, ERIC GORDON AND BRADLEY UDALL

NOAA Goal 3: Weather and Water

Project Goal: Provide overall guidance to project as well as day-to-day management.

Milestone 1. WWA will begin a structured review process for all activities, which will require WWA to listen to its local stakeholders and regularly reconsider its role within NOAA and NOAA-administered programs (e.g., NIDIS), including the emerging National Climate Service. This will be implemented over the next five years.

Western Water Assessment (WWA) has hired Elizabeth McNie, an assistant professor at Purdue University whose dissertation focused on Regional Integrated Sciences and Assessments (RISA) programs, to conduct an independent evaluation of WWA's work. McNie has interviewed WWA staff, compiled background information on existing and historic WWA work and is proceeding with semi-structured interviews of WWA team members and stakeholders. A preliminary internal report for WWA is expected later this year, although the overall project will continue into next year. In addition, in January 2011 WWA conducted an informal survey of Advisory Board members to help provide new research ideas and incorporated those ideas into its 2011-2012 research agenda. WWA will hold its annual Advisory Board meeting in September 2011 to solicit further input and help incorporate stakeholders directly into research activities.

Milestone 2. WWA will co-locate a research liaison with respective state climatologists in Colorado, Utah and Wyoming to build stakeholder relationships, identify climate science critical to the state and integrate locally needed and locally occurring research with other WWA activities. These partnerships will also strengthen the relationship between WWA and National Integrated Drought Information System (NIDIS) as the state climatologists are involved in the NIDIS Upper Colorado River Basin Pilot study. Partners will meet on at least a quarterly basis at the WWA core office.

At the request of NOAA's Climate Program Office, the research liaisons positions were removed from prospective employment with the Wyoming and Utah state climatologists' offices and instead became direct CIRES hires. The Utah Liaison, Tim Bardsley, was hired in December 2010 and placed at the NOAA Colorado Basin River Forecast Center in Salt Lake City. He has worked to develop a Utah-based network of stakeholders and scientists; begun compiling background information for the National Climate Assessment; and is helping the Salt Lake City Public Utilities draft an adaptation plan. The Wyoming Liaison is intended to be housed by the Ruckelshaus Institute at the University of Wyoming. Our year-long effort to find a liaison there, however, has not yet yielded a qualified candidate. After consultation with University and other contacts in Wyoming, we have decided instead to try to hire an experienced person connected with the water sector in the state as a part-time consultant. That process is ongoing.

Science on a Sphere

IA-03 Education and Outreach

■ GSD-08 Science Education and Outreach

GSD-08 Science Education and Outreach

FEDERAL LEAD: WILLIAM BENDEL
CIRES LEAD: ELIZABETH RUSSELL

NOAA Goal 3: Weather and Water

Project Goal: Enhance scientific environmental literacy and improve understanding, value and use of weather and water information and services to the public, including the K-12 education community.

Milestone 1. Communicate and coordinate NOAA educational activities with respect to Science On a Sphere (SOS) with the SOS user community and the public. Specific activities include the creation of thematic narratives for the user community, the annual SOS Users Group meeting, numerous traveling exhibits and field trips from local schools and universities.

The July 2010–June 2011 period has been very active for the Science On a Sphere (SOS) team. The year culminated with the 2011 SOS Users Collaborative Network Workshop in Chicago, Ill., hosted by the Museum of Science and Industry. This workshop had more than 100 participants and served as a place to highlight recent accomplishments and innovations and provide direction for the future. Many SOS sites shared new educational content developed for SOS that is now available to the whole SOS network. The SOS team also took this time to present some of the recent additions to the SOS data catalog. Over the past year, 23 new data sets have been made available to the SOS network, in addition to several scripts and playlists generated by SOS sites.

The traveling NOAA SOS exhibit was set up three times for public display at the SuperComputing 2010 conference; the 2011 South Florida Fair; and the American Association for the Advancement of Science Annual Meeting. The South Florida Fair is considered a particular success with more than 6,000 people attending a SOS presentation during the fair. In addition, 18 new permanent SOS exhibits were installed around the world, in locations such as China, Mexico, England, Denmark and the United States.

In the past year, more than 2,000 students visited SOS at the Earth System Research Laboratory and enjoyed a presentation from a NOAA scientist.

Milestone 2. Develop new and enhance existing features of the SOS system through software improvements.

During this fiscal year, two new CIRES employees have been added to the technical SOS team. Jon Loptien was hired in October 2010 to serve as technical support for the growing number of SOS sites, and Shilpi Gupta was hired in January 2011 as a software engineer to develop new features for SOS. A new version of the SOS software with major improvements is set for release in July 2011. The past year has seen much effort put into developing the upcoming software release, including increased functionality and ease of use of existing features, as well as new additions such as an iPad application for controlling SOS.

As new hardware pieces, such as computers, graphics cards and projectors, become available, the technical team integrates them into SOS and ensures that they are compatible with the current version of the software. Software improvements have also been made to take advantage of the new hardware in the past year. The technical team also made enhancements to the software to accommodate a new version of the operating system used for SOS. Another significant technological effort over the past year has been to simplify the installation process for new or upgrading SOS sites.

Milestone 3. Explore the expanding frontiers of virtual worlds, simulation and visualization tools to aid NOAA education and outreach, science, and support to the public, in line with NOAA's mission

This last year has seen a technology upgrade and change of focus in the development of virtual worlds. The virtual worlds group has successfully transitioned to the latest generation of visualization tools; has been recognized as a national leader in government and education; has delivered products to customers both within and outside NOAA; and continues to expand its skill set with standalone, massively multiuser online and mobile applications. The biggest change has been a switch from proprietary existing platforms like Second Life to Unity3D, a cutting-edge graphics engine. This technology allows NOAA's Technology Outreach Branch (TOB) to create virtual worlds directly within a web browser; to deliver simulations for classroom use on a CD; and to create mobile visualization applications. This switch also allows TOB to directly use models created by data-visualization labs and other groups within and outside of NOAA.

The increase from part-time to full-time of Brandon Lynge has allowed the virtual worlds group to expand from education to data visualizations and simulations, to better fit customers' needs. This effort has required significant training, but the group continues to reach significant milestones. For instance, the group has created what is perhaps NOAA's first 3-D role-playing simulation, which was delivered to students at the Interdisciplinary Scientific Environmental Technology (ISET) Cooperative Science Center (CSC). Another deliverable was made to the Department of Energy (DOE), and work on web products is ongoing with DOE and the National Ocean Service. TOB's efforts are at the bleeding edge of government and education, and as a result, all team members have been asked to present work at national gaming and virtual worlds conferences.

IA-04 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 Agricultural Adjustments to Drought

FEDERAL LEAD: CHRISTINA ALVORD
CIRES LEAD: WILLIAM R. TRAVIS

NOAA Goal 2: Climate

Project Goal: Explain the mixture of findings of an earlier WWA-funded project (Drought Impact Indicators); determine how farmers, ranchers and the federal grazing system respond to climate variability and what role climate information plays in decision-making.

Milestone 1. Design field project, conduct interviews and write up findings for peer review.

Graduate student Kristin Gangwer completed this study, which formed the basis for her thesis. She received her master's in geography in spring 2011. Her abstract follows:

Ranchers in the Rocky Mountain West navigate a complex land-tenure system comprised of deeded, leased and public grazing lands. Droughts create management challenges for ranchers across their land holdings and impose physical, social and economic impacts on the ranching system. However, while some studies have explored Western ranchers' drought experiences and management strategies, none have looked specifically at the role land tenure plays in their drought responses, and most literature on the relationship between land tenure and drought has thus far focused outside the United States. The goal of this study, then, was explore the implications of land tenure on ranchers' drought coping behaviors and adaptive capacity. What adjustments and adaptations do ranchers deploy to cope with drought? How do ranchers' drought experiences and management strategies differ across land holdings? What role do institutions play? And what factors influence the future adaptability of the system, particularly to potential climate change?

Presentations:

1) Society for Range Management 2011 Annual Meeting (poster presentation), February 2011.

2) Center for Science and Technology Policy Research Noontime Talk, March 2011.

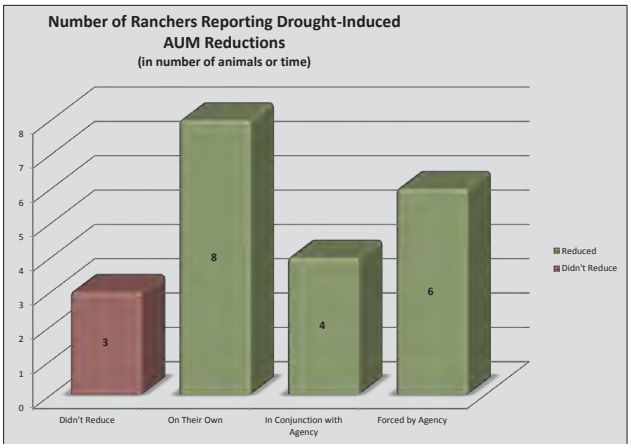
3) CIRES Rendezvous 2011 (poster presentation), April 2011.

Products:

1) Thesis

2) Journal article (to come)

3) White paper (to come)



Policy-03 Impacts of Earlier Snowmelt on Water Rights Holders in the Intermountain West

FEDERAL LEAD: CHRISTINA ALVORD
CIRES LEAD: ROBERTA KLEIN

NOAA Goal 2: Climate

Project Goal: This project will determine whether agricultural water-rights holders in the U.S. West have experienced impacts from, and made adaptations to, earlier snowmelt.

Milestone 1. Design field project, conduct interviews and write up and present findings.

This project was not funded.

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Measures of Achievement

CIRES scientists and faculty published 512 peer-reviewed papers in 2010, commanding attention from the scientific community and the news media. International awards and a strong record of service reflect institutional excellence.

BRIAN CLARK/CIRES

Allyson Eller takes notes while collecting samples of poplar hybrids she planted to study the emissions of volatile organic compounds, which can reduce air quality.

Publications by the Numbers

CIRES scientists and faculty published 512 peer-reviewed papers during calendar year 2010. The table below tabulates publications by affiliation of first author. CIRES scientists and faculty published an additional 138 non-refereed publications in 2010. 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	2009	2010
CIRES Lead Author	112	177	165	188	141	130	110	158	137
NOAA Lead Author	60	31	56	20	81	73	99	79	63
Other Lead Author	110	183	134	145	289	264	385	342	312
Total	**282**	**391**	**355**	**353**	**511**	**467**	**594**	**579**	**512**

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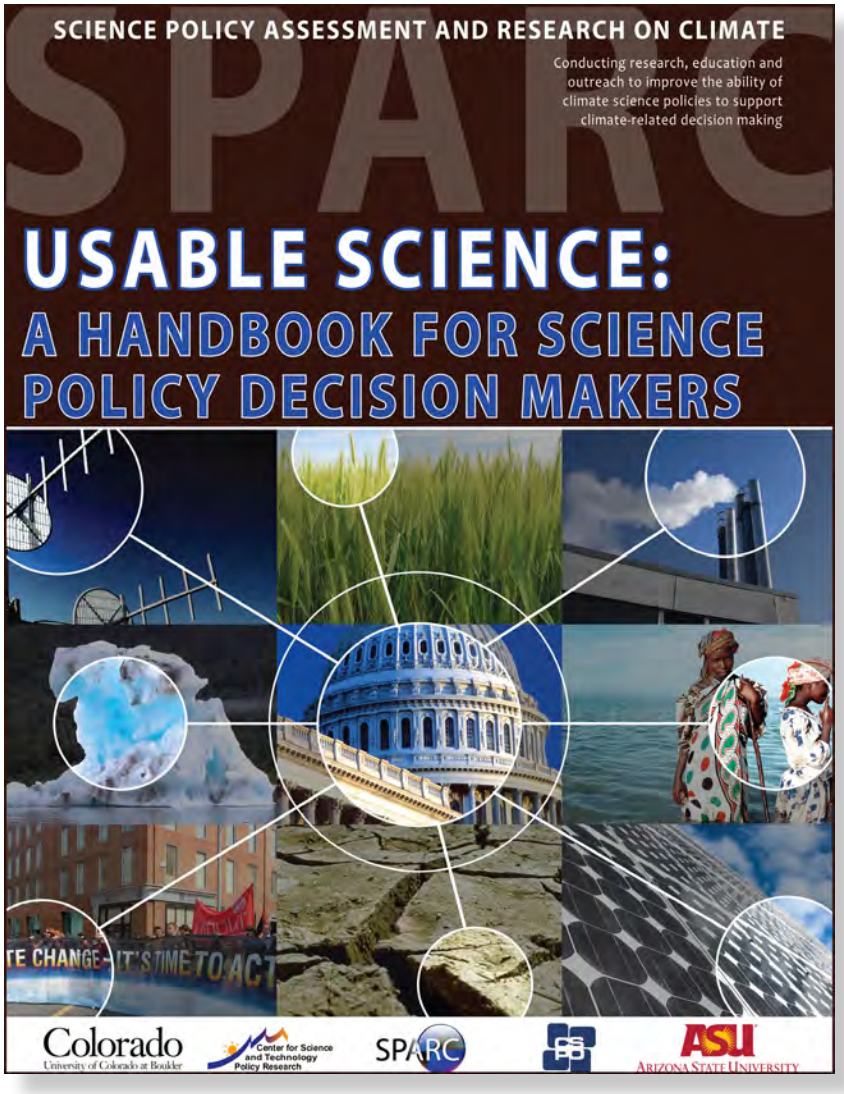

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Refereed Journals in which CIRES Scientists Published, 2010

Acta Meteorologica Sinica
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Aerosol Science and Technology
Agricultural and Forest Meteorology
Analytical Chemistry
Annales Geophysicae
Annals of Glaciology
Annual Review of Earth and Planetary Sciences
Applied Optics
Arctic, Antarctic, and Alpine Research
Asia-Pacific Journal of Atmospheric Sciences
Astrobiology
Astronomical Journal
Astrophysical Journal
Astrophysical Journal Letters
Atmospheric Chemistry and Physics
Atmospheric Environment
Atmospheric Measurement Techniques
Atmospheric Science Letters
Biochemistry
Biogeochemistry
Biogeosciences
Boundary-Layer Meteorology
Bulletin of the American Meteorological Society
Bulletin of the Seismological Society of America
Canadian Journal of Forest Research-Revue Canadienne de Recherche Forestiere
Canadian Journal of Remote Sensing
Chemical Physics Letters
ChemPhysChem
Chinese Journal of Geophysics-Chinese Edition
Chinese Science Bulletin
Climate Dynamics
Climate of the Past
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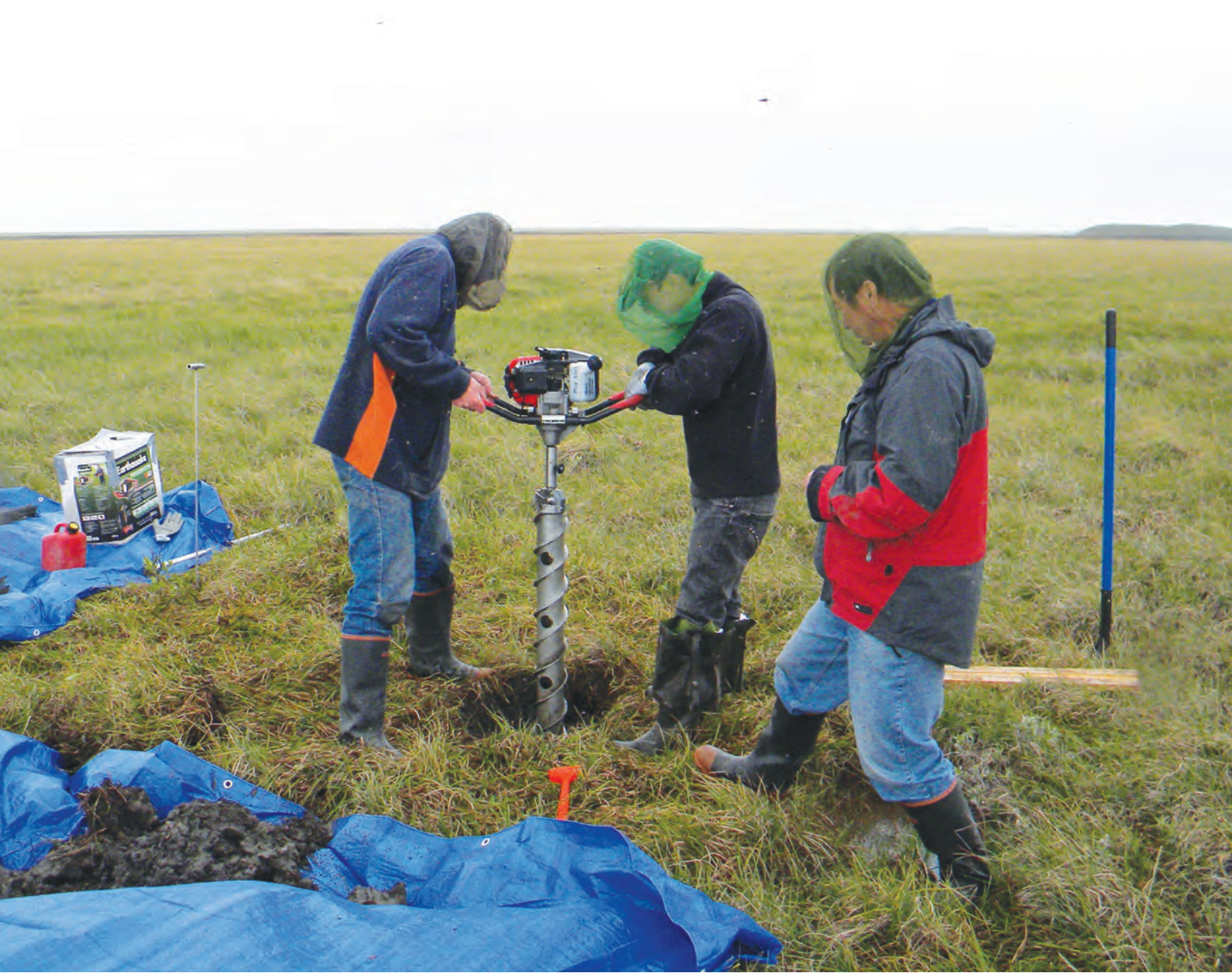
Conservation Biology
Cryosphere
Current Opinion in Environmental Sustainability
Earth and Planetary Science Letters
Earth Planets and Space
Earth Surface Processes and Landforms
Ecography
Ecological Applications
Ecology
Energies
Environment and Planning C: Government and Policy
Environmental Microbiology
Environmental Modelling and Software
Environmental Research Letters
Environmental Science and Technology
Fems Microbiology Letters
Freshwater Biology
Frontiers in Ecology and the Environment
Genome Biology
Geochemistry Geophysics Geosystems
Geographical Journal
Geological Society of America Bulletin
Geology
Geomorphology
Geophysical Journal International
Geophysical Research Letters
Geoscientific Model Development
Geosphere
Global and Planetary Change
Global Biogeochemical Cycles
Global Change Biology
Global Environmental Change: Human and Policy Dimensions
Hydrological Processes
Icarus
IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing
International Journal of Chemical Kinetics
International Journal of Climatology
International Journal of Environmental Analytical Chemistry
International Journal of Mass Spectrometry
International Journal of Offshore and Polar Engineering
International Journal of Wildland Fire
ISME Journal
Izvestiya: Physics of the Solid Earth
Journal of Applied Meteorology and Climatology
Journal of Arid Environments
Journal of Asian Earth Sciences
Journal of Atmospheric and Oceanic Technology
Journal of Atmospheric and Solar-Terrestrial Physics
Journal of Atmospheric Chemistry
Journal of Chemical Physics
Journal of Climate
Journal of Construction Engineering and Management–ASCE
Journal of Geophysical Research-Atmospheres
Journal of Geophysical Research-Biogeosciences
Journal of Geophysical Research–Earth Surface
Journal of Geophysical Research–Oceans
Journal of Geophysical Research–Solid Earth
Journal of Geophysical Research–Space Physics
Journal of Glaciology
Journal of Hydrologic Engineering
Journal of Hydrometeorology
Journal of Physical Chemistry A
Journal of Physical Oceanography
Journal of the Acoustical Society of America
Journal of the American Society for Mass Spectrometry
Journal of the American Statistical Association
Journal of the Atmospheric Sciences
Marine Geodesy
Molecular Systems Biology
Monthly Weather Review
Natural Hazards
Nature
Nature Geoscience
Nature Methods
New Phytologist
Oceanography
Oecologia
Optics Express



Tim Schaefer, Lin Liu and Tingjun Zhang drill a permafrost core sample near Deadhorse, Alaska.

Paleoceanography
Pharmacogenomics
Physical Chemistry Chemical Physics
Physics of Fluids
Physiologia Plantarum
Plant Cell and Environment
Plos One
Proceedings of the IEEE
Proceedings of the National Academy of Sciences of the United States of America
Quarterly Journal of the Royal Meteorological Society
Quaternary Science Reviews
Radiocarbon
Remote Sensing of Environment
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Resources Conservation and Recycling
Reviews of Geophysics
Science
Science China–Earth Sciences
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Sensors
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Solar Physics
Space Science Reviews
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Standards in Genomic Sciences
Tectonics
Tellus Series B–Chemical and Physical Meteorology
Terra Nova
Theoretical and Applied Climatology
Vector-Borne and Zoonotic Diseases
Water Resources Research
Weather and Forecasting
Zeitschrift Fur Physikalische Chemie–International Journal of Research in Physical Chemistry and Chemical Physics

Honors and Awards, 2010

Abdalati, Waleed
- Named Chief Scientist at NASA, where he will serve for two years as the principal adviser to the NASA administrator on agency science programs, strategic planning and the evaluation of related investments.

Barry, Roger
- Humboldt Research Fellowship in Geophysics, Bavarian Academy of Sciences, Commission on Glaciology, Munich, Germany, Aug. 2–Oct. 30, 2010.

Cherney, David
- Environmental Public Policy and Conflict Resolution Ph.D. Fellowship from the Morris K. Udall and Stewart L. Udall Foundation.

Davis, Sean
- Alan Berman Research Publication Award, Naval Research Laboratory (NRL), recognizing outstanding publications from within each division of NRL, awarded to the authors of Bucholtz et al., Directly measured heating rates of a tropical subvisible cirrus cloud.

Elespuru, Peter
- NASA Earth Science Data Systems Software Award given to the Space Physics Interactive Data Resource (SPIDR) team for development of Representational State Transfer (ReST) web-services.

- NOAA/CIRES Customer Service Award to the customer service team of the SPIDR group.

Herzfeld, Ute
- NASA Group Achievement Award and Ames Honor Award to members of the Characterization of Arctic Sea Ice Experiment (CASIE) team for outstanding accomplishments in the execution of CASIE in Svalbard, Norway.

Jimenez, Jose Luis
- Rosenstiel Award in Marine and Atmospheric Science from the Rosenstiel Foundation and the Rosenstiel School of the University of Miami, for outstanding contributions and a significant and growing impact in the last decade in marine and atmospheric science.

Lack, Steven
- CIRES Cash Award received for work on highly visible convective evaluations.

Layne, Geary
- CIRES Cash Award received for work on highly visible convective evaluations.

Lewis, William
- Baldi Memorial Lecture Award, International Society of Limnology.

Michelson, Sara
- CIRES Bronze Medal for her work to develop the modeling component of the Coastal Atmospheric River Monitoring and Early Warning System for the Hydrometeorological Testbed (HMT), an atmospheric water vapor flux tool that combines observations and numerical model output to document and monitor the atmospheric river conditions that often lead to excessive precipitation.

Molnar, Peter
- Honorary Doctor of Science Degree, Oberlin College.

Moran, Kenneth
- Special Recognition Award from the Department of Energy Atmospheric Radiation Measurement (ARM) Program, recognizing original work in the design, development and deployment of the 35 GHz Millimeter Cloud Radars for the ARM program over the past 15 years.

Noone, David
- National Science Foundation Faculty Early Career Development Award.

Rajagopalan, Balaji
- Distinguished Achievement Award from the Department of Civil, Environmental and Architectural Engineering, University of Colorado.

Russell, Elizabeth
- NOAA Earth System Research Laboratory Global Systems Division Web Award for Most Improved Site for the improvements to the Science On a Sphere® (SOS) site, http://sos.noaa.gov, enabling visitors to explore SOS, get help on the system and access a large collection of Earth System visualizations.

Shah, Anju
- CIRES Bronze medal for advancing the nation's ability to recognize, mitigate and adapt to drought through the development of the United States Drought Portal at http://www.drought.gov.

Solomon, Susan
- Career Achievement Service to America medal for her pioneering atmospheric research, including identifying the cause of the ozone hole.

Tolbert, Margaret
- Named University Distinguished Professor by Board of Regents, University of Colorado.

Vaida, Veronica
- American Chemical Society E.B. Wilson Award in Spectroscopy.

Watts, Laurel
- National Instruments Graphical System Design Achievement Award for Wireless Monitoring and Editor's Choice Award for the application 'Monitoring Atmospheric Ozone on the Global Hawk UAV With CompactRIO.'

Williams, Eric
- CIRES Bronze Medal for leadership of field missions during the International Polar Year that provided data on the climate-sensitive, fast-changing region of the Arctic.

CIRES Bronze Medal

Alexander, Curtis; Hu, Ming; and Smirnova, Tatiana
- CIRES Bronze Medal for contributions to developing the first National Centers for Environmental Prediction (NCEP) operational radar reflectivity assimilation technique, which improved short-range numerical forecasts for convective storms.

Outstanding Performance Award for Service

Billingsley, Brendan; Brodzik, Mary J.; Collins, Julia; Fowler, Doug; Kovarik, Jonathan; Miller, Deann; O'Barr, Barbara; Raup, Bruce; Scott, Donna; and Truex, Stephen
- CIRES Outstanding Performance Award for Service for contributions to the Searchlight Team, which created a new online interface and data system infrastructure for cryospheric data at the National Snow and Ice Data Center (NSIDC).

Peckham, Steven
- CIRES Outstanding Performance Award for Service for his contributions to the development of the WRF-Chem (Weather Research and Forecasting model coupled with Chemistry) air-quality model and his further work supporting WRF-Chem with workshop tutorials around the world to benefit air-quality studies.

Outstanding Performance Award for Science and Engineering

Loto'aniu, Paul; Mayer, Leslie; Rodriguez, Juan; and Shouldis, Mary
- CIRES Outstanding Performance Award for Science and Engineering for successful delivery of the Phase One Space Weather algorithms to process raw space weather observations into useful data for the R-series Geostationary Operational Environmental Satellite (GOES-R).

Nair, Manoj
- CIRES Outstanding Performance Award for Science and Engineering for developing an empirical prompt penetration model, which predicts electric field variations in the equatorial ionosphere from solar wind observations, significantly improving our understanding of prompt penetration and directly benefiting electrodynamic models of the equatorial ionosphere.

Reinard, Alysha
- CIRES Outstanding Performance Award for Science and Engineering for groundbreaking scientific work using subsurface helicity to predict solar flares that results in a major improvement to predict the time, strength and location of solar flares.

Rigler, Josh
- CIRES Outstanding Performance Award for Science and Engineering for successful delivery of the Phase One Space Weather algorithms to process raw space weather observations into useful data for the R-series Geostationary Operational Environmental Satellite (GOES-R).

HPC Innovation Excellence Award

Compo, Gilbert, and Sardeshmukh, Prashant
- The National Energy Research Scientific Computing Center (NERSCC) received a 2011 HPC Innovation Excellence Award for providing supercomputing services to the 20th Century Reanalysis Project, which Compo and Sardeshmukh helped spearhead.

Best Posters & Presentations

Chu, Xinzhao
- Best Poster Paper Award, 25th International Laser Radar Conference, St. Petersburg, Russia.

Higgins, Matthew
- Outstanding Presentation Award in the 2010 Boulder Postdoctoral Poster Symposium organized by the Department of Commerce Boulder Labs Diversity Council.

Kahan, Tara
- Outstanding Presentation Award at the 2011 Boulder Laboratories Postdoctoral Poster Symposium for her work measuring the absorption of sunlight by ozone and hydrogen peroxide.

Yamashita, Chihiko
- Best Poster at the 26th CEDAR (Coupling, Energetics and Dynamics and Atmospheric Regions) workshop for elucidation of the stratospheric sudden warming phenomenon and its effects on the atmosphere.

Conferences, Workshops, Events, Presentations

- **Global Monitoring Division:** Observations of multi-species at a rural site in China—constraints on regional emissions (07/10)
- **Goals and Plans of ATTREX,** Eric J. Jensen, NASA Ames (07/10)
- **CSTPR Graduate Student Seminar:** Acid mine drainage, stream and groundwater geochemistry (**Caitlin Crouch**, 07/10)
- **CSTPR Graduate Student Seminar:** Reconciliation environmentalism: Philosophy and theology (**Ricardo Simmons**, 07/10)
- **CIRES staff-appreciation picnic** (07/10)
- **Communication and the Environment:** Theory and practice (panel discussion; 08/10)
- **Gordon Research Conference on Science and Technology Policy** (08/10)
- **Science, Politics, and Emotion:** Talking climate change (**Maxwell Boykoff,** 08/10)
- **Analytical Chemistry Seminar, Margaret A. Tolbert** and **Rainer Volkamer** (09/10)
- **The Global Hawk Pacific Mission:** Demonstrating unmanned aircraft technology for Earth Science (**David Fahey,** 09/10)
- **Marine Renewable Energy:** A blue chip in the portfolio (**Howard P. Hanson**, 09/10)
- **CSTPR Graduate Student Seminar:** Valuing the forest for the trees, the water or the future? Nonmarket values for invasive species management (**James Meldrum,** 09/10)
- **CSTPR Graduate Student Seminar:** Hurricane intensity, frequency and controversy: Presenting information useful to those living on land (**Jessica Weinkle**, 09/10)
- **CIRES Graduate Students Association** kickoff and symposia (09/10 and throughout FY11)
- **Analytical Chemistry Seminar,** by **Daniel Feldheima** and **Robert E. Sievers** (09/10)
- **CIRES director's coffee** (09/10)
- **Hydrology & Water Resources Seminar:** Global primary production of lakes (**Dr. William Lewis,** 09/10)
- **Analytical Chemistry Seminar,** by **Carl A. Koval** and **Jose L. Jimenez** (09/10)
- **Climate change controversies in the media:** Sociological insights (**Maxwell Boykoff**, 09/10)
- **Analytical Chemistry Seminar,** by **Delphine K. Farmer** and **Patrick L. Hayes** (10/10)
- **CIRES Special Lecture:** Arctic seasons: An Inuit perspective (10/10)
- **CSTPR:** The Western Water Assessment and Climate Adaptation in Colorado (**Eric Gordon**, 10/10)
- **Hydrology & Water Resources Seminar,** by **Len Wright** (10/10)
- **CSTPR Graduate Student Seminar:** Weather modification governance as a proxy for generating geoengineering governance (**Rachel Hauser**, 10/10)
- **CSD Seminar,** Hokkaido University, Japan (**Masatomo Fujiwara,** 10/10)
- **Analytical Chemistry Seminar,** by **Alison Craven** (10/10)
- **Analytical Chemistry Seminar,** by **Callie Cole** and **Brett Palm** (11/10)
- **Hydrology & Water Resources Seminar,** by **Vijay Gupta** (11/10)
- **CIRES Innovative Research Program,** reception and poster session (11/10)
- **Roundtable Discussion** with **Mike Hulme** and graduate students (11/10)
- **DynVar Workshop 2** (11/10)
- **Why We Disagree about Climate Change:** An evening with Professors **Mike Hulme** and **Michael Zimmerman** (11/10)
- **CSD Seminar,** University of Delaware (**James Corbett,** 11/10)
- **CSTPR Graduate Student Seminar:** Climate change adaptation in Western U.S. public lands (**Kelli Archie**, 11/10)
- **Analytical Chemistry Seminar**, by **Raea Lessard** (11/10)
- **PSD Seminar:** Trajectory analysis of air mass and moisture associated with atmospheric rivers on the West Coast of the United States (**Ju-Mee Ryoo,** 11/10)
- **CSD Seminar:** The Brewer-Dobson circulation as revealed by stratospheric temperature data (**Paul Young,** 11/10)
- **Analytical Chemistry Seminar,** by **Ivan Ortega** (11/10)
- **PSD Seminar:** Integrated remote sensing and modeling of mountain snow distribution: Implications for water resource management adaptation to climate change (**Noah Paul Molotch,** 12/10)
- **CSD Seminar:** A fresh look at gas phase acids: Improving our ability to measure and understand organic and inorganic acids in the atmosphere (**Patrick Veres,** 12/10)
- **CSTPR Graduate Student Seminar:** Regional eddy covariance measurements of CO2 exchange from a tall tower near Boulder, Colorado (**Emily Graham,** 12/10)
- **CSTPR Graduate Student Seminar:** Quantifying evolving glacier landscapes with my camera (and yours too) (**Ethan Welty,** 12/10)
- **CSD Seminar:** Black carbon in snow and sea ice: Why do we care and what do we know? University of Washington (**Sarah Doherty,** 12/10)
- **CSD Seminar:** Deepwater Horizon atmospheric emissions constrain air-water partitioning, hydrocarbon fate and leak rate (**Tom Ryerson,** 12/10)
- **Retirement party** for **Roger Barry** (12/10)
- **CSD Seminar:** Impacts of climate change on tropospheric ozone: Intercontinental transport and lightning influences (**Ruth Doherty,** 01/11)
- **CSTPR, COP16,** Roundtable panel on climate adaptation (**William Boyd, Ben Hale, Marilyn Averill, Mickey Glantz** and **Jorge Rafael Figeroa,** 01/11)
- **CSTPR,** Report card for the environment: 1 C, 3 Bs, 1 A and 1 Incomplete (**Michael Glantz,** 01/11)
- **CSTPR:** Quantification of the treatment of uncertainty by the IPCC AR4 (**Roger Pielke, Jr.,** 01/11)
- **CSD Seminar:** Organic aerosol formation downwind from the Deepwater Horizon Oil Spill, NOAA/ESRL/Chemical Sciences Division & CU CIRES (**Joost de Gouw,** 01/11)
- **Analytical Chemistry Seminar,** by **Mark Hernandez** (01/11)
- **Analytical Chemistry Seminar** by **Peter Bernath** (02/11)
- **Special Talk at CIRES,** by **Jorge Chau** from the Instituto Geofísico del Perú's Jicamarca Radio Observatory near Lima (02/11)
- **CIRES and CU's Aerospace Engineering Present,** by **Chiao-Yao She (Joe)** (02/11)
- **Analytical Chemistry Seminar,** by **John Carpenter** (2/11)
- **CSTPR Graduate Student Seminar:** Can organic matter in the Boulder Creek watershed tell us if human activity is affecting aquatic carbon not in our backyard? (**Rachel Gabor,** 02/11)
- **Cryospheric and Polar Processes Seminar:** Optimizing projections of Arctic change (02/11)
- **CSD Seminar:** Clouds in a bowl of soup (**Graham Feingold,** 02/11)

- **Analytical Chemistry Seminar,** by **Eleanor Waxman** (02/11)
- **CIRES Fellows** science retreats/workshops, Energy and the environment (**Joost De Gouw,** 03/11)
- **CSTPR, Forest Governance:** The right rules (**Ashwin Ravikumar,** 03/11)
- **CSTPR:** What microbes can teach us about climate change at the bottom of the Earth (**Lee Stanish,** 03/11)
- **Analytical Chemistry Seminar,** by **Kyle Zarzana** (03/11)
- **National Ocean Sciences Bowl** (03/11)
- **CSD Seminar,** NASA Goddard Space Flight Center (**James Abshire,** 03/11)
- **Analytical Chemistry Seminar,** by **Keith P. Johnston** (03/11)
- **CSD Seminar:** Top-down mesoscale estimate of emission inventories using aircraft observations and an inverse modeling technique: Houston as an example (**Jerome Brioude,** 03/11)
- **Yelena Pichugina:** Sustainable Energy and Atmospheric Sciences Seminar (03/11)
- **Analytical Chemistry Seminar,** InDevR (**Erica Dawson,** 03/11)
- **Analytical Chemistry Seminar,** Colorado State University (**Charles S. Henry,** 04/11)
- **Analytical Chemistry Seminar,** by **J'aime Manion** and **David McAdams** (04/11)
- **Panel on Japan's recent disaster** (04/11)
- **CIRES Members' Council Rendezvous!** Science symposium (04/11)
- **CSTPR Graduate Student Seminar:** Climate change and increasing zinc concentrations in a Rocky Mountain acid rock drainage stream (**Caitlin Crouch,** 04/11)
- **CSTPR Graduate Student Seminar:** Regional integration among M&I water providers: Lessons in climate adaptation and risk management for Colorado's Front Range (**Kelsey Cody,** 04/11)
- **CSTPR, Campus2 Congress:** Energy & Environment LAs Wendy Adams and Sean Babington represent **Mark Udall** and **Michael Bennett** (04/11)
- **Deep Water Horizon Data Workshop** (04/11)
- **Analytical Chemistry Seminar,** by **Jesse H. Kroll** (04/11)
- **CSD Seminar:** Secondary organic aerosol formation in the aqueous phase of cloud droplets and aerosol particles (aqSOA) (**Barbara Ervens,** 04/11)
- **Western Water Assessment,** Beetle-Water Symposium II (04/11)
- **CSTPR,** Climate Change and Development Policy: Reflections from 1.5 years in the U.S. Government (04/11)
- **Physics Colloquium:** The Haiti earthquake and other recent and future disasters (**Roger Bilham,** 04/11)
- **CSTPR, Campus2 Congress** with **Jared Polis** (04/11)
- **Cryospheric and Polar Processes Seminar,** by **Maria (Masha) Tsukernik** (05/11)
- **CSTPR:** Defining and assessing maladaptation (**Saffron J. O'Neill,** 05/11)
- **CSTPR,** Gaining from Losses: Using disaster loss data as a tool for appraising natural disaster policy (**Shali Mohleji,** 05/11)
- **CSD Seminar:** Chemical, aerosol and cloud processes in closed and open cells (**Jan Kazil,** 06/11)
- **WWA–Colorado River Basin Workshop** (06/11)

- **CSTPR noontime seminars:**
  Paul S. Chinowsky: The cost of climate change adaptation for infrastructure: The relative impact on developing and developed countries. (09/10)
  Christine Kirchhoff: Integrating science and policy: Climate change assessments and water resources management. (09/10)
  Mark Serreze: Arctic sea changes: Prospects for increased marine traffic with unpredictable sea ice conditions. (10/10)
  Bill Travis: Declaring a climate emergency: Geo-engineering and the doctrine of last resort. (10/10)
  Mike Hulme: How climate models gain and exercise authority. (11/10)
  Waleed Abdalati: Observing and understanding changes in ice sheets: The sea level wild card. (11/10)
  Gesa Lüdeck: Media and climate-related responsible behavior: The impact of television program on individual action for climate protection regarding adolescents in Germany. (11/10)
  Rebecca Morss: Improving communication of weather forecasts and warnings to aid decisions. (12/10)
  Elizabeth McNie: Producing useful science for policy: How scientists perceive the likely utility of their research. (12/10)
  James R. (Russ) McGoodwin: Enhancing the resilience of small high-latitude fishing communities to climatic and marine-ecosystem change. (02/10)
  Roger Bilham: Global earthquake fatalities: Nature vs. human nature. (03/10)
  Kristin Gangwer: Dryness and desperate measures: Ranching, land tenure, and drought coping in the Rocky Mountain West. (03/10)
  Jeffrey K. Lazo: Inundation or ignorance? Public perception of storm surge risk. (04/10)

- **ENVS Colloquia:**
  Lisa Dilling: Research on adapting to climate change: Are we asking the right questions? (09/10)
  Julie Teel: Climate change impacts in Indian country: Adapting 'adaptation' for American Indian tribes. (10/10)
  Ted Nordhaus and **Michael Shellenberger:** Adaptation and the construction of risk. (11/10)
  Jim White: Climate change: Why we are in too deep already, and why we won't avoid serious consequences. (12/10)
  Will Toor: Planning for climate change mitigation and adaptation in Boulder County. (03/11)
  Kristopher Wilson: Adapting to climate change: How television news directors and weathercasters report the science. (04/11)

Appendices

Personnel Demographics

CIRES Personnel Breakdown 2010–2011

Category	Total CIRES Personnel	NOAA-supported CIRES Personnel	Highest Degree Earned by NOAA-supported Personnel B.S.	M.S.	Ph.D.
Faculty	22				
Research Scientist	193	121		1	120
Visiting Scientist	29	1			1
Postdoctorate Researcher	28	6			6
Associate Scientist	228	131	61	70	
Administrative	32	26	19	4	3
Total > 50% NOAA support		**285**	**80**	**75**	**130**
Undergraduate Students	86	46			
Graduate Students	96	22	22		
Received < 50% NOAA Support		**39**	**7**	**15**	**17**
Total CIRES personnel	**714**				

CIRES Personnel in NOAA Boulder Laboratories	
OAR	237
ESRL-DIR	6
Chemical Sciences Division	71
Global Monitoring Division	48
Global Systems Division	39
Physical Sciences Division	73
NESDIS/NGDC	42
NWS/SWPC	26
Total NOAA	**305**
Obtained NOAA Employment in Last Year	1

Director Konrad Steffen speaks to researchers and employees at CIRES' 2010 Rendezvous! science symposium in Boulder, Colo.

DAVID OONK/CIRES

Acronyms

20CR	Twentieth Century Reanalysis
ACCMIP	Atmospheric Chemistry and Climate Model Intercomparison Project
ACE	Atmospheric Composition Explorer
ACF	Appalachicola-Chattahoochee-Flint
ACRF	ARM Climate Research Facility
AGCM	Atmospheric General Circulation Models
AMIP	Atmospheric Model Intercomparison Project
AMO	Atlantic Multidecadal Oscillation
AMOS	Advanced Modeling and Observing Systems
AR	Assessment Report
ARM	Atmospheric Radiation Measurement
ASCOS	Arctic Summer Cloud Ocean Study
ASINA	Arctic Sea Ice News and Analysis
AWC	Aviation Weather Center
AWIPS	Advanced Weather Interactive Processing System
BB	Biomass Burning
BVSD	Boulder Valley School District
CADWR	California Department of Water Resources
CALIPSO	Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations
CalNex	California Nexus field campaign
CAM	Community Atmosphere Model
CAVE	Common AWIPS Visualization Environment
CBRFC	Colorado Basin River Forecast Center
C-BT	Colorado-Big Thompson Project
CCFP	Collaborative Convective Forecast Product
CCMC	Community Coordinated Modeling Center
CCPP	Colorado Climate Preparedness Project
CDCP	Centers for Disease Control and Prevention
CDC	Climate Diagnostics Center
CDMP	Climate Data Modernization Program
CEAS	Cavity Enhanced Absorption Spectroscopy
CEC	California Energy Commission
CEDAR	Couple Energetics and Dynamics of Atmospheric Regions
CET	Center for Environmental Technology, CU-Boulder
CFC	Chlorofluorocarbon
CHAMP	Challenging Minisatellite Payload
CIERA	Community Initiative for Emissions Research and Applications

CIMS	Chemical Ionization Mass Spectrometry
CIP	Current Icing Potential
CIRES	Cooperative Institute for Research in Environmental Sciences
CLASS	Comprehensive Large Array-data Stewardship System
CLEAN	Climate Literacy and Energy Awareness Network
CLIVAR	Climate Variability and Predictability
CLWP	Cloud Liquid Water Path
CORS	Continuously Operating Reference Stations
COSMOS	Community Earth System Models
CoSPA	Consolidated Storm Prediction for Aviation
CPC	Climate Prediction Center
C-POL	C-band scanning Polarimetric Radar
CPU	Central Processing Unit
CRDS	Cavity Ring-down Spectroscopy
CSC	Cooperative Science Center
CSD	Chemical Sciences Division (NOAA ESRL)
CSDMS	Community Surface Dynamics Modeling System
CSTPR	Center for Science and Technology Policy Research (CIRES)
CSV	Climate System Variability
CU	University of Colorado
CUMAV	University of Colorado Micro Autonomous Vehicle
CWCB	Colorado Water Conservation Board
DART	Deep-ocean Assessment and Reporting of Tsunamis
DEM	Digital Elevation Model
DMSP	Defense Meteorological Satellite Program
DMT	Data Management Tools
DOE	Department of Energy
D-RAP	D-Region Absorption Prediction
DTC	Developmental Testbed Center
DynVar	Dynamics and Variability
ECS	Extended Continental Shelf
EDR	Eddy Dissipation Rate
EMS	Enterprise Metadata System
ENSO	El Niño–Southern Oscillation
ENVS	Environmental Studies Program
EO	Education and Outreach (CIRES)
EPA	Environmental Protection Agency
ESIP	Earth Science Information Partners
ESOC	Earth Science and Observation Center (CIRES)

ESRL	Earth System Research Laboratory (NOAA)
FAA	Federal Aviation Administration
FEMA	Federal Emergency Management Agency
FGDC	Federal Geographic Data Committee
FIM	Finite-volume Icosahedral Atmospheric Model
FIP	Forecast Icing Potential
FNIH	Foundation for the National Institutes of Health
FOC	Full Operating Capability
FTIR	Fourier Transform Infrared
GasEx III	Gas Exchange Experiment
GC	Guanine-Cytosine
GCEW	Goodwin Creek Experimental Watershed
GCM	General Circulation Model
GCWIN	Grand County Water Information Network
GDS	Ground Data System
GEO	Geodynamics
GEUS	Geological Survey of Denmark and Greenland
GIA	Glacial Isostatic Adjustment
GIS	Geographic Information System
GMD	Global Monitoring Division (NOAA ESRL)
GOCART	Goddard Chemistry Aerosol Radiation and Transport
GOES	Geostationary Operational Environmental Satellite
GPS	Global Positioning System
GPU	Graphical Processor Unit
GRACE	Gravity Recovery and Climate Experiment
GSD	Global Systems Division (NOAA ESRL)
GSHHS	Global Self-consistent, Hierarchical, High-resolution Shoreline
GSI	Gridpoint Statistical Interpolation
GSRF	Graduate Student Research Fellowship
GTG	Graphical Turbulence Guidance
GV	Gulfstream V
GVAX	Ganges Valley Aerosol Experiment
HadCRUT	Hadley Centre and Climatic Research Unit
HIAPER	High-Performance Instrumented Airborne Platform
HIPPO	HIAPER Pole-to-Pole Observations
HKH	Himalaya-Karakoram-Hindu Kush
HMT	Hydrometeorology Testbed
HPC	High Performance Computing
HRDL	High Resolution Doppler Lidar

HRRR	High Resolution Rapid Refresh
HR-ToF-AMS	High Resolution Time-of-Flight Aerosol Mass Spectrometry
HWRF	Hurricane Weather Research and Forecasting
IA	Integrating Activities
IARC	International Artic Research Center
ICD	Interface Control Documents
ICEE	Inspiring Climate Education Excellence
ICESat-2	Ice Cloud and Land Elevation Satellite-2
ICR	Indirect Cost Recovery
IDA	Micro Interdigitated Electrode Array
IDB	Interface Database
ILRC	International Laser Radar Conference
IMAU	Institute for Marine and Atmospheric Research Utrecht
IN	Ice Nucleus
INSTAAR	Institute for Arctic and Alpine Research
IOC	Initial Operating Capability
IOCM	Integrated Ocean and Coastal Mapping
IPCC	Intergovernmental Panel on Climate Change
IRI	International Research Institute
IRP	Innovative Research Program
ISDAC	Indirect and Semi-Direct Aerosol Campaign
ISES	International Space Environment Services
ISET	Interdisciplinary Scientific Environmental Technology
ISO	International Standards Organization
ITIC	International Tsunami Information Center
IWCS	Intermountain West Climate Summary
IWP	Ice Water Path
LARISSA	Larsen Ice Shelf System, Antarctica
LASCO	Large Angle Spectrometric Coronagraph
LBL	Lower Boundary Layer
LEO	Low-Earth Orbit
LFMCW	Linear Frequency Modulated Continuous Wave
LiDAR	Light Detection And Ranging
LIF	Laser Induced Fluorescence
LIM	Linear Inverse Model
MACPEX	Mid-Latitude Airborne Cirrus Properties Experiment
MADIS	Meteorological Assimilation Data Ingest System
MAGT	Mean Annual Ground Temperature
MASIE	Multisensor Analyzed Sea Ice Extent
MASIE-NH	Multisensor Analyzed Sea Ice Extent–Northern Hemisphere

MERRA	Modern Era Retrospective-Analysis for Research and Applications
MFRSR	Multi-Filter Rotating Shadowband Radiometer
MIASMA	Mapping and Integrated Analysis of Microbes in the Atmosphere
MIRRMAG	Mirror of Online Magnetic Data
MODIS	Moderate Resolution Imaging Spectrometer
MRI	Major Research Instrumentation
NAO	North Atlantic Oscillation
NARCCAP	North American Regional Climate Change Assessment Program
NAS	Network-Attached Storage
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
NCEP	National Centers for Environmental Prediction
NCO	NCEP Central Operations
NCS	National Critical Systems
NEAAT	NOAA Enterprise Archive Access Tool
NESDIS	National Environmental Satellite, Data, and Information Service
NGDC	National Geophysical Data Center (NOAA)
NIC	National Ice Center
NIDIS	National Integrated Drought Information System
NIH	National Institute of Allergy and infectious Diseases
NIST	National Institute of Standards and Technology
NIWA	National Institute of Water and Atmospheric Research
NOAA	National Oceanic and Atmospheric Administration
NOSB	National Ocean Science Bowl
NREL	National Renewable Energy Laboratory
NSDL	National Science Digital Library
NSF	National Science Foundation
NSIDC	National Snow and Ice Data Center (CIRES)
NWP	Numerical Weather Prediction
NWS	National Weather Service
OAR	Oceanic and Atmospheric Research
OGC	Open Geospatial Consortium
OFIM	Icosahedral Ocean Circulation Model
OLR	Outgoing Long-Wave Radiation
OLS	Operational Linescan System
OOB	Out-of-Band Stray Light
OSMOSIS	Ocean Surface Mixing, Ocean Sub-nesoscale Interaction Study
PAMs	Payload Activation Messages
PARCA	Program for Arctic Regional Climate Assessment
PCP	Pesticide Pentachlorophenol

PDSI	Palmer Drought Severity Index
PFMP	Perfluoro-2-methyl-3-pentanone
PI	Principle Investigator
PLP	Pulsed Laser Photolysis
PLT	Post-Launch Test
PM	Planetary Metabolism
PSD	Physical Sciences Division (NOAA ESRL)
PSI	Paul Scherrer Institute
PWC	Pacific Walker Circulation
RAQMS	Real-Time Air Quality Modeling System
RCP	Representative Concentration Pathway
RH	Relative Humidity
RISA	Regional Integrated Sciences and Assessments
RP	Regional Processes
RR	Rapid Refresh
RTGM	Real-Time Ground Magnetometer
RUC	Rapid Update Cycle
SCICEX	Science Ice Exercise
SDO	Solar Dynamics Observatory
SGP	Southern Great Plains
SHEBA	Surface Heat Budget of the Arctic Ocean
SLR	Satellite Laser Ranging Observations
SOA	Secondary Organic Aerosol
SOARS	Significant Opportunities in Atmospheric Research and Science Program
SOM	Slab Ocean Model
SOS	Science on a Sphere
SPIDR	Space Physics Interactive Data Resource
SST	Sea Surface Temperature
SSW	Sudden Stratospheric Warmings
STAR	Center for Satellite Applications and Research
STEM	Science, Technology, Engineering and Math
STEREO	Solar Terrestrial Relations Observatory
StormVEX	Storm Peak Laboratory Cloud Property Validation Experiment
STPD	Solar and Terrestrial Physics Division
SUMO	Small Unmanned Aerial Observer
SURFA	Surface Flux Analysis
SURFRAD	Surface Radiation Budget Network
SUVI	Solar Ultraviolet Imager
SWPC	Space Weather Prediction Center (NOAA)
SWV	Stratospheric Water Vapor

SXI	Solar X-ray Imager
TES	Total Emission Spectrometer
TIMS	Thermal Ionization Mass Spectrometry
TOB	Technology Outreach Branch
TOC	Telecommunications Operations Center
TOPAZ	Tunable Optical Profile for Aerosol and Ozone
TOPEX	Topography Experiment
TSP	Thermal State of Permafrost
TWP	Tropical Western Pacific
UAS	Unmanned Aircraft Systems
UCRB	Upper Colorado River Basin
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNOLS	University-National Oceanographic Laboratory System
UoM	University of Manchester
UROP	Undergraduate Research Opportunities Program
UT/LS	Upper Troposphere and Lower Stratosphere
UTM	Universal Transverse Mercator
UV	Ultraviolet
VAMOS	Variability of the American Monsoon Systems
VIC	Variable Infiltration Capacity
VOC	Volatile Organic Compound
VOCALS-REX	VAMOS Ocean-Cloud-Atmosphere-Land Study Regional Experiment
WAM	Whole Atmosphere Model
WMO	World Meteorological Organization
WRF	Weather Research and Forecasting
WRF-Chem	WRF with Chemistry
WSA	Wang-Sheeley-Arge
WWA	Western Water Assessment