



CIRES ANNUAL REPORT

2010

COOPERATIVE

INSTITUTE

FOR RESEARCH

IN ENVIRONMENTAL

SCIENCES

CRYOSPHERIC AND POLAR PROCESSES | ENVIRONMENTAL CHEMISTRY
ECOSYSTEM SCIENCE | SOLID EARTH SCIENCES | WEATHER AND CLIMATE
ENVIRONMENTAL OBSERVATIONS, MODELING, AND FORECASTING

Colorado
University of Colorado at Boulder

**COOPERATIVE INSTITUTE FOR RESEARCH
IN ENVIRONMENTAL SCIENCES**

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*Cover image shot by a camera aboard an unmanned
aircraft system flying over Arctic sea ice, courtesy of NOAA.*

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From the Director

CIRES researchers are excited to face the challenge of creating a new climate service, which will engage our cross-disciplinary research teams in cryosphere, biosphere, atmosphere, geosphere, and hydrosphere sciences.

A new climate service has been proposed for the United States. The National Oceanic and Atmospheric Administration Climate Service, modeled loosely on the 140-year-old National Weather Service, would provide forecasts and information to farmers, regional water managers, emergency responders, infrastructure planners, and the many other sectors affected by changing climate conditions.

Meeting the needs of these and other users of climate information will be an enormous challenge. The first eight months of 2010 tied the same period in 1998 for the warmest combined land and ocean surface temperature on record worldwide. The June-August summer was the second warmest on record globally after 1998, and this August was the third warmest on record. Climate variability and change are impacting our society and the environment. Commerce, public health, natural resources, and major economic sectors, such as water utilities, energy, transportation, agriculture, forestry, and fisheries are highly sensitive to climate influences.

The researchers at the Cooperative Institute for Research in Environmental Sciences (CIRES) in collaboration with our NOAA colleagues are excited to face the challenge of creating a new climate service, which will engage our cross-disciplinary research teams in cryosphere, biosphere, atmosphere, geosphere, and hydrosphere sciences. Just last year, the National Research Council published a report on restructuring federal climate research to meet the challenges of climate change, one of the most important global environmental problems facing the world today.

CIRES shows a healthy growth both in funding and research personnel. We had a remarkable increase of 10 percent in research funding in FY10, with equal parts for the cooperative research with NOAA and the remaining funding sources from NSF, NASA, and the University of Colorado, totaling over \$58.8 million. Our research productivity remains very strong with 579 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 (464) and excellent administrative staff (30), working with over 100 graduate students as one team to advance our knowledge and understanding in environmental sciences. CIRES has grown to a 664-person institute and we continue to remain a world leader in interdisciplinary research.

CIRES researchers and staff received a total of 44 awards, ranging from Professor of Distinction by the CU-Boulder College of Arts and Sciences (Dr. John Wahr), Recognition by Rear Admiral Jonathan Bailey for the development of the NOAA Research Fleet Air Emission Study (Dr. Daniel Lack), NASA Group Achievement Award for participating in the 2008 Newly-Operating and Validated Instruments Comparison Experiment (Drs. Joshua Schwarz and Laurel Watts), the Governor's Award for Research Impact (Dr. Robert Sievers), and the Partners in Conservation Award from the U.S. Department of Interior for work developing innovative, new operational guidelines for manag-



ing the Colorado River in drought years (Mr. Bradley Udall and Dr. Balaji Rajagopalan), to name a few.

We welcome a new CIRES tenure-track faculty researcher, Dr. Maxwell Boykoff, Assistant Professor in the Department of Environmental Studies and a new member of the CIRES Center for Science and Technology Policy Research. This increases our tenure track faculty lines in the graduate school to 22 in eleven 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, the Western Water Assessment, and education and outreach. 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, Dr. Katy Human, and Mr. Steve Miller, who were instrumental in coordinating this effort. Enjoy your reading!

A handwritten signature in black ink, appearing to read "Maxwell Boykoff". The signature is written in a cursive, flowing style.

Executive Summary and Research Highlights

CIRES: Science in Service to Society

The Cooperative Institute for Research in Environmental Sciences (CIRES) at the University of Colorado at Boulder has been a world leader in interdisciplinary research and teaching since 1967 when it was established as NOAA's first cooperative institute. In service to society, CIRES researchers use established and innovative approaches to study all aspects of Earth system science. This summary highlights many of the past year's activities and research accomplishments, demonstrating how CIRES continues to help NOAA meet its strategic goals and how CIRES continues to communicate its research findings to help inform decision makers and the public about how to best ensure a sustainable environment.

Among CIRES' many accomplishments in FY10 was our researchers' quick-response science to evaluate air quality concerns and other atmospheric effects of the Deepwater Horizon oil spill in the Gulf of Mexico. Next year's Annual Report will include results from that mission, but it should be noted here that CIRES scientists successfully diverted a sophisticated research aircraft (the NOAA WP-3D) to the Gulf and conducted careful science in collaboration with the U.S. Environmental Protection Agency and the Occupational Safety and Health Administration—and still managed to complete the mission goals of the California Nexus campaign. That mission, reported upon in this document, used many platforms to investigate the intersection of air quality and climate change in California.

CIRES had a remarkable year of research support during fiscal year 2010 (FY10, 1 July 2009 to 30 June 2010), with total extramural research expenses of \$54,745,635 (nearly 10 percent or \$5 million more than FY09). The outlook for CIRES science remains strong, as CIRES researchers submitted, through the services of the administrative staff, 326 proposals for external funding compared with 273 in the previous year. Including university faculty support, CIRES' total budget was \$58,766,357. NOAA support through the Cooperative Agreement (Agreement) accounted for \$28,040,167 (48 percent), external research awards accounted for \$26,705,468 (45 percent), and university faculty support accounted for \$4,020,722 (7 percent).

CIRES supported 183 research scientists, 226 associate scientists, 35 visiting scientists, 20 postdoctoral researchers, 30 administrative staff, 105 graduate students, and 65 undergraduate students. In total, CIRES supported 664 scientists, staff, and students. In FY10, CIRES added a new faculty line increasing the total number of faculty lines to 22. In total, CIRES researchers published 579 peer-reviewed publications in 2009.

The CIRES Council of Fellows welcomed Dr. Maxwell Boykoff, Assistant Professor of Environmental Studies, now located at CIRES' Center for Science and Technology Policy Research. Previously, he was a research fellow in the Environmental Change Institute and lecturer in the School of Geography at the Oxford University Centre for the Environment. Dr. Boykoff's research focus is on the interactions between state and non-state actors at the interface of environmental science, policy and practice—in particular, the transformations of carbon-based economies and societies.

CIRES completed the new Scientific Workplan for the 27-month period from 1 July 2010 to 30 September 2012, based on the extension award for Cooperative Agreement NA10OAR4320142. The Workplan describes the proposed collaborative research, according to themes outlined in the Agreement, which will be undertaken during this time-frame. For each of the proposed research projects, the goal, approach, and milestones are described in detail.

The University of Colorado reviews all departments and institutes every seven years. The review process, called ARPAC (Academic Review and Planning Advisory Committee), allows the Boulder Campus to diagnose strengths and weaknesses of primary administrative units. CIRES underwent review during 2010. The review involves preparation of a self-study document, a review by an internal committee, and a review by an external committee. The self-study and the two written reviews are submitted to a Campus Review Board. The outcome of the review is a list of requirements that must be addressed by the unit prior to the next review. CIRES' 2010 review was laudatory.

The Western Water Assessment, a NOAA Regional Integrated Sciences and Assessments project created in 1999 as a joint effort with CIRES, successfully rebid and was awarded its third five-year contract in 2009, and received additional funds from NOAA's Climate Program Office for work over two years on supporting the U.S. National Assessment of Climate Change.

A new series of forward-looking scientific workshops was initiated by CIRES to engage the Council of Fellows and the Boulder scientific community to identify common strengths on which to build and to bridge with different researchers. Workshop participants focused on how to develop those strengths and linkages within the next three to five years, fostering future research programs and contributing to CIRES' goal of conducting research relevant to society's greatest challenges. The workshops also serve in identifying needed areas of expertise for new faculty hires, the appointment of new Fellows and CIRES affiliates at the university, Boulder research laboratories, and elsewhere. Five workshops were held on the following topics: environmental change and decision making under uncertainty, organic molecules in the atmosphere, remote sensing in geosciences, paleo perspectives in climate change, and energy and the environment.

The new CIRES Fellow and senior research scientist seminar series at NOAA's David Skaggs Research Center started in July 2009. CIRES Fellows Waleed Abdalati, Mark Serreze, and Rainer Volkamer initiated the popular new event by giving engaging presentations on CIRES research and discussing possible collaborations with NOAA researchers.

CIRES enhanced its communications efforts this past year in support of our mission to share world-class research in ways that help inform decision makers and the public. A new periodic magazine, *Spheres*, was created to highlight the diversity of CIRES research in the hydrosphere, biosphere, cryosphere, atmosphere, geosphere, and others—as well as accomplishments in education and outreach. The popular series is available online and has been widely



Burning oil in the Gulf.

U.S. COAST GUARD

distributed in print version. Also, in November 2009, CIRES launched a newly designed and restructured website. Since then, visits to the website and page views have increased by about 50 percent. Dynamic homepage features on CIRES research, news, multi-media spotlights (video, podcasts, slide shows, and interactive panoramas), blogs written by CIRES researchers, as well as improvements in usability all contributed to the impressive gains. CIRES research continues to be featured widely in the media, including, for example: USA Today, Time, The New York Times, Scientific American, CBS, Discovery, National Geographic, BBC, BusinessWeek, MSNBC, Fox News, and the Los Angeles Times. A summary of CIRES communication products has been added to this year's annual report.

CIRES is very pleased to continue support of its established competitive programs that provide research and education opportunities to visiting scientists, innovative CIRES scientists, and graduate students. This past year, the CIRES Visiting Fellow program supported four sabbatical and four postdoctoral scientists conducting diverse research on Antarctic seabird population responses to climate change, volatile organic compound emissions from hybrid poplars under various carbon dioxide conditions, fungi in arid land soils and biological soil crusts, organic aerosol mass balance, optical properties and direct radiative impacts of atmospheric aerosols, and more.

The Innovative Research Program funded six inventive proposals to support exploratory research. Examples of the innovative and collaborative work supported by this program include a tsunami wave propagation study by CIRES geophysicists and NOAA-NGDC marine scientists, who will use their extraordinary dataset of seafloor pressure gauges to help bridge the earthquake-to-tsunami modeling gap, which could improve monitoring tsunamis and forecasting effects. Other funded projects include the use of remote sensing to monitor the benefits of "green infrastructure" on carbon sequestration and heat-island effects in urban environments, the use of ancient coral to reconstruct the El Niño-Southern Oscillation history from decades to millennia for past and present comparisons, novel three-dimensional aircraft-based measurements of wind and ozone transport, development of new instrumentation to measure accurately for the first time weak ozone absorption of near ultraviolet light, and development of a vaccine for human papillomavirus that does not require the use of needles or refrigeration.

The CIRES Distinguished Lecture Series featured two prominent speakers: Dr. Steve Rayner, James Martin Professor of Science and Civilization and Director of the Institute for Science, Innovation and Society at Oxford University presenting "The problem of uncomfortable knowledge in science policy debates;" and Dr. Peter B. Kelemen, Arthur

D. Storke Professor of Geochemistry in Columbia University's Department of Earth and Environmental Sciences, based at Lamont Doherty Earth Observatory presenting "In situ mineral carbonation in peridotite for geological capture and storage of CO₂."

CIRES continues to strongly support its expanding graduate student enrollment through fellowships and sponsorship of its Graduate Student Association, which was created to provide a venue for students to discuss their research in organized seminars and to enjoy social events with colleagues. New this year was a career seminar series with panelists from academia, federal laboratories, non-profit organizations, consulting companies, and industry to offer guidance for careers in Earth system science. CIRES offers two graduate student fellowships. The CIRES Graduate Student Research Fellowship was awarded to six doctoral students, who are advised by a CIRES Fellow, with dissertation topics that include: the influence of fish stocking on food webs in mountain lakes, impacts of multiple interacting disturbances on a subalpine forest, nitrogen effects on volatile organic compound emissions from soil and plant detritus, modeling the impacts of riparian vegetation control on floodplain morphology, processing of organics in atmospheric aerosols, and sources and chemical transformations of ambient aerosol. The ESRL-CIRES Graduate Student Research Fellowship, initiated in FY08, is offered in alternate years to prospective master's and doctoral students. The next competition will be announced in the fall of 2010 and awarded in the spring of 2011.

CIRES participated in, organized, and sponsored numerous events in FY10. Highlights include the inaugural annual symposium of the Center for Research and Education in Wind—part of the Colorado Renewable Energy Collaboratory comprised of three academic institutions and three federal labs including NOAA; the Energy Initiative fall symposium, in collaboration with the CIRES Center for Science and Technology Policy's Energy Initiative; the Mountain Pine Beetle Symposium; the Colorado Climate Curriculum workshop on Climate Literacy Essential Principles; an inaugural annual Visiting Fellows poster reception; and a reception in recognition of CIRES Fellow and former Director Robert Sievers, who received the American Chemical Society's prestigious Astellas Prize for his work developing an inhalable measles vaccine.

This annual report is an accounting of collaborative research goals described in the CIRES-NOAA FY09 and FY10 Scientific Workplan, year two. 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.



ISTOCK

CIRES and NOAA researchers are creating new high-resolution digital elevation models, which help emergency managers understand how waves and storm surges will affect their coastal communities.

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 datasets and other information products that can help assess coastal hazards and support seafloor research.

The *Scan Eagle* unmanned aircraft system aboard the NOAA vessel *MacArthur II* collected more than 27,000 images over the Arctic waters that were analyzed through an automated program to identify and characterize the sea ice and to identify images of seals. This accomplishment has added importance because NOAA is now able to carry out its mission to monitor seal populations in hazardous field conditions without needing to rely on other agencies for helicopter-capable ships and without putting pilots at unnecessary risk.

CIRES and NOAA researchers are enhancing the Hurricane Weather Forecasting and Research model to improve forecasts for tropical cyclone intensity, wave and storm surge, and hurricane-related inland flooding. Assessment of flooding risks related to very heavy precipitation that falls upwind of mountain ranges along the U.S. West Coast was aided by the development of a web-accessible, real-time, quasi-operational version of the orographic-precipitation support tool. This tool was made accessible to scientists, forecasters, and decision makers to help monitor and study these extreme precipitation events.

Other efforts include improving the integration of coastal data and developing new products—such as accurate high-resolution digital elevation models—that enable improved assessment of hazards and coastal vulnerability, and help coastal emergency managers prepare communities for tsunami and storm-surge events. These researchers are also contributing to a streamlined, more fully automated, and accessible process for archiving and delivering marine geophysical data in support of seafloor research. Two specific, ongoing U.S. mapping efforts include the Extended Continental Shelf project, and the Integrated Ocean and Coastal Mapping 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 FY10 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 84).

Advances in climate observations and monitoring by CIRES and NOAA researchers include the development and deployment of a new instrument—the Aerosol Scattering-To-Extinction Ratio—for measuring the climate effect of aerosol particles. An exciting new discovery of long-term increase in irradiance (brightening) at Earth’s surface, corresponding with changes in cloudiness was published. Also, the first product of the Paleoclimate Network was released, integrating dozens of high-resolution temperature records derived from paleoclimate proxies, mostly tree rings, over the past 2,000 years-plus.

In climate research and modeling, CIRES researchers played key roles in the completion of a major mission in California, the multi-agency, multi-platform California Nexus (or CalNex) exploring the intersection of climate change and air quality in California. This mission was in collaboration with the California Air Resources Board, which is interested in how policies to address one of those issues may be beneficial to the other, or may have unintended detrimental impacts on the other. Results from several other recent climate-related research missions were published, including: International Chemistry Experiment in the Arctic Lower Troposphere; Aerosol, Radiation, and Cloud Processes affecting Arctic Climate; Arctic Summer Cloud Ocean Study; and Arctic Mechanisms of Interaction between Surface and Atmosphere. Research and modeling work resulted in a major new publication highlighting how changes in water vapor in the stratosphere affect surface temperature trends (Solomon et al. 2009), with a decrease in lower stratospheric water vapor slowing the rate of decadal warming after 2000.

In support of NOAA’s goal to serve society with climate products, CIRES’ Western Water Assessment (WWA) con-

tinues to focus on delivering useful scientific information to users, and to incorporate user needs into scientific research. In FY10, WWA updated delivery of its signature publication, *Intermountain West Climate Summary*, an important tool for water managers and other climate-sensitive sectors in the region. WWA also extended popular dendrohydrological workshops, due to demand from water managers, and helped develop a web portal for paleo records, <http://treeflow.info>. WWA continues to provide technical support for the Governor of Colorado’s Water Availability Task Force and the Front Range Water Providers, with a new report—The Joint Front Range Climate Change Vulnerability Study—nearly complete. Collectively, WWA researchers gave more than 100 public talks and seminars during FY10 as part of its core objective to enhance outreach, communication, and education.

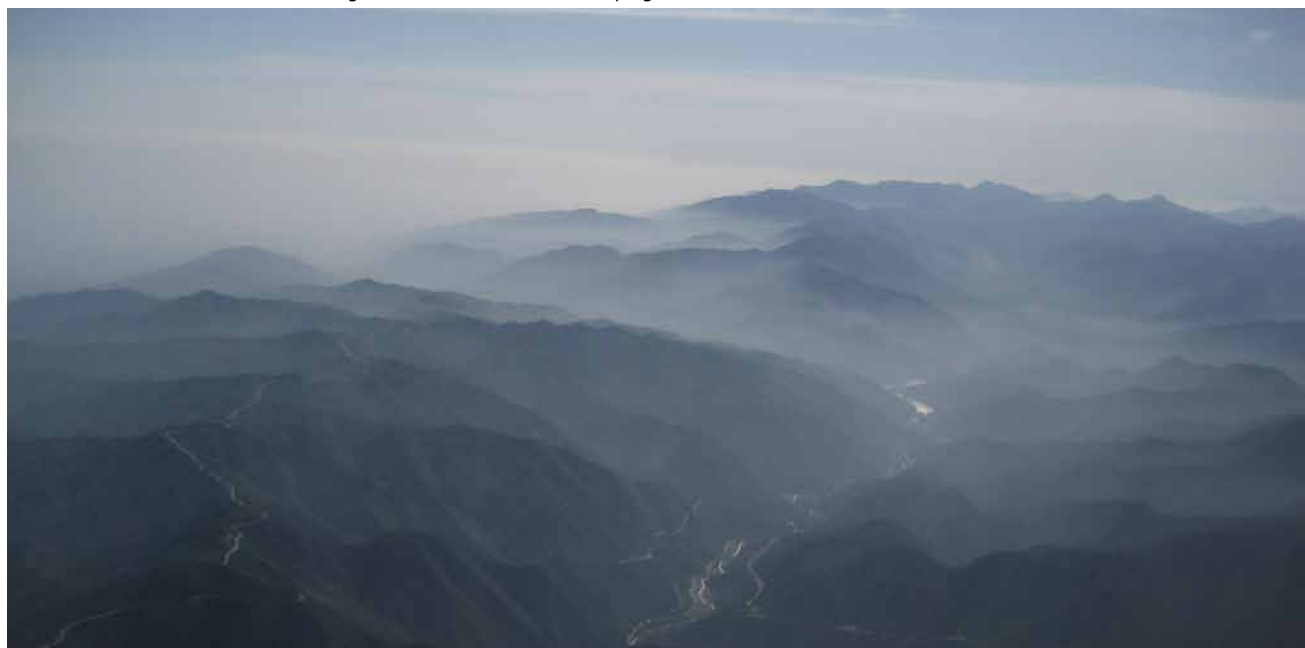
CIRES researchers have also been instrumental in the development of the 2010 *Ozone Assessment*, a quadrennial product of the United Nations Environmental Programme and the World Meteorological Organization. The 2010 report defines the current scientific understanding of the ozone layer and the phenomenon of stratospheric ozone depletion. It is an international report with global implications, relied upon by international scientists and decision makers trying to protect the ozone layer.

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. CIRES continued its state-of-the-art research to develop and maintain a version of the Hurricane Weather Research and Forecasting model (HWRF) and the experimental Flow-following finite-volume Icosahedral Model (FIM) for use by the weather-research modeling

Haze in the San Gabriel Mountains during the California Nexus field campaign.

SARA LANCE/CIRES



community. CIRES also continued its leadership role in the worldwide development of the Weather Research and Forecasting with Chemistry model (WRF-Chem). WRF-Chem version 3.2 was released in April of 2010 with many new additions, including effects of shallow convection, lightning NO_x parameterizations, coupling of aerosols with atmospheric radiation, and volcanic ash transport and ash-fall predictions.

A fascinating discovery was made while applying the WRF-Chem regional chemical transport model to conduct a detailed study of the California ozone budget. Springtime ozone levels above western North America were discovered to rise primarily due to air flowing eastward from the Pacific Ocean, a trend that is largest when the air originates in Asia. These increases in ozone could make it more difficult for the United States to meet Clean Air Act standards for ozone pollution at ground level.

Several forecast and research centers are using the WRF-Chem model and other models to improve forecast capabilities over regional and continental scales for particulate matter with a diameter of 2.5 micrometers or less (PM_{2.5}) because they are a public health concern. Though modifications to the WRF-Chem model and systematic testing and evaluations are still ongoing, this research will lead to recommendations that the National Weather Service and other forecast centers can use to improve the currently limited real-time PM_{2.5} forecasts.

An emissions processor from the WRF-Chem model was modified for use with FIM to estimate global wild fire emissions and anthropogenic emissions. Responding quickly to the major volcanic eruption in Iceland in April, researchers also included volcanic ash in FIM and the emissions pre-processor. The resulting "FIM-Chem-ash" has been running in real time twice a day since the volcanic eruption.

Research continues on improving ground-based, airborne, and spaceborne radar rainfall estimates through increased understanding of the number and size of raindrops in precipitating cloud systems.

A parameterization scheme was developed to account for the effects of sea spray on the momentum and heat fluxes in numerical weather prediction models. Researchers demonstrated that the overall impact of sea-spray droplets on the mean profiles of wind, temperature, and moisture depends on the wind speed at the level of sea-spray generation (or wave state if available).

CIRES continues its mission to deliver relevant research results to the broader scientific community by publishing and disseminating the Community *HWRF Users' Guide*



Iceland volcanic eruption.

ISTOCK

Iowa flood.

USGS



and *HWRF Scientific Documentation*. Both products cover all aspects of HWRF: the atmospheric model, atmospheric initialization, ocean model, ocean initialization, coupler, and post-processing. A sold-out tutorial of lectures and hands-on practical sessions was offered to 40 participants from academia, government, and the private sector from various countries.

Water. CIRES serves society's needs for water information in several ways, including by increasing knowledge of regional and global water cycle processes.

The 2010 Hydrometeorology Testbed-West (HMT-West) field campaign, in the northern California American River Basin, was conducted for the fifth consecutive season (December 2009 through March 2010). In comparison with previous years, precipitation during HMT-West 2010 was near-normal. Plans are underway for the first HMT-East field campaign, likely to be conducted in the mid to southern Atlantic region of the eastern United States. CIRES investigators will be key participants and contributors to these activities.

Related efforts by other CIRES researchers include the development and deployment of remote and in situ systems to measure critical atmospheric, surface, and oceanic parameters. For example, a roving calibration standard system was developed and deployed in two research vessels, a carbon dioxide measurement system was developed and deployed in several cruises including the Southern Ocean Gas Exchange Experiment, and the W-band radar was tested aboard the Woods Hole Oceanographic Institution's research vessel *Atlantis* during the California Nexus field campaign in May-June 2010. Current activities include working on a mounting platform for deployment on the NOAA WP-3D aircraft.

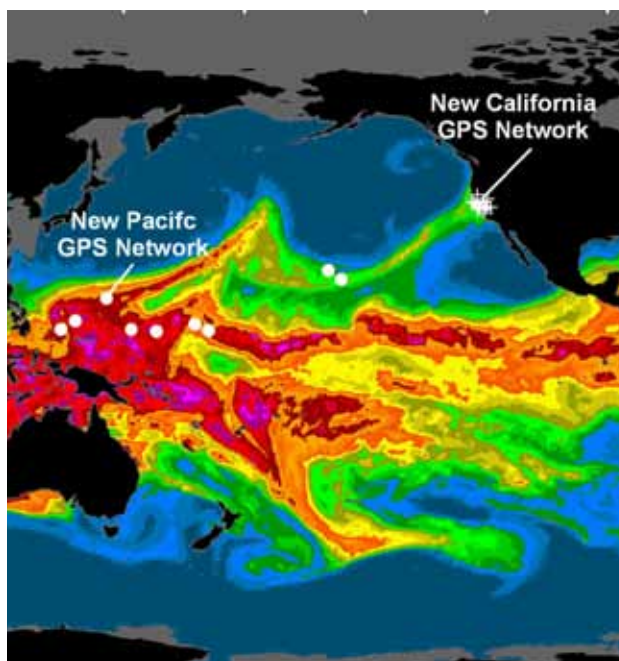
Extensive work was accomplished on analyzing the Arctic Summer Cloud Ocean Study and Arctic Mechanisms of Interaction between Surface and Atmosphere data to better understand the physical processes producing the end of the summer melt season.

CIRES researchers at WWA used the U.S. Bureau of Reclamation's Colorado River Seasonal Forecasting model to investigate the vulnerability of the Upper Colorado River Basin to changes in inflows based on stochastically-generated streamflows identified in historic and paleo records. By developing a method to directly simulate daily data at multiple locations from a single annual flow value, it was shown that this simple, data-driven procedure is compatible with any streamflow generation technique and produced good results for daily, monthly and seasonal timeframes.

Water-resource managers also rely on WWA's web-based *Intermountain West Climate Summary*—a monthly summary of pertinent information such as precipitation, temperature, snow water equivalent, long-lead temperature and precipitation outlooks, reservoir levels, and streamflow forecasts. A related climate product also helps Western wildfire managers and water managers plan operations during drought.

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

The CIRES geomagnetism team at NOAA's NGDC, in collaboration with the British Geological Survey, produced

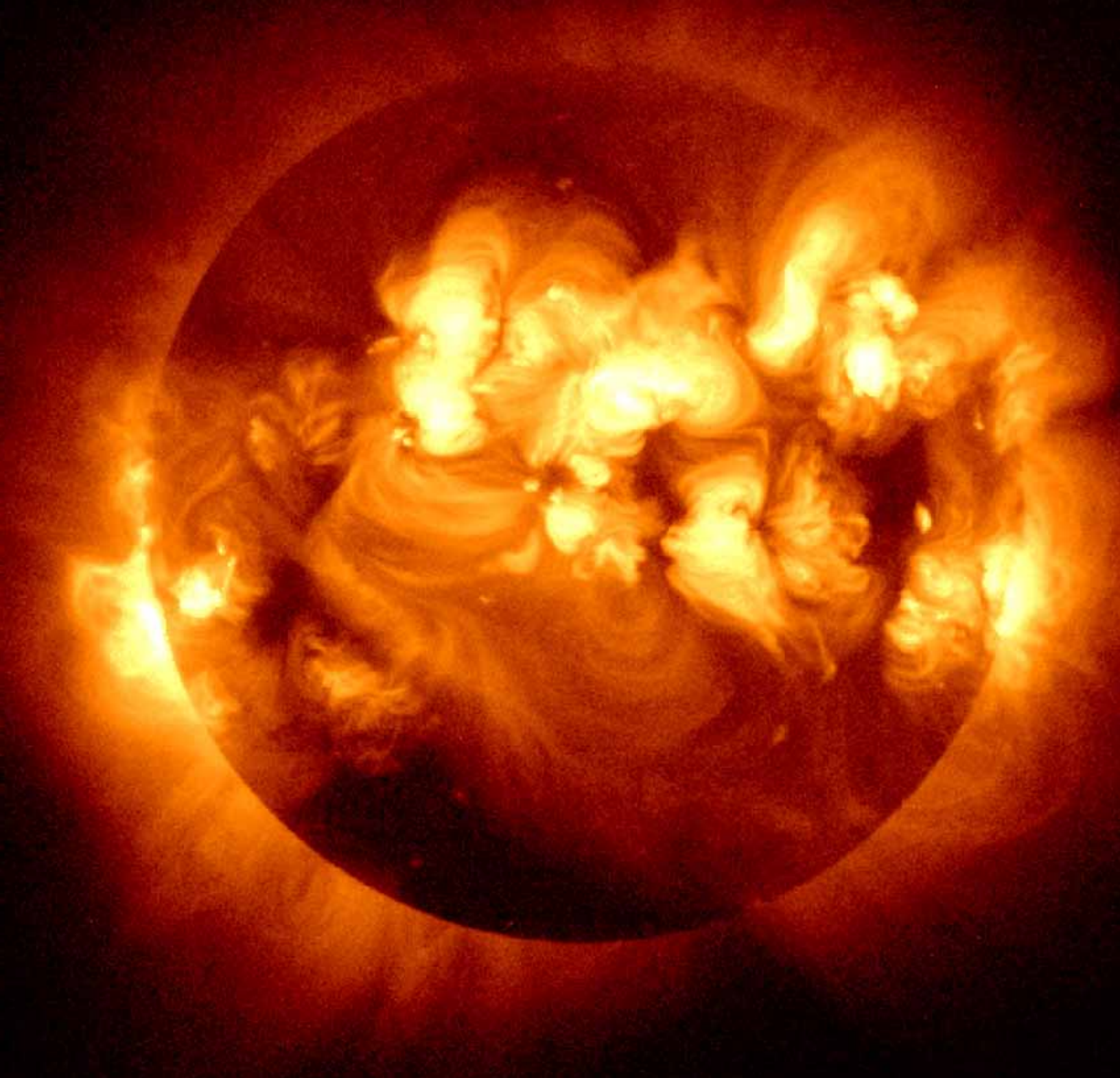


NOAA
Data from custom instruments deployed across California as part of the Hydrometeorological Testbed are helping CIRES researchers understand "atmospheric rivers" of moisture that can deliver valuable precipitation to the U.S. West Coast—and also major flooding.

the World Magnetic Model 2010 (WMM)—a magnetic field reference model updated every five years—which provides the basis for converting compass magnetic bearing to true bearing in navigation and heading systems. The user base of WMM has increased substantially during the past two years and is embedded into millions of navigational devices worldwide, including aircraft, ships, hand-held navigation devices, cell phones, and cameras. The WMM is also essential in surveying, orienting of antennas and solar panels, modeling of radio wave propagation, and space weather prediction. CIRES is also helping NOAA meet its transportation goal by improving the accuracy of directional drilling in the oil and gas industry with the new Enhanced Magnetic Model, released together with the WMM.

CIRES and SWPC researchers are continuing to investigate geomagnetic disturbances from events on the Sun, to prevent or lessen the associated damage to satellites and electric power grids and disruption of radio communications. In major news this year, CIRES researchers and colleagues published a new technique for forecasting solar flares with unprecedented accuracy.

CIRES researchers continue to work closely with the Federal Aviation Administration (FAA), to improve forecasts of aviation-relevant parameters such as convection, turbulence, and ceiling and visibility. CIRES and NOAA researchers are developing and evaluating new forecast systems—including cutting-edge quality assessment tools and automated notifications—and helping high-level decision makers determine whether the products are ready for transition to operational platforms at the National Weather Service. A Network-Enabled Verification Service prototype for evaluating convective and turbulence forecast quality in real time was completed. A convection



NOAA

In FY10, CIRES scientists in NOAA's Space Weather Prediction Center identified a new way to predict damaging solar flares. They hope the technique will give extra preparation time to the operators of power grids and satellites, which are vulnerable to geomagnetic disturbances from the Sun.

forecast exercise was conducted during summer 2009 to evaluate the potential effectiveness of the High-Resolution Rapid Refresh (HRRR) in correctly predicting high-impact aviation weather, particularly convection, 3-10 hours in advance. Improved forecasts of convection over the continental United States (CONUS) would reduce summertime weather-caused commercial flight delays, particularly at

major hubs such as Chicago O'Hare International Airport. The HRRR domain was expanded in the spring of 2009 to encompass approximately the eastern two-thirds of the CONUS. Following these successes, FAA provided additional resources for an expanded 2010 demonstration covering the whole CONUS.

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

This is CIRES

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

University Departments

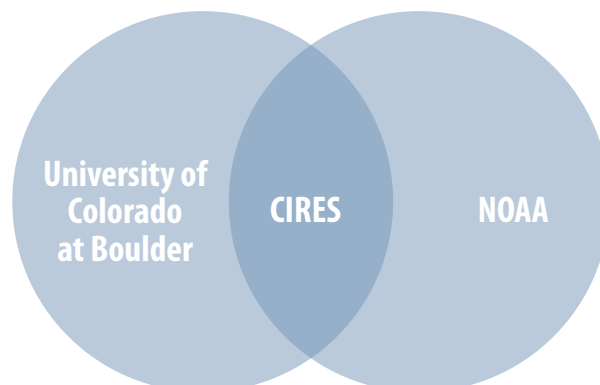
Aerospace Engineering Sciences
Atmospheric and Oceanic Sciences
Chemistry and Biochemistry
Civil, Environmental, and Architectural Engineering
Ecology and Evolutionary Biology
Electrical and Computer Engineering
Geography
Geological Sciences
Molecular, Cellular, and Developmental Biology
Physics
Environmental Studies

CIRES Divisions

Cryospheric and Polar Processes
Ecosystem Science
Environmental Chemistry
Environmental Observations, Modeling, and Forecasting
Solid Earth Sciences
Weather and Climate Dynamics

Interdisciplinary Centers

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



NOAA Earth System Research Laboratory (ESRL)

Chemical Sciences Division
Global Monitoring Division
Global Systems Division
Physical Sciences Division

NOAA Centers

National Geophysical Data Center
Space Weather Prediction Center

Governance and Management

CIRES Leadership

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William Lewis, Jr., Associate Director
Jon Rush, Associate Director for Administration
Suzanne van Drunick, Associate Director for Science

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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 FY10: 10 September, 15 October, and 19 November 2009; and 21 January, 25 February, 18 March, and 22 April 2010.

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
- **Roger Barry** Distinguished Professor of Geography; Director, World Data Center for Glaciology
- **Maxwell Boykoff** Assistant Professor of Environmental Studies
- **Roger Bilham** Professor of Geological Sciences
- **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 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

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

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.

■ **Peter Molnar** Professor of Geological Sciences

■ **Russell Monson** Professor of Ecology and Evolutionary Biology

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

■ **Steven Nerem** Professor of Aerospace Engineering

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

■ **Roger Pielke, Jr.** Professor of Environmental Studies

■ **Balaji Rajagopalan** Associate Professor of Civil, Environmental, and Architectural Engineering

■ **Prashant Sardeshmukh** CIRES Senior Research Scientist, ESRL PSD; Director 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** 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

■ **George Reid** CIRES Senior Scientist Emeritus, ESRL CSD

■ **Doug Robertson** Retired NOAA National Ocean Service, National Geodetic Survey

■ **Hartmut Spetzler** Professor Emeritus of Geological Sciences

Fellow Affiliate

■ **Ray Fall** Professor of Chemistry and Biochemistry

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.

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 at 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 allow coordinated studies on a scale that could not be addressed by university research units on their own.

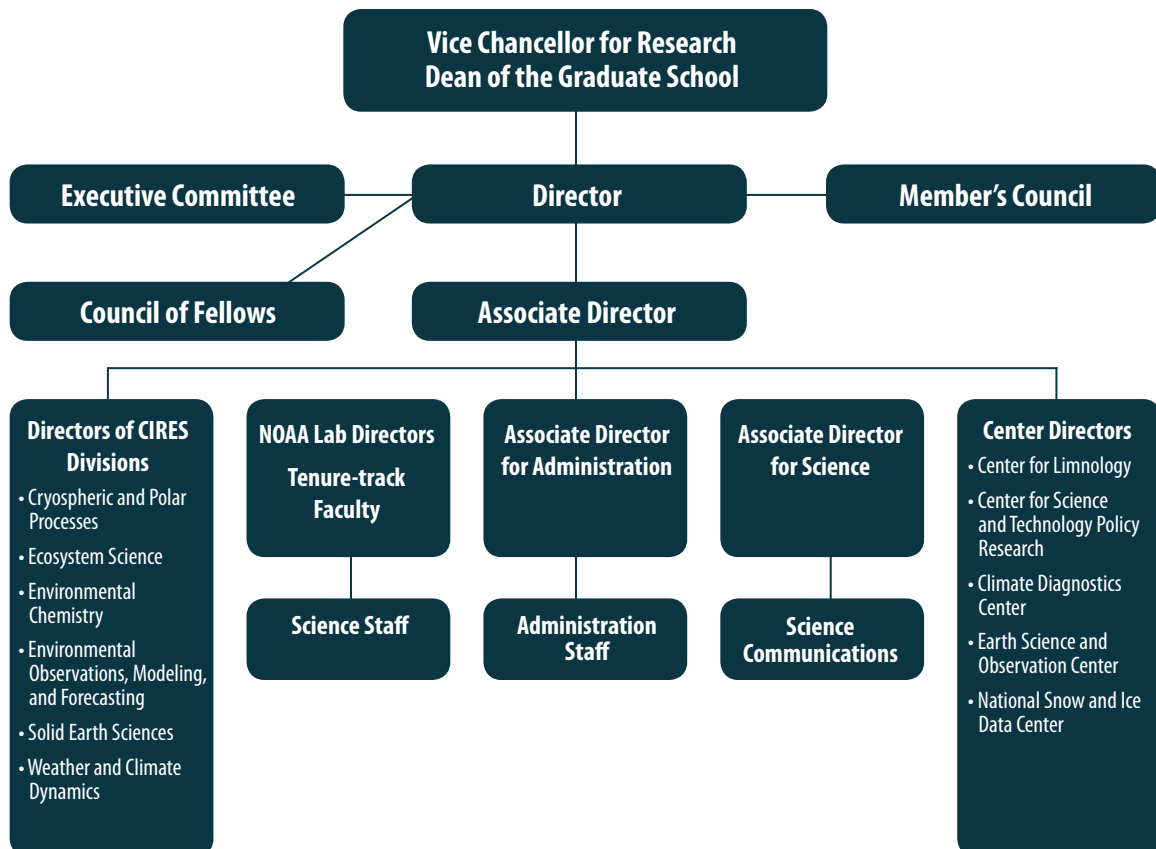
CIRES' direction is provided through its Council of Fellows and an advisory Executive Committee. The Institute fosters interdisciplinary science through five centers that bridge traditional boundaries—the National Snow and Ice Data Center, the Center for Limnology, the Center for Science and Technology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

CIRES' campus affiliation links NOAA to 1% university departments (see page 13). 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

Vision and Mission

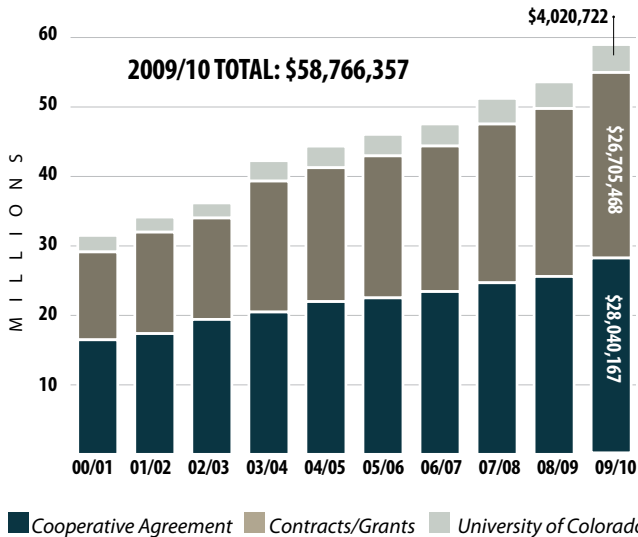
As a world leader in environmental sciences, CIRES is committed to identifying and pursuing innovative research in Earth system science and fostering public awareness of these processes to ensure a sustainable future environment. CIRES is dedicated to fundamental and interdisciplinary research targeted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

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.



Funding

Expenditures by NOAA Cooperative Agreement, individual awards and CU funds



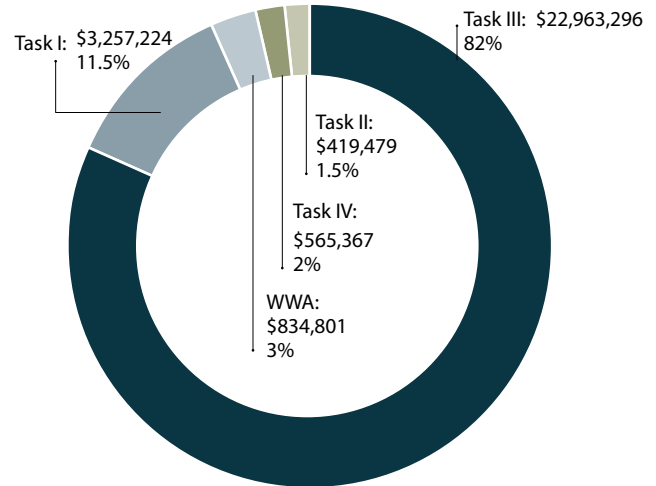
In recent years, CIRES has maintained steady growth including a remarkable increase in FY10 of nearly 10 percent (bar graph above). The largest portion of CIRES' funding (48 percent) is provided by the Cooperative Agreement (Agreement) with NOAA, and expenditures in this category have increased every year for the last decade. CIRES researchers have also had continuing success in obtaining external research awards (45 percent of CIRES' total funding). The university's monetary contribution to CIRES primarily covers faculty salaries, and it varies with year-to-year changes in the CIRES-affiliated university faculty roster.

Agreement expenditures by task for FY10 are shown in the top figure at right. Task I expenditures include CIRES administration and internal scientific programs, such as the Visiting Fellows program. Task II provides partial funding for the National Snow and Ice Data Center, the largest of CIRES' five interdisciplinary scientific centers. Task III funds CIRES' collaboration with NOAA's Earth System Research Laboratory, National Geophysical Data Center, and Space Weather Prediction Center. Task IV was created to serve as an efficient administrative mechanism for directing NOAA research grants and awards, which would otherwise be stand-alone projects outside the Agreement, to university researchers in fields aligned with CIRES' mission. Two Task IV projects have been awarded through our NOAA "shadow" award, NA08OAR4320914.

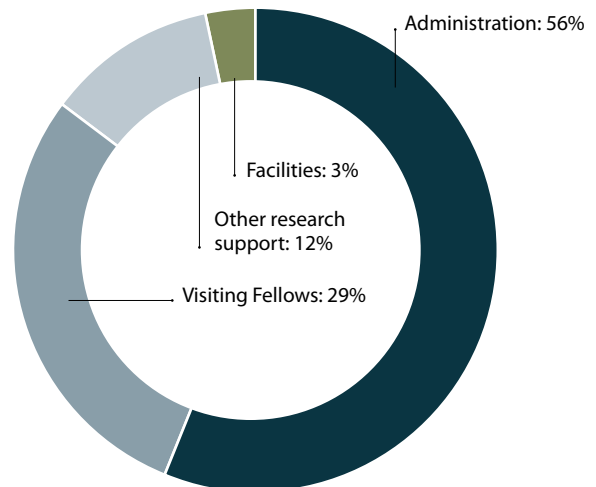
The largest share (56 percent) of Task I base funds support CIRES administration, primarily salaries and benefits for the administrative staff (middle figure at right). The Visiting Fellows program receives the second largest share (29 percent) of Task I expenditures, and is supported by other funding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

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

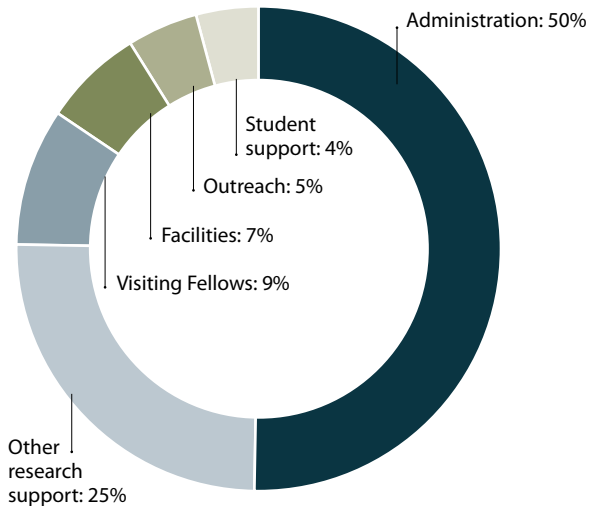
Cooperative Agreement expenditures by Task



CIRES Task 1 base fund expenditures



CIRES Task 1 base and ICR-supported expenditures



CREATING A DYNAMIC RESEARCH ENVIRONMENT

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

Western Water Assessment

The Western Water Assessment (WWA) is CIRES' signature integrating activity, relying on multidisciplinary teams of experts in climate, 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

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.



Western Water Assessment. Page 72



Education and Outreach. Page 74

CIRES EO served as the lead education team for an instrument onboard the NASA Solar Dynamics Observatory, which launched in February 2010. EO also helped lead the development of *Climate Literacy: The Essential Principles of Climate Science*, which has been reviewed and endorsed by the U.S. Global Change Research Program.

■ cires.colorado.edu/education/outreach

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 250 Visiting Fellowships. Recipients have included previous CIRES Director Susan Avery and current Director Konrad Steffen.

■ cires.colorado.edu/collaboration/fellowships

Rendezvous!

More than 350 people attended the CIRES Members' Council's fifth annual Rendezvous! research symposium on 15 April 2010. 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.

The CIRES Awards Committee, comprised of CIRES Members' Council representatives, annually reviews nominations and recommends awards for outstanding professional achievement. Five awards of \$2,000 each were given at the Rendezvous! this year, three in the science and engineering category, and two in the service category. This year, CIRES recognized Alysha Reinard (Space Weather Prediction Center), Manoj Nair (National Geophysical Data Center) and a team of Paul Lotoaniu, Josh Rigler, Juan Rodriguez, Leslie Mayer, and Mary Shouldis (Space Weather Prediction Center) for outstanding performance in the science and engineering category. Steve Peckham (ESRL Global Systems Division) and a team of MaryJo Brodzik, Brendan Billingsley, Julia Collins, Doug Fowler, Jonathan Kovarik, Donna Scott, Barbara O'Barr, Stephen Truex, Bruce Raup, and Deann Miller (National Snow and Ice Data Center) were recognized for outstanding achievements in service.

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

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 12th annual Innovative Research Program in 2010 funded six projects, including research into El Niño's past, a study of the effects of "green infrastructure" on urban environments, and investigations into the needle-free delivery of the human papillomavirus vaccine.

■ 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. The next competition for the ESRL-CIRES Graduate Student Fellowship is in 2011. This year, CIRES awarded GSRFs to six doctoral students advised by CIRES Fellows.

■ cires.colorado.edu/education/cu/gsrp

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

Konrad Steffen and Manoj Nair during the 2010 Rendezvous!



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.

23 OCTOBER 2009

Steve Rayner

Oxford University, United Kingdom

The problem of uncomfortable knowledge in science policy debates

12 MARCH 2010

Peter B. Kelemen

Arthur D. Storke Professor of Geochemistry in Columbia University's Department of Earth and Environmental Sciences, based at Lamont Doherty Earth Observatory

In situ mineral carbonation in peridotite for geological capture and storage of CO₂

CIRES staff appreciation picnic.

MORGAN HEIM/CIRES

CONFERENCES, WORKSHOPS, EVENTS, PRESENTATIONS

- **Colorado Renewable Energy Collaboratory's** Center for Research and Education in Wind inaugural annual symposium, CU Boulder (08/09)
- **Rocky Mountain Hydrologic Research Center** 64th Annual Meeting (10/09)
- **CIRES organized seminars and laboratory tours** for a team of Brazilian journalists (04/10)
- **Mountain Pine Beetle Symposium** at NCAR (04/10)
- **WWA Science Advisory Board** meeting (04/10)
- **Climate Literacy Essential Principles**, Colorado Climate Curriculum workshop (07/09)
- **Effectively Communicating Climate Change workshops** (throughout FY10)
- **CIRES/NCAR journalism reception** (08/09)
- **CIRES staff appreciation picnic** (08/09)
- **CIRES Graduate Students Association kickoff and symposia** (08/09 and throughout FY10)
- **CIRES Graduate student career workshops** (10/09, 11/09, and 03/10)
- **Robert Sievers reception** (Astella's Award) (09/09)
- **The first 300 days:** An assessment of President Obama's energy and climate policy, panel discussion (09/09)
- **Energy Initiative fall symposium**, in collaboration with the CSTPR Energy Initiative (10/09)
- **2009 Association of Environmental Studies and Sciences meeting** (10/09)
- **Forum on science ethics and policy** informational meeting for prospective members (10/09)
- **The role of natural gas in a clean energy economy** (10/09)
- **STEMapalooza**, CIRES booth/exhibit (10/09)
- **Continental dynamics** workshop (11/09)



- **Colorado Science Convention**, CIRES booth (11/09)
- **CIRES Innovative Research Program** reception and poster session (11/09)
- **NASA research proposal workshop** (11/09)
- **Assessing the mitigation and remediation options, COP15** (12/09)
- **Project Extremes research in Antarctica** (12/09-01/10)
- **CIRES staff appreciation and holiday celebration** (12/09)
- **CIRES Fellows science retreats/workshops:**
 - Environmental change and decision making under uncertainty (**William Travis**, 01/10)
 - Organic molecules in the atmosphere (**Joost DeGouw**, 02/10)
 - Remote sensing in geosciences (**Waleed Abdalati**, 02/10)
 - Paleo perspectives in climate change (**Baylor Fox-Kemper**, 04/10)
 - Energy and the Environment (**Veronica Vaida**, 04/10)
- **CSD planning meeting** (01/10)
- **Reflections on the COP15 conference:** CSTPR (01/10)
- **Maxwell Boykoff:** Climate and weather—focusing on wind energy solutions. (01/10)
- **Maxwell Boykoff:** Exploring how climate change becomes meaningful in our everyday lives. (01/10)
- **CIRES director's coffee** (02/10)
- **Kuujuaq, Canada and Montreal, Canada workshops**, National Snow and Ice Data Center (02/10)
- **Jennifer Schneider and Jason Delborne:** Citizen voices in the global climate and energy challenge. (02/10)
- **Benjamin Hale:** Nonrenewable resources and the inevitability of outcomes. (02/10)
- **Maxwell Boykoff:** Understanding climate change skepticism: Its sources and strategies. (02/10)
- **National Ocean Sciences Bowl**, Regional Trout Bowl (03/10)
- **Geoengineering and climate change:** Possibilities, promises and perils workshop (03/10)
- **ESRL Physical Sciences Review** (03/10)
- **Usable science:** A CSTPR-CSPO briefing workshop on science for decision making (04/10)
- **CIRES Members' Council Rendezvous!** Science symposium (04/10)
- **Visiting Fellows** poster session and reception (04/10)
- **Adam Reed:** Carbon tales: Information infrastructures for sustainable biofuels governance. (04/10)
- **COSEE lecture series and summer institute** (04, 05, and 06/10)
- **Maxwell Boykoff:** Who speaks for the climate? Understanding media representations of climate change. (5/10)
- **CIRES Fellows seminars** at the David Skaggs Research Center, **Waleed Abdalati** (07/09), **Mark Serreze** (09/09), and **Rainer Volkamer** (10/09)
- **Roger Pielke, Jr.:** Efficiency illusion and other energy myths: Why cap and trade won't work—and what can. (07/09)
- **Maxwell Boykoff:** Signals and noise: examining media representations of climate change. (09/09)
- **Steve Rayner:** Finding the right trousers: Radically rethinking climate policy and low-carbon energy. (10/09)
- **David Cherney:** Yellowstone's saviors? Nongovern-

- mental organizations in policy and American democracy. (10/09)
- **Maxwell Boykoff:** Who speaks for the climate? Historical account of media coverage of climate change. (12/09)
- **Maxwell Boykoff:** NOAA Seminar: The cultural politics of climate change: Focusing on mass media. (12/09)
- **Lisa Dilling:** Providing policy-relevant information for greenhouse gas management. (12/09)
- **Ursula Rick:** Relative magnitude of mass change mechanisms on the Greenland Ice Sheet. (12/09)
- **CSTPR noontime seminars:**
 - Krister Andersson:** CSTPR/IBS-ESP: Community self-governance of forests in Bolivia. (09/09)
 - Robert Frodeman:** CSTPR/IBS-ESP: What is interdisciplinary? (09/09)
 - Sonia Akter:** CSTPR/IBS-ESP: Climate change mitigation in Australia. (09/09)
 - Radford Byerly:** CSTPR/IBS-ESP: The Colorado Air Quality Control Commission. (10/09)
 - Deserai Anderson Crow:** CSTPR/IBS-ESP: Recreational water rights in Colorado. (10/09)
 - Maxwell Boykoff:** CSTPR/IBS-ESP: Inconvenient celebrity? Celebrities and climate change. (10/09)
 - Ursula Rick:** CSTPR/IBS-ESP: Sea-level rise as a climate change metric. (11/09)
 - Marilyn Averill:** CSTPR/IBS-ESP: The role of the Judiciary in U.S. climate policy. (11/09)
 - Yohei Mitani:** CSTPR/IBS-ESP: The effects of ecological information provision. (12/09)
- **Jennifer Schneider and Jason Delborne:** CSTPR/RA-SAEI/ESP: Citizen voices in the global climate and energy challenge. (02/10)
- **Julie Lundquist:** CSTPR/RASEI/ESP: Harnessing the power of the wind. (02/10)
- **Karen Maguire:** CSTPR/RASEI/ESP: Impacts of regulation on wind energy development. (03/10)
- **Max Boykoff, Lisa Dilling, Ben Hale, Roger Pielke, Jr., and William Travis:** CSTPR/RASEI/ESP: Geoengineering and climate change. (03/10)
- **Jonathan Hughes:** CSTPR/RASEI/ESP: Carbon trading, low-carbon fuel standards and renewable standards (04/10)
- **Adam Reed:** Carbon tales: Information infrastructures for sustainable biofuels governance. (04/10)
- **Barbara Farhar:** CSTPR/RASEI/ESP: Community acceptance of concentrating solar power. (05/10)
- **ENVS Colloquia:**
 - Tania Schoennagel:** Bugs and bugaboos: Mountain pine beetles. (09/09)
 - Steve Rayner:** Climate geoengineering. (10/09)
 - Darrell Moellendorf:** Justice and mitigation: U.S. policy and the Copenhagen Accord. (01/10)
 - Sarah Krakoff:** Climate change and adaptation. (02/10)
 - Stephen Gardiner:** Is arming the future with geoengineering really the lesser evil? (03/10)
 - Bernard Amadei:** Engineering with a human face. (03/10)
 - Deen Chatterjee:** How is climate justice related to cosmopolitan justice? (04/10)

People&Projects

NOAA Scientists

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

CU-Boulder Teaching Faculty

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

CIRES Scientists

Richard Armstrong	Prashant Sardeshmukh
Joost de Gouw	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 Themes Reports (page 84).

Waleed Abdalati

Studying Ice from Space

FUNDING: NASA

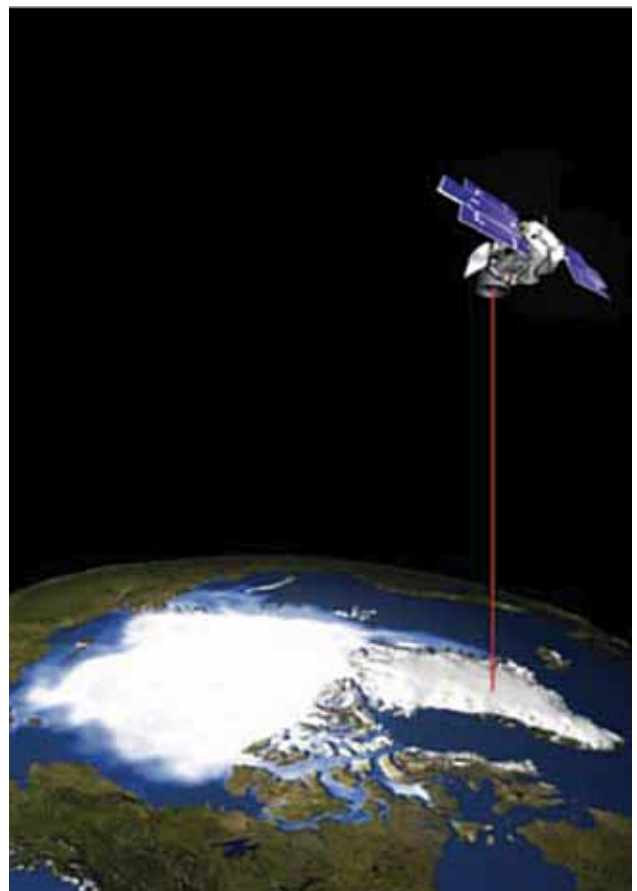


NASA's planned Ice Cloud and land Elevation Satellite-2 (ICESat-2) mission is designed to significantly improve upon measurements begun by its predecessor, ICESat, to map changes in ice sheet elevation using space-based laser altimetry. I am lead of the ICESat-2 Science Definition Team, which is carrying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

The objectives of ICE-Sat-2 are to 1) quantify the contributions of the Greenland and Antarctic ice sheets to sea-level rise, and provide key insights into the underlying mechanisms; 2) assess the thickness of the Earth's sea-ice cover to improve our understanding of the exchanges of moisture and energy among the oceans, ice, and atmosphere; and 3) map global land biomass to quantify its carbon storage.

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

I am also 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



WALEED ABDALATI USING NASA IMAGES

The ICESat-2 mission must be designed to capture the very rapid changes of outlet glaciers, observe the impacts of summer speedup of ice flow due to the penetration of surface meltwater to the ice-sheet bottom, and examine the detailed character of the rapidly thinning Arctic sea-ice cover.

ice deformation processes.

Using these tools, I am working 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.

Richard Armstrong

An Application of GLIMS data to Himalayan Hydrology

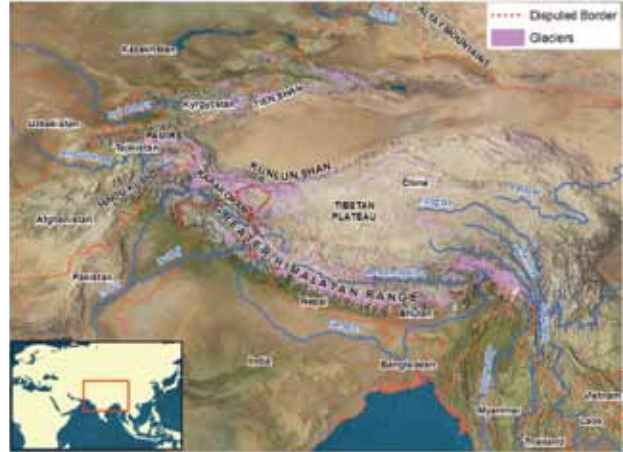
FUNDING: NASA EARTH SCIENCE, WORLD BANK



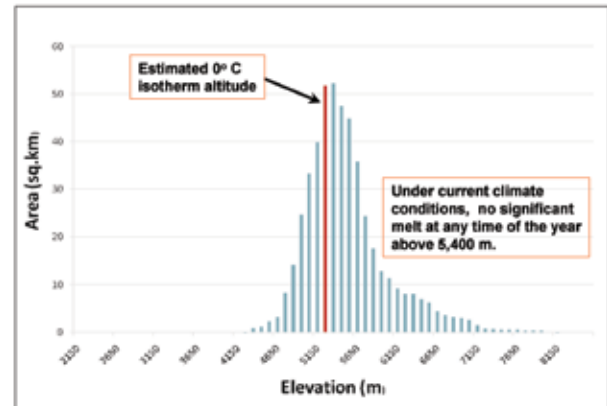
We are applying Global Land Ice Measurements from Space (GLIMS) data in the assessment of the role of glaciers in the hydrologic regime of the monsoon-dominated eastern Himalaya, specifically Nepal. The methodology developed for this study involved establishing a relationship between the area-altitude distributions of catchment basins and glaciers, and associated water and energy exchange gradients. Our glacier melt model is based on a “vertical mass

balance gradient” (the rate of increasing specific ice melt with decreasing altitude in the ablation zone), defining the mean maximum altitude of the 0°C isotherm during the ablation period (about 5,400 m for the eastern Himalaya). We determine the volume of ablation as the product of specific ice-melt values taken from the balance gradient and the area-altitude values of corresponding belts in the glacier ablation zone. Topography is defined by digital elevation data acquired from the NASA Shuttle Radar Topography Mission; glacier outlines are from the GLIMS database, as provided by the International Center for Integrated Mountain Development (ICIMOD), Kathmandu, Nepal; and streamflow data are from the Department of Hydrology and Meteorology, Nepal.

Preliminary results indicate that the annual contribution of glacier meltwater to streamflow in the Nepal Himalayas varies among catchment basins, but is not likely to exceed 2-13 percent of the total annual flow volume measured at lower-altitude hydrometric stations. The contribution of glacier melt to the total river flow in the eastern Himalaya is estimated to be less than about five percent. Outside the monsoon-dominated eastern Himalaya, the contribution from melting glacier ice is estimated to be as much 30 percent or more, but no accurate quantitative assessments have been undertaken. Therefore, our new project focuses on quantifying the contribution of melting glacier ice, melting snow, and rainfall to the total streamflow of the western Himalaya, with specific focus on the Indus Basin. Precipitation and basin runoff generally decrease from the east to west as a direct result of the weakening of the summer



The Himalayan Arc, extending approximately 2000 km from Bhutan and Nepal in the east to the Indus River and the Karakoram and Hindu-Kush mountain ranges in the west.



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

monsoon. The glacier accumulation and ablation patterns are distinct, 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. Glacier termini extend to lower elevations, approximately 2,500 m in the west, compared to approximately 3,500 m to 4,500 m in the east, due primarily to the lower temperatures at the higher latitudes of the more western mountain ranges. The extensive irrigation of arid agricultural lands in the Lower Indus Basin depends heavily on streamflow generated by snow and ice melt in the Upper Indus Basin. Key to these studies are the glacier outline shape files, which were available from ICIMOD for the Nepal study. These data are not currently available for the Upper Indus Basin, and we are therefore developing an automated algorithm based on MODIS reflectance data, which identifies the locations of glacier ice and semi-permanent snow cover. Preliminary results from the Indus Basin study are expected later in 2010.

Ben Balsley

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



We have begun to examine the meter-scale details that are critical for understanding the dynamics of energy-cascading processes throughout the troposphere and the atmospheric boundary layer using high-resolution in situ measurements. The primary vehicle for these measurements is a small, low-cost, programmable, reusable, autonomous, GPS-controlled aircraft that is being equipped with fast-response temperature, humidity, and wind-speed sensors. Data from this vehicle (the

“Stryker,” developed by Professor Dale Lawrence of CU’s Aerospace Engineering Department) can be both telemetered to the ground as well as archived aboard for later downloading and analysis. For the upper tropospheric measurements, the Stryker will be carried aloft beneath a conventional meteorological balloon, released to fly to a specific location, and then spiral downward and land at a pre-determined site. Spiral diameter is 100-200 meters, while the vertical resolution of the measurements is on the order of one meter.

The sensor electronics are embedded in the main body of the aircraft and the “pusher” propeller is in the rear. The GPS antenna is near the leading edge of the right wing. During a balloon launch, the Stryker is suspended below a conventional 200-gm meteorological balloon prior to release (Figure 1).

Examples from our preliminary tests appear in Figure 2: Panel A is a plot of height vs. time for a single, three-minute ascent-descent flight to 300 m. Panel B shows crude initial profiles of humidity (blue) and temperature (red). The accuracy of subsequent temperature profiles will be improved by almost 200 times by using advanced digitization techniques. Panel C is a plan view that demonstrates the accuracy of the GPS-controlled spiral ascents-descents (the dotted curves delineate takeoff and landing patterns).

We expect this technique to provide the impetus for developing a unique, new, and powerful method for studying fine-scale processes throughout the first 10 km of the atmosphere.



Figure 1: The Stryker suspended below a conventional meteorological balloon, a technique that will be employed for high-altitude measurements.

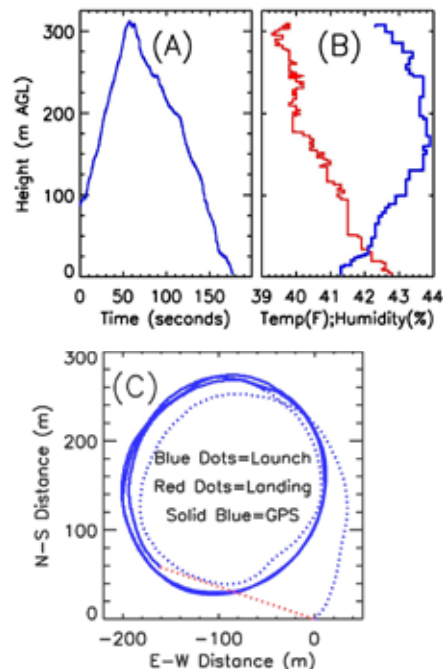


Figure 2: Example data plots from a preliminary Stryker test flight.

Roger Barry

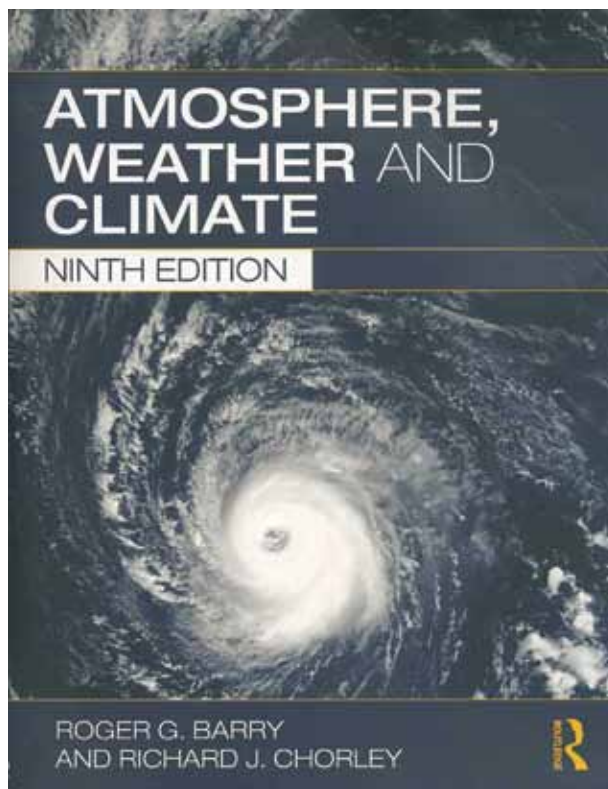
Climate and Cryosphere

FUNDING: HUMBOLDT FOUNDATION, GERMANY



I completed and published the ninth edition of *Atmosphere, Weather and Climate* (Barry, R.G. and R.J. Chorley (deceased), Routledge, London, 516 pp.). First published in 1968, the work is a comprehensive introductory textbook that has been updated to reflect recent advances. Following an introductory overview of the historical development of the field, there is an extended treatment of atmospheric composition and energy, stressing the heat budget of the Earth

and the causes of the greenhouse effect. Then it turns to the manifestations and circulation of atmospheric moisture, including atmospheric stability and precipitation patterns in space and time. A consideration of atmospheric and oceanic motion on small to large scales leads on to a new chapter on modeling of the atmospheric circulation and climate, which also presents weather forecasting on different time scales. This chapter was prepared by CIRES Fellow Tom Chase. It is followed by a discussion of the structure of air masses, the development of frontal and non-frontal cyclones, and development of mesoscale convective systems in mid-latitudes. The treatment of weather and climate in temperate latitudes begins with studies of Europe and America, extending to the conditions of their subtropical and high-latitude margins and includes the Mediterranean, Australasia, North Africa, the southern westerlies, and the sub-Arctic and polar regions. Tropical weather and climate are also described through an analysis of the climatic mechanisms of monsoon Asia, Africa, Australia, and Amazonia, together with the tropical margins of Africa and Australia and the effects of ocean movement and the El Niño–Southern Oscillation and teleconnections. Small-scale climates—including urban climates—are considered from the perspective of energy budgets. The final chapter, revised by CIRES Fellow Mark Serreze, stresses the struc-



ture and operation of the atmosphere–Earth–ocean system and the causes of its climate changes. Since the previous edition was released in 2003, the pace of research on the climate system and attention to global climate change has accelerated and the 2007 Intergovernmental Panel on Climate Change report has been published. A consideration of other environmental impacts of climate change is included. Apart from the two new chapters, all figures have been redrawn in color.

During May–October 2009, I was supported by an award from the Humboldt Foundation of Germany at the Kommission fuer Glaziologie of the Bavarian Academy of Sciences in Munich. During the first month, I prepared the index for *Atmosphere, Weather and Climate*. I then began preparing a text, *The Cryosphere: Past, Present, and Future* with Thian Gan of the University of Edmonton. The work, which is under contract to Cambridge University Press, is continuing, and I will return to Munich during August–October 2010.

Roger Bilham

Buildings as Weapons of Mass Destruction



Global earthquake disasters are hardly new science, but 2010 brought the world to a new, shameful record—more people have died in catastrophic earthquakes in the first decade of the new millennium than in any decade in the history of civilization. Since 2000, more than 650,000 people died unnecessarily from earthquakes in Indonesia, India, Pakistan, Iran, China, Haiti, Chile, and a handful of other earthquake-prone countries.

The new record is shameful because seismologists have been aware, since the late 19th century, that building collapse is largely responsible for deaths from earthquakes. In a 2009 article on the seismic future of cities, I note that earthquake-resistant design is applied with rigor by very few countries. As a result of the rapid growth of cities in the developing world, the tenfold increase in global population since 1900 has been approximately matched by a tenfold increase in earthquake fatalities (Figure 1).

Earthquakes have not become more numerous in recent years, nor are they stronger. The 230,000 deaths of the Haiti Mw7 earthquake resulted from the release of elastic energy equivalent to a 2-megaton nuclear bomb, whereas the 802 deaths from the Chile Mw8.8 earthquake were caused by energy release equivalent to a 500-megaton bomb. The factor of 287 in the number of Haitian deaths compared to Chile was entirely due to Port au Prince's virtual absence of earthquake resistance (illustrated with global data in Figure 2).

Throughout the epicentral region of the Haiti earthquake, it was evident that the buildings had been doomed from their inception. Every possible construction error was visible in the mangled steel and concrete of Port au Prince and Leogane—weak cement sometimes mixed with sea water or dirt, rounded aggregate, brittle steel often missing corrugations, and insufficient stirrups. Traditional wooden buildings fared better and stood like beacons surrounded by piles of rubble.

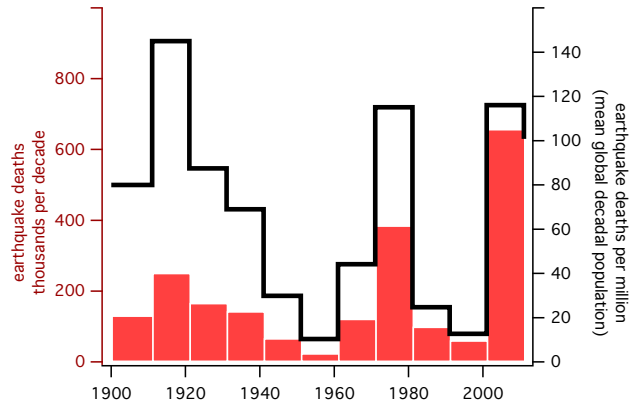


Figure 1: Earthquake deaths per decade, 1900-2010.

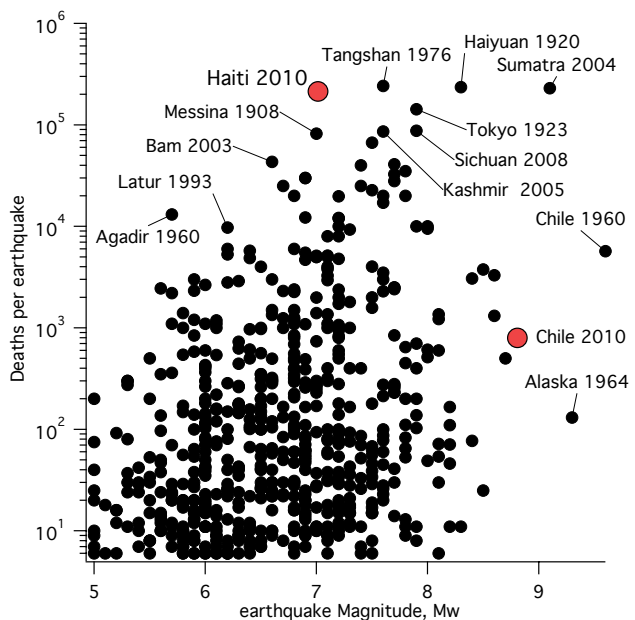


Figure 2: Earthquake deaths since 1900 are not related to earthquake magnitude, but to the absence of earthquake resistance in structures.



A damaged church in Leogane, 30 km northwest of the epicenter of the Haiti earthquake.

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 more formally 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. Over time, many “agents” have struggled to make claims via mass media and thereby influence the ways in which institutions and individuals grapple with critical climate challenges. My research has analyzed how a burgeoning array of “actors,” “agents of definition,” and

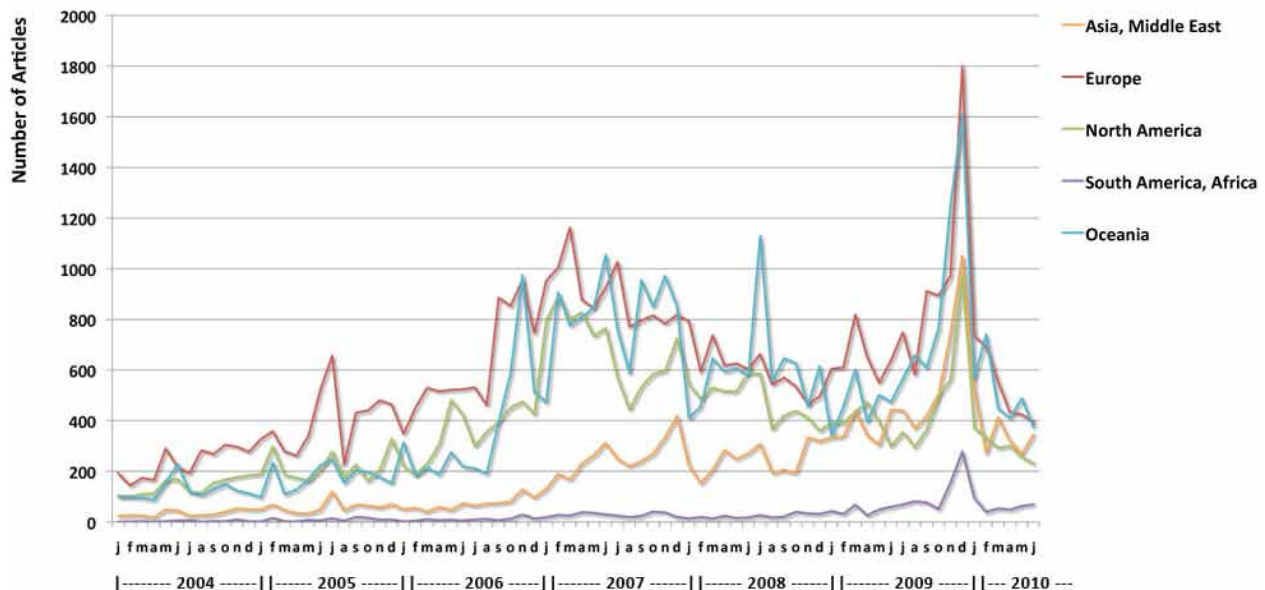
“claims-makers” in these spaces have created, contested, negotiated, and re-configured discourses and meaning via mass media, and how they have shaped ongoing climate science and policy endeavors through time.

Many dynamic, non-linear, and complex factors contribute to how media outlets portray various facets of climate change. Swirling contextual factors and competing journalistic pressures and norms contribute to how issues, events, and information 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.

The ways in which media sources conflate or accurately represent different aspects of climate change—from what role humans play in the changing climate to how to effectively construct and deploy climate adaptation funds—contribute to citizen perceptions in everyday spaces and deliberations for action in the public sphere.

This research is situated in a 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 a spectrum of possibilities for related pursuits. Such an exploration is critical to further strengthening a foundation of understanding architectures and actions in environmental governance, particularly as we move into the post-Kyoto climate era.

2004-2010 World Newspaper Coverage of Climate Change or Global Warming, updated April 2010



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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. Our research group recently completed the first wintertime flights of unmanned aircraft systems (UAS) in Antarctica.

This project used an Aerosonde UAS 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 (Figure 1). Formation and maintenance of this polynya is linked to strong katabatic winds draining from the East Antarctic plateau into Terra Nova Bay. These winds promote strong heat and moisture fluxes over the open water of the polynya, leading to pronounced modification of both the ocean and atmosphere.

During September 2009, we flew a total of 130 flight hours during eight missions to Terra Nova Bay. These flights were completed at the end of the Antarctic winter, with air temperatures less than -30°C and wind speeds in excess of hurricane force (up to 40 m/s). UAS observations included standard atmospheric state variables (temperature, pressure, humidity, and wind, Figure 2), net radiation, aerial photographs of the surface (Figure 3), and laser-altimeter observations of surface features such as wave state and sea-ice thickness. These measurements provided the first in situ observations of the atmospheric state and air-sea interaction over this polynya during the late winter/early spring. Data from this field campaign will provide insight into the formation of Antarctic bottom water, details of the atmospheric forcing for this polynya, and validation data for high-resolution numerical simulations.



Figure 1: Visible satellite image of Terra Nova Bay polynya (October 2007).

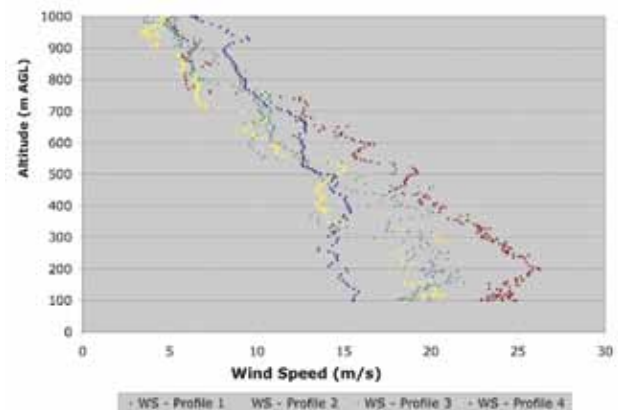


Figure 2: UAS-measured wind profiles over the Terra Nova Bay polynya (24 September 2009). The profiles show the downwind evolution of the winds as they pass over the polynya.



Figure 3: Aerial photograph of the polynya surface showing bands of wind-accumulated frazil ice with open water and white cap waves (24 September 2009).

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 (Figure 1) seems to have reduced monsoon rainfall and slowed the East Asian Jet maximum, indicating that circulations around the globe can 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 adiabatically to reach the observed minimum by 500 mb. We are proposing to extend this hypothesized mechanism 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 2 and 3 show trends in inversion frequency and strength in Denver, CO). 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.

Percentage of Land Equipped for Irrigation

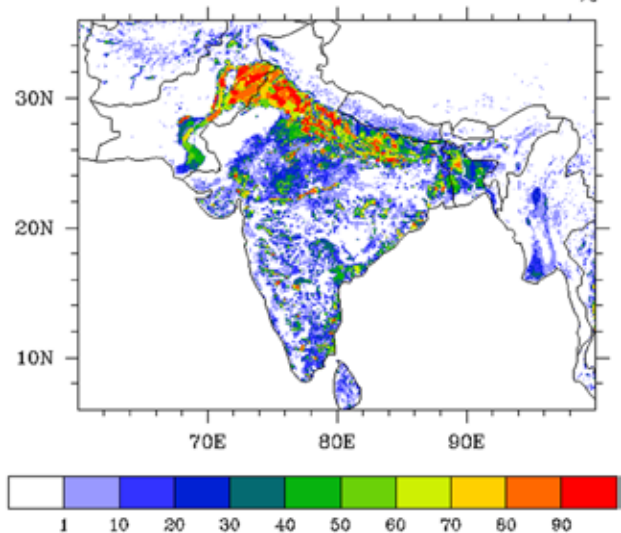


Figure 1: Irrigation percentage in India.

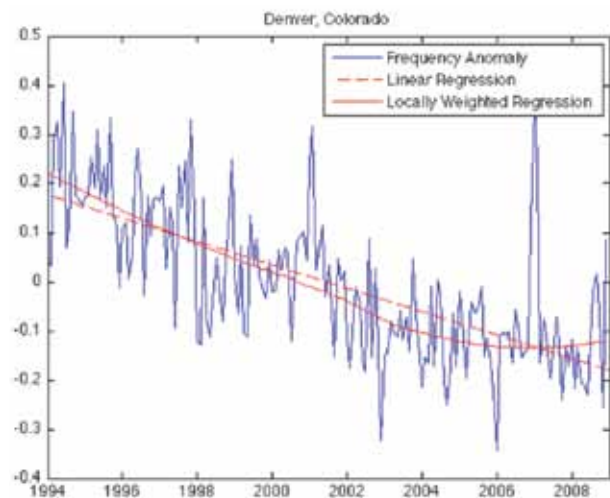


Figure 2: Monthly anomalies in the occurrence of two or more consecutive days in Denver, CO during which low-level daytime inversions were present. Y-axis is fraction of days per month, and x-axis is calendar year. Locally weighted regressions smooth the original data using a 0.7 span.

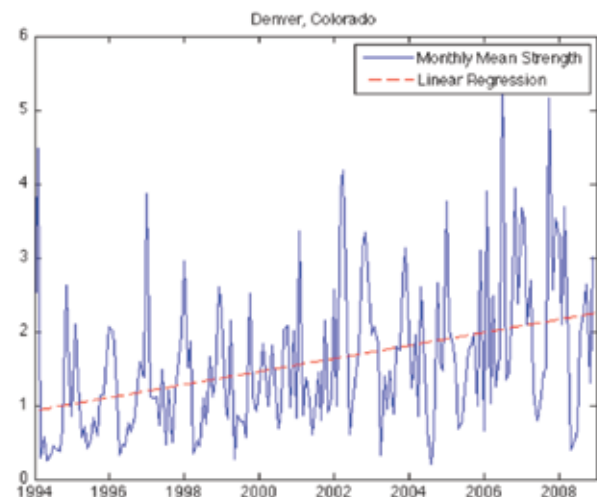
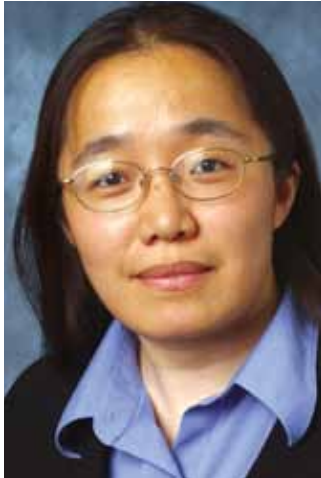


Figure 3: Monthly anomalies in frequencies (fraction of days per month during which inversions were present) of low-level inversions. Y-axis is fraction of days per month, and x-axis is calendar year.

Xinzhao Chu

LIDAR Technology Innovation and Atmospheric Sciences Study

FUNDING: NATIONAL SCIENCE FOUNDATION (POLAR PROGRAMS; MAJOR RESEARCH INSTRUMENTATION; CAREER; AERONOMY; AND COUPLING, ENERGETICS, AND DYNAMICS OF ATMOSPHERIC REGIONS) AND THE EUROPEAN SPACE AGENCY

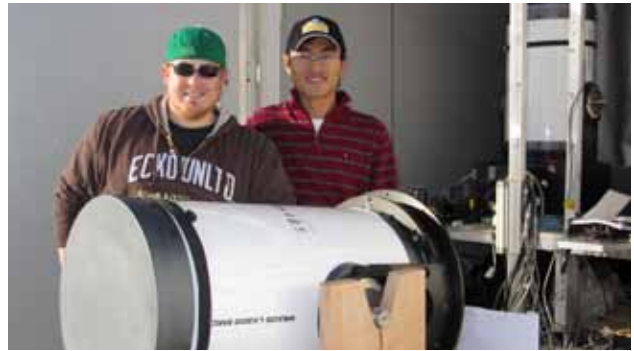


The most remarkable point for the Chu research group in FY10 is perhaps the fact that significant progress is being made simultaneously in lidar development and atmospheric science study. Three lidars are being developed: the NSF Major Research Instrumentation (MRI) Fe-resonance / Rayleigh / Mie Doppler lidar; the McMurdo Fe Boltzmann / Rayleigh lidar; and the CAREER Na Doppler lidar. Science studies using lidar, satellite, and ra-

diosonde data as well as models (the European Centre for Medium-Range Weather Forecasts model and the Thermosphere Ionosphere Mesosphere Electrodynamics General Circulation Model) are being conducted on atmospheric gravity waves, thermal structures, and compositions. Six Ph.D. students, two master's degree students, and one research scientist are working with me to make these things happen. We welcomed four new group members: Ph.D. students Zhangjun Wang, Zhibin Yu, and Weichun Fong, and master's student Ian Dahlke. We enjoyed the sabbatical visit of Adrian McDonald from the University of Canterbury in the fall of 2009. We shared the happiness of Ph.D. student Chihoko Yamashita when she won the Coupling, Energetics, and Dynamics of Atmospheric Regions (CEDAR) poster prize at an NSF workshop in Santa Fe, NM in the summer of 2009.

Ambitiously aiming to achieve bias-free resonance Doppler lidar for advancing the middle atmosphere physics and chemistry, my research group and I started to develop the MRI lidar. A key was to develop a state-of-the-art pulsed alexandrite ring laser in collaboration with John Walling of Light Age, Inc. Excellent results have been achieved in the laser development and optical heterodyne detection for laser diagnosis.

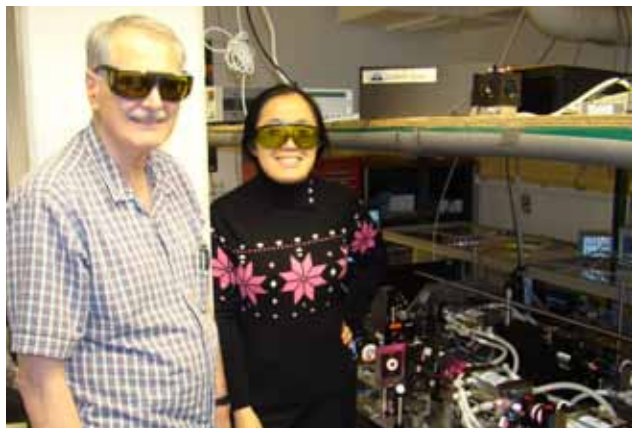
An exciting award from NSF's Office of Polar Programs is funding the Chu group to deploy an Fe Boltzmann lidar to McMurdo, Antarctica to measure the middle and upper atmosphere for three years. My colleagues and I developed this lidar more than 10 years ago. With it, I made lidar observations from the North Pole to the South Pole. In particular, I made lidar measurements at the South



Brendan Roberts and Zhangjun Wang align a telescope.



Chu's research group hosted the first Coupling, Energetics, and Dynamics of Atmospheric Regions lidar school in Boulder in June, which included this group trip to the Table Mountain Lidar Observatory.



John Walling and Xinzhao Chu.

Pole (90°S) and Rothera (67.5°S) from 1999-2005. Now my research group is upgrading this lidar and will deploy it to McMurdo (78°S) in November 2010, to complete an observational chain in Antarctica.

The CAREER lidar is supported under my NSF CAREER grant and is for graduate education and science study with a classical lidar system. Three Ph.D. and two master students have been involved in this project, through which students have learned a lot about lidar and how to build it.

Shelley Copley

The Evolutionary Potential of Catalytically Promiscuous Enzymes

FUNDING: NATIONAL INSTITUTES OF HEALTH



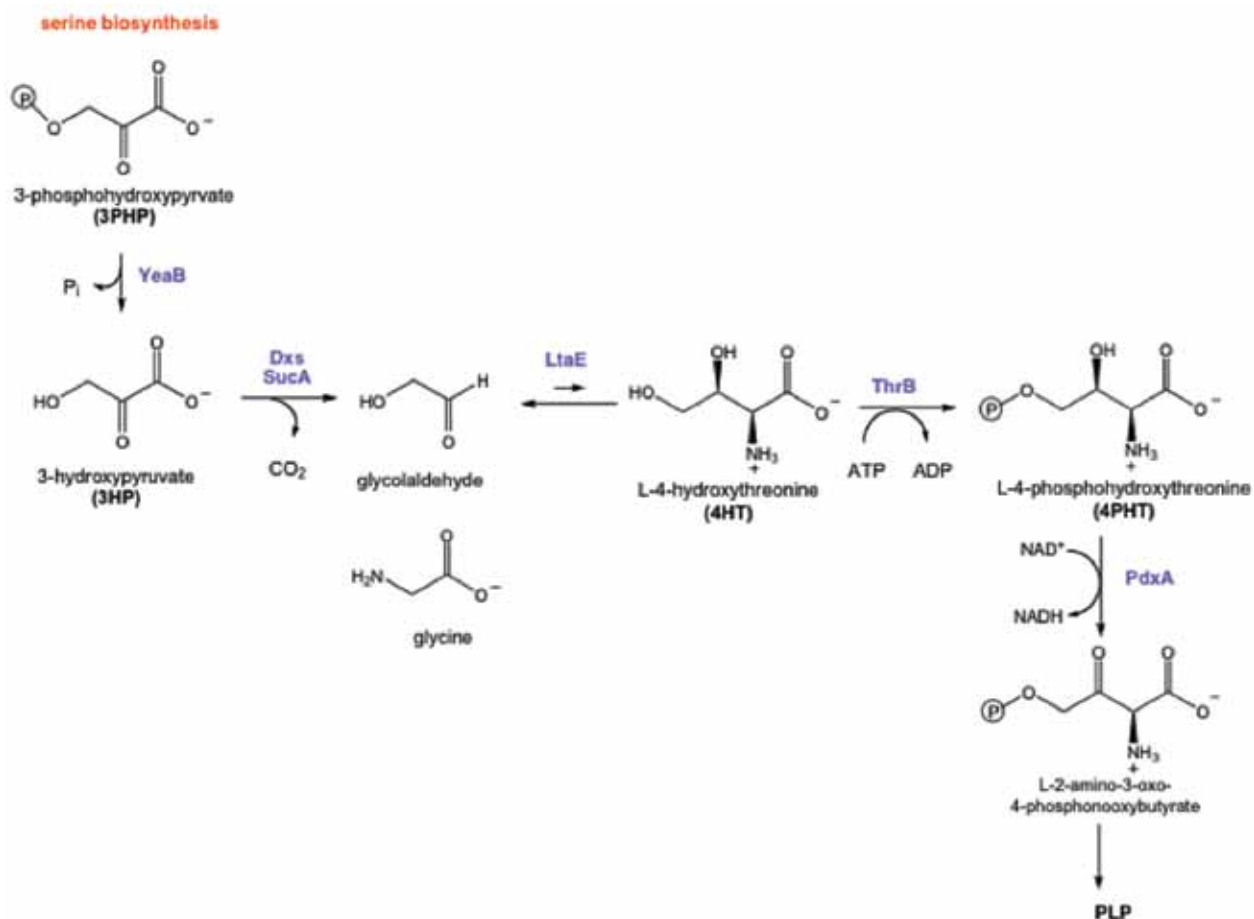
Enzymes are superb catalysts, capable of accelerating reactions by up to 17 orders of magnitude. The conditions required to produce and to use enzymes are “green”—they do not require toxic organic solvents or high temperatures and pressures that are costly in terms of energy usage.

New enzymes can emerge from promiscuous activities that arise from the collection of reactive catalytic residues and cofactors at active sites. Although promiscuous activities are normally of

no particular use to the organism, they provide an expanded catalytic repertoire from which enzymes may be recruited under novel environmental conditions. However, the potential of promiscuous enzymes goes beyond just catalysis of a single reaction. Promiscuous activities can be assembled into novel combinations to generate what we term “serendipitous” pathways.

We are currently studying three pathways that are patched together from promiscuous enzymes to allow *E. coli* to bypass a metabolic block. A strain of *E. coli* lacking erythronate 4-phosphate dehydrogenase cannot grow on glucose because it cannot make the cofactor pyridoxal phosphate. We have identified seven enzymes that, when over-expressed, allow this strain to grow on glucose. Genetic analyses suggest that these enzymes facilitate three serendipitous pathways that allow *E. coli* to produce a metabolite downstream of the block. We have identified enzymes capable of catalyzing the four steps in one of these pathways (see figure). These pathways illustrate the remarkable evolutionary potential of catalytically promiscuous enzymes residing within the proteome of *E. coli*, which contains about 2,000 enzymes.

This project will enhance our understanding of the potential for assembling novel metabolic pathways by patching together enzymes that normally serve other functions in the cell. Such pathways could be engineered to allow degradation of anthropogenic chemicals such as pesticides and industrial pollutants, or to allow “green” synthesis of pharmaceuticals, specialty chemicals, and biofuels.



Joost de Gouw

Composition and Transport of Biomass Burning Emissions

FUNDING: NATIONAL SCIENCE FOUNDATION



Biomass burning is a large but poorly described source of trace-gas and aerosol emissions to the atmosphere. Biomass burning occurs both naturally in forest fires, but a significant fraction is human induced—for example, the burning of bio-fuels for heating and cooking, agricultural residue, and trash. In addition, the frequency and intensity of forest fires may be increasing due to higher temperatures, droughts, and earlier snowmelts in boreal re-

gions as a result of climate change.

The impact of biomass-burning emissions on the atmosphere is poorly described for a variety of reasons. The fuels are only partially combusted, and the highly oxidized nature of the emissions poses a challenge for current analytical instruments. The variability in fuels and burning conditions gives rise to a very large variability in the chemical composition of emissions. The episodic nature of

biomass burning makes it difficult to study these sources systematically during field missions.

In our work, we have studied the chemical composition of biomass burning emissions in the laboratory, as well as the long-range transport and transformation of forest-fire emissions in the atmosphere.

To characterize the emissions of trace gases, we conducted detailed measurements of biomass-burning emissions at the Fire Sciences Laboratory of the U.S. Forest Service in Missoula, MT. Using a newly developed negative-ion proton-transfer chemical ionization mass spectrometer, we identified large emissions of nitrous acid (HONO), isocyanic acid (HNCO) and several carboxylic acids. These observations are of interest for various reasons. HONO molecules readily produce free radicals in the atmosphere upon photolysis, which affects the chemical transformation of biomass-burning emissions. HNCO has not been observed previously in the atmosphere, and work is in progress to evaluate the atmospheric chemistry of this trace gas. Finally, several of the measured carboxylic acids are efficient precursors of aerosol formation in biomass-burning plumes.

Forest-fire emissions have been observed during several airborne field missions conducted with the NOAA WP-3D research aircraft. For example, forest-fire plumes from Siberia were observed in the Alaskan Arctic in April 2008. This year, we studied how commonly Siberian fires contribute to the aerosol loadings in the Arctic. We found that for organic and black carbon aerosol in particular, the contribution from forest-fire emissions is very large, even in an average year. These observations are significant, as aerosol in the Arctic has been speculated to play an important role in the radiative forcing of Arctic climate as well as in the melting of sea ice and the ice sheet after deposition.



De Gouw studies the chemical composition of biomass-burning emissions in the laboratory, as well as the long-range transport and transformation of forest-fire emissions in the atmosphere.

DANIEL WELSH-BON

Lisa Dilling

The Weakest Link: The Uptake of Knowledge on Vulnerability Into Decision Making



As the dimensions and reality of climate change have become more evident in recent years, attention is now beginning to focus on the issue of adaptation. While much attention has been focused on estimating future impacts from climate change on various sectors and parts of the world (e.g., Working Group II of the Intergovernmental Panel on Climate Change 2007), much remains to be understood about the barriers to successful adaptation. These barriers include lack of know-

ledge about what to do and lack of capacity (whether financial, institutional, or human) to act (Adger et al. 2007).

However, many may assume that given knowledge about how to reduce negative outcomes, and given sufficient societal capacity, society will take action to adapt to the risks of climate change. From existing research about the response to hazards, even without the prospect of climate change, we might have reason to doubt this assumption. As Mickey Glantz and colleagues wrote, “lessons learned” might more appropriately be called “lessons identified”—only until someone actually applies the knowledge to reduce the risks associated with future hazards do they actually become lessons truly learned

(Glantz et al. 2009).

In an important review, White, Kates, and Burton wrote about where hazards scholarship stands on the “situation in which more is lost while more is known” (White et al. 2001). While the good news is that losses of life are decreasing, property damage is increasing in both developing and the developed countries. Losses of life, while declining, remain unacceptably high, given the number of preventable deaths (especially in developing countries).

With respect to the role of knowledge in improving outcomes in regards to hazards, White et al. (2001) briefly reviewed five potential explanations for why, in face of ever-growing knowledge about hazards and their natural and social causes, losses continue to mount. The possible explanations they offer include: 1) knowledge is still lacking; 2) knowledge is available but not used; 3) knowledge is used, but ineffectively or with unintended consequences; 4) there is a lag time between the effective use of relevant knowledge and improving the situation; and 5) all best efforts to use knowledge have occurred but background increases in vulnerability swamp any positive gains. White et al. conclude with a plea for more appraisal of the “actual results of applying the best available knowledge in the best possible way” and better integration of knowledge of hazards into the practice of sustainable development.

One of the key barriers to successful adaptation that must not be overlooked, therefore, is the uptake and use of knowledge about reducing vulnerability in decision-making processes. Otherwise, as Glantz has written, we reach the situation where “lessons have been identified, but not learned,” meaning that knowledge gained even as a result of disaster or tragedy, is not acted upon to improve future outcomes. This paper sets forth a theoretical framework to underpin case studies examining three related questions for adaptation: 1) Is lack of information a barrier for successful adaptation measures?, 2) What are the barriers to the successful uptake of information for adaptation in policy?, and 3) Are there limits to the use of information for improving outcomes?



A broken California levee in 2004.

CALIFORNIA DEPARTMENT OF WATER RESOURCES

Lang Farmer

Mining the North American
Volcanic Rock Database

FUNDING: NATIONAL SCIENCE FOUNDATION



The Farmer laboratory has been involved for the past eight years in the development and population of an online database for the age and chemical compositions of western North America volcanic rocks. This North America Volcanic and Intrusive Rock Database (NAVDAT; <http://www.navdat.org/>) now contains information for nearly 65,000 separate rocks samples, allowing variations in the compositions of these rocks through time and geographic position to be

interrogated at an unprecedented level of detail.

Our efforts in 2009 to mine the database concentrated on intermediate- to silicic-composition magmatism that occurred during the mid-Cenozoic “ignimbrite flare-up” in western North America. This immense volcanic event is generally attributed to a melting event in the upper mantle, related in some fashion to shallowing and resteeptening of the subduction angle of oceanic lithosphere underthrust beneath the continent. To address what exactly produced the flare-up, we reexamined space-time-composition patterns in mid-Cenozoic magmatism in the Rocky Mountain region, using more than 5,500 individual rock chemical analyses now compiled in NAVDAT for rocks of this age. We divided the Rocky Mountain and northern Mexico regions into 15, 5° x 5° grid elements and interrogated volcanic rock ages and compositions from each. At this scale, the ignimbrite flare-up clearly occurs in two pulses: from 40-60 million years ago (Ma) north of about 45°N latitude and from 20-40 Ma to the south—in Colorado, New Mexico, west Texas, and northern Mexico. The chemical compositions of the mid-Cenozoic volcanic rocks, in contrast, vary little with latitude, but instead show longitudinal variations (Figure 1), from largely calc-alkaline in the west to alkaline (basically high sodium contents) in the east. These observa-

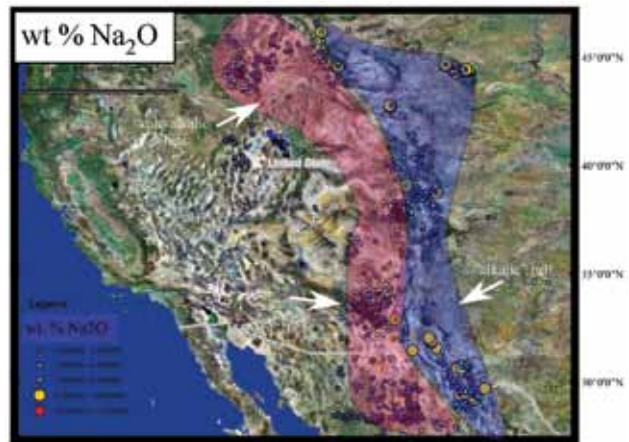


Figure 1: Sodium contents for mid-Cenozoic volcanic rocks from the southwestern portions of North America, using data extracted from the North American Volcanic and Intrusive Rock database (NAVDAT).



LANG FARMER

Mid-Cenozoic volcanic rocks in the Never Summer Mountains, north-central Colorado.

tions are at least consistent with the volcanic episodes being ultimately related to subduction of oceanic lithosphere, but with major west-east changes occurring in the mantle sources of the magmas parental to the volcanic rocks, potentially as a function of the dip angle of the underthrust oceanic lithosphere. We plan to continue to investigate these regional variations in volcanic rock compositions in the upcoming year, expanding our studies to comparing space-time-composition patterns in volcanism in the western United States and northern Mexico.

Noah Fierer

Microbial Life in the Atmosphere

FUNDING: NATIONAL SCIENCE FOUNDATION, U.S. DEPARTMENT OF AGRICULTURE



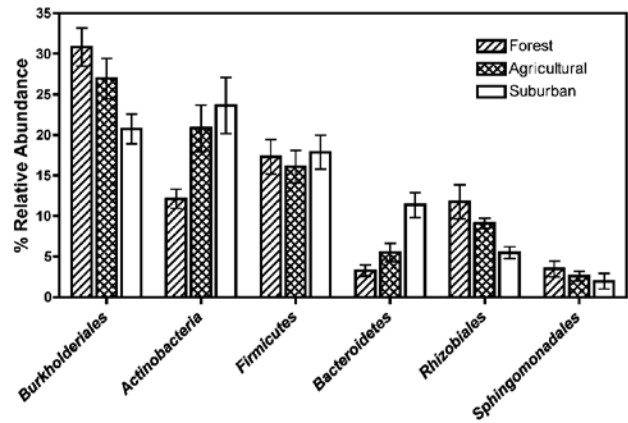
Bacteria are abundant in the atmosphere with the near-surface atmosphere containing more than 10^6 bacterial cells per cubic meter of air. Atmospheric transport is a key mode of microbial dispersal, and the transmission of airborne plant and animal pathogens can significantly affect ecosystems, agriculture, 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 precipitation events by facilitating atmospheric ice nucleation and cloud condensation. If this is valid, it would suggest a novel linkage between the land surface (the source of bacterial cells) and the atmosphere, with micron-sized organisms having far-reaching impacts on local and regional atmospheric conditions.

Our ongoing work addresses three 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 across land-use types?, and 3) How abundant are high-temperature bacterial ice nucleators in the atmosphere?

During the past year, we have been addressing these questions with a series of studies conducted across the Colorado Front Range. We have focused on 15 sites in three land-use types that dominate the Front Range area (urban/suburban, agricultural fields, and forests). We used a range of molecular techniques, including high-throughput pyrosequencing, to characterize the bacterial communities in the collected air samples. We found that the atmosphere over each land-use type harbored significantly different bacterial communities, and we could link these shifts in the bacterial communities to changes in the relative importance of soil (dust) versus leaf inputs of bacteria to the atmosphere. We also found



The dominant bacterial phyla and sub-phyla found in air samples collected from across the three land-use types in the Colorado Front Range: forest ($n = 5$), agricultural ($n = 5$), and suburban ($n = 5$). Error bars indicate ± 1 standard error of the mean.



Graduate student Bob Bowers with air sampling equipment at an agricultural field east of Boulder.

that the atmosphere above agricultural fields has far higher concentrations of bacterial ice nucleators than the other land-use types, and we link these airborne ice nucleators to those bacteria commonly found on wheat and other agricultural crops. Finally, we show that bacterial diversity in the atmosphere is far higher than expected, with hundreds of bacterial species per cubic meter of air.

We are currently expanding on this work to examine airborne bacterial diversity across broader spatial and temporal gradients. We are also investigating whether we may be able to use airborne bacteria to track the sources of air parcels as they move across the continental United States.

Baylor Fox-Kemper

Improving Subgridscale Physics in Ocean Climate Models

FUNDING: NATIONAL SCIENCE FOUNDATION, NASA, CIRES INNOVATIVE RESEARCH PROGRAM, CU-BOULDER INNOVATIVE SEED GRANT PROGRAM



My research group focuses largely on the representation of mesoscale (100 km), submesoscale (1-10 km), and Langmuir-scale (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 20 April 2010, the explosion of the Deepwater Horizon oil platform and subsequent

oil leakage has 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 (Figure 1), and the formation of windrows between the Langmuir cells (Figure 2), are disturbing examples of oceanic stirring at different scales.

High-resolution regional models can directly represent these processes, but they are far too small to be directly represented in global climate models, in which one grid cell usually spans more than 200 km. Scaling laws found from high-resolution simulations and mathematical analyses of these subgrid processes can be transformed into simple models of their bulk behavior. These simple models, or parameterizations, are then incorporated into global climate models.

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.

Looking even farther ahead, improving the representation of Langmuir mixing in global climate models and validating the results against satellite wave observations is occupying much of my group's present work, in collaboration with scientists from the National Center for Atmospheric Research (NCAR), CU-Boulder, the University of Washington, and the University of New Hampshire. The CIRES Innovative Research Program began this project, and it continues with NASA funding and a new NSF proj-



NASA

Figure 1: This image, taken by the International Space Station Expedition 23 crew on 4 May 2010, shows the oil slick approaching the 25-km wide Mississippi River Delta. The shape of the slick has been strained and stirred, likely by mesoscale eddies, submesoscale fronts, and submesoscale eddies.



NASA

Figure 2: A false-color image from NASA's Terra satellite on 1 May 2010. The streaking patterns perpendicular to the wave crests are likely windrows between Langmuir circulations.

ect on interactions between Langmuir and submesoscale phenomena.

Scientists working on representing mesoscale eddies in global climate models celebrated the 20th anniversary of the Gent-McWilliams parameterization this year. Yet, much remains unknown. My research group, with NCAR and University of Hamburg scientists, has completed a massive simulation allowing stirring by mesoscale eddies to be mapped globally in three dimensions for the first time. Improving the Gent-McWilliams parameterization based on these results is ongoing.

Finally, testing new parameterizations requires statistical tools to probe the behavior of complex phenomena such as El Niño. The group develops these tools, and they are being used to test ongoing IPCC AR5 model results against modern observations and paleoclimate proxy data.

Vijay Gupta

Generalizing a Scaling Flood Theory to Medium-Sized River Networks

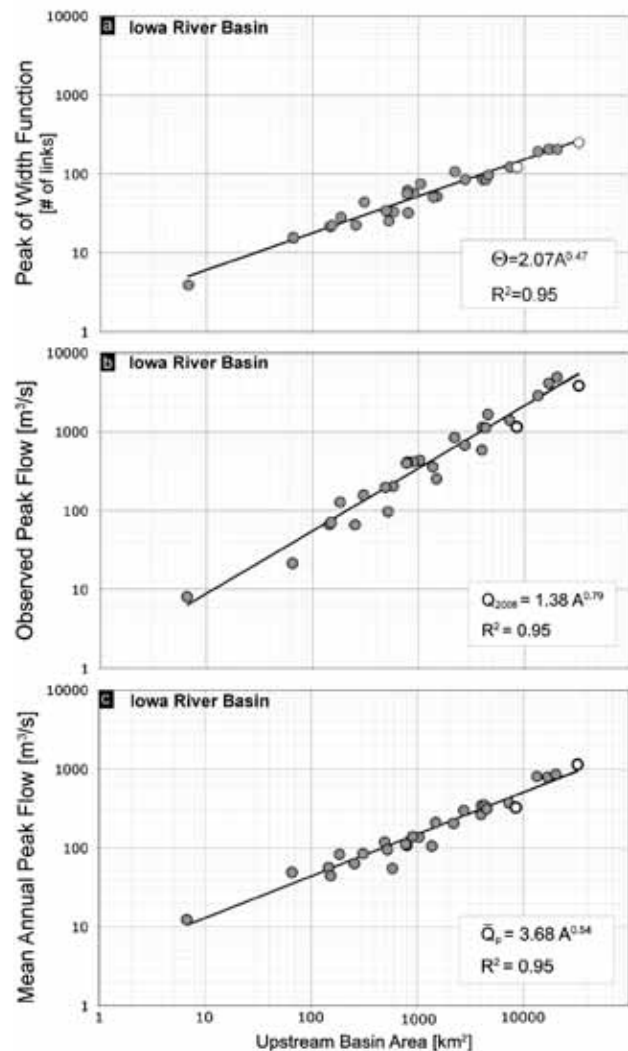


The U.S. Geological Survey recently published a report on “Flooding in the United States Midwest, 2008.” It states that “the June floods were by far the most severe and widespread with substantial (and in places record) flooding and damage occurring in Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, Oklahoma, South Dakota, and Wisconsin.” The report, following the conventional hydrologic wisdom, says “record precipitation amounts,

coupled with already saturated soils, resulted in flooding along many rivers in the United States Midwest.”

Gupta and his colleagues have uncovered that “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 that each part of a network is a tiny version of the whole (panel a). Gupta and his colleagues analyzed the Geological Survey’s streamflow data from the Iowa floods of June 2008 at multiple locations in the Iowa River Basin. They observed the presence of a power law, or a scaling, relation (panel b). This observation supports the central hypothesis of a nonlinear geophysical flood theory—that multi-scale solutions of mass and momentum conservation equations on random self-similar channel networks produce spatial scaling (power laws) in mean peak flows as drainage area increases to infinity. In this sense, scaling is an emergent property of the system that is not directly built into the conservation equations. The hypothesis supported by observations shown in the figure suggests that a key physical reason for flooding lies in the spatial organization of runoff due to river network pattern in a river basin. Preliminary simulation work of Iowa colleagues for the June 2008 flood event has documented that soils need not be saturated for major floods to occur.

The role of channel network in major flooding adds a fundamental new dimension in understanding and



a) The scaling plot for the peak of the width function at 29 sites embedded in the Iowa River basin above Wapello, IA. The observed power law is a property of the river network structure. b) Observed peak flow values during the June 2008 event at the same sites, and c) Mean annual maximum streamflow estimated at the same locations. The existence of power-law relations in these datasets form the basis for diagnostics of the Geophysical Theory of Floods. Locations where gauging records are affected by upstream regulation are shown as empty circles.

predicting floods. As mentioned in the 2009 CIRES Annual Report, practical applications of this theory will range from development of new methods to greatly improve real-time flood forecasting to estimation of annual flood frequencies for the management of flood plains in a changing climate.

Jose-Luis Jimenez

Evolution of Organic Aerosols in the Atmosphere

FUNDING: NATIONAL SCIENCE FOUNDATION, U.S. DEPARTMENT OF ENERGY, ENVIRONMENTAL PROTECTION AGENCY



Organic compounds coat airborne particles like a lacquer of spray paint and make up as much as 90 percent of all fine particle mass aloft in the atmosphere. These particles influence cloud formation and therefore rainfall. They also affect human health and can lead to illnesses such as asthma, heart disease, and lung cancer. But so far only about 10-30 percent of the thousands of individual compounds have been identified, and past research has focused on following specific

molecules with the idea that these compounds remain relatively static in nature once they enter the atmosphere. Recent discoveries by my research group and colleagues show that the life cycle of these compounds is much more complex, with organic molecules reacting many times over in many different ways. Attempts by atmospheric scientists to track this life cycle often leave researchers with a sea of divergent paths to follow.

To find some order in this chaos, my colleagues and I began looking at organic aerosols (OA) with a more holistic mindset. Through a series of field observations and lab experiments from all over the world, we found that organic matter ultimately tends to evolve towards a similar end, regardless of the source or where they occur in the atmosphere. In a paper in the journal *Science* (Jimenez et al. 2009), we presented a unifying model framework describing the atmospheric evolution of OA, which is constrained by high-time-resolution measurements of their composition, volatility, and oxidation state. OA and OA-precursor gases evolve by becoming increasingly oxidized, less volatile, and more hygroscopic, leading to the formation of oxygenated organic aerosol (OOA) mass with concentrations comparable to sulfate aerosol throughout the Northern Hemisphere. The complex evolution of OA contrasts with the simpler behavior of sulfate, which is irreversibly oxidized and condensed. Current modeling frameworks for OA are constructed in analogous way to those for sulfate, with either no aging or one-step oxidation. This paper presented a unifying framework describing the atmospheric evolution of OA, which is directly connected to worldwide observations and experimentally verifiable, and can be used to evaluate and form the basis of practical, phenomenological modeling approaches. The combination of measurements and the modeling framework imply that most OA is an intermediate state of organic material, between primary emissions of reduced species and highly oxidized volatile products (CO and CO₂). Future models, inventories, and measurements will almost certainly need to account for the dynamic sources and sinks of OA to accurately predict regional and global OA distributions and properties, and thus the associated health and climate effects.

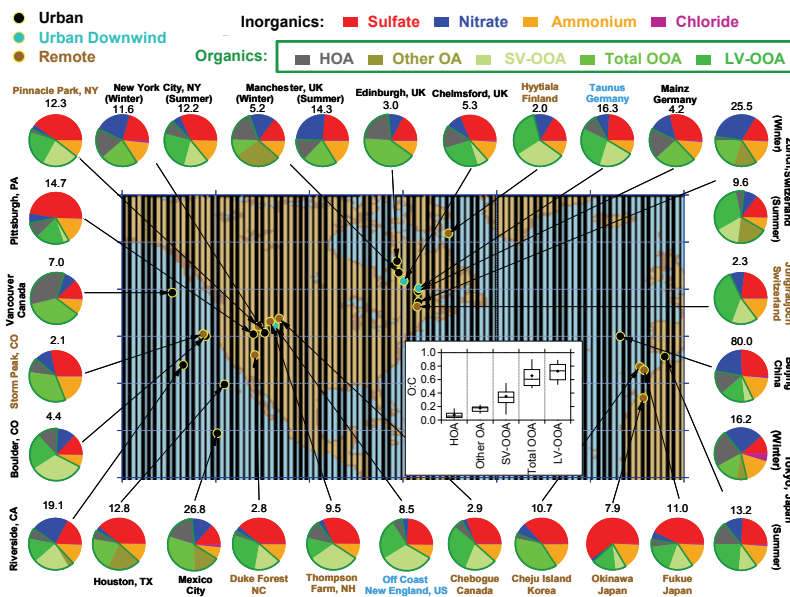


EDWARD DUNLEA

The NSF/NCAR C-130 research aircraft taking off during a field campaign in Spring 2006.

lution of OA, which is constrained by high-time-resolution measurements of their composition, volatility, and oxidation state. OA and OA-precursor gases evolve by becoming increasingly oxidized, less volatile, and more hygroscopic, leading to the formation of oxygenated organic aerosol (OOA) mass with concentrations comparable to sulfate aerosol throughout the Northern Hemisphere. The complex evolution of OA contrasts with the simpler behavior of sulfate, which is irreversibly oxidized and condensed. Current modeling frameworks for OA are constructed in analogous way to those for sulfate, with either no aging or one-step oxidation. This paper presented a unifying framework describing the atmospheric evolution of OA, which is directly connected to worldwide observations and experimentally verifiable, and can be used to evaluate and form the basis of practical, phenomenological modeling approaches. The combination of measurements and the modeling framework imply that most OA is an intermediate state of organic material, between primary emissions of reduced species and highly oxidized volatile products (CO and CO₂). Future models, inventories, and measurements will almost certainly need to account for the dynamic sources and sinks of OA to accurately predict regional and global OA distributions and properties, and thus the associated health and climate effects.

Total mass concentration ($\mu\text{g}/\text{m}^3$) and mass fractions of non-refractory inorganic species and organic components in submicron aerosols measured at multiple surface locations in the Northern Hemisphere. The organic components were obtained from factor analysis of aerosol mass spectrometry data (FA-AMS). For some studies the FA-AMS methods identified one oxygenated organic aerosol (OOA) factor, while in other locations two types, semivolatile (SV) and low-volatility (LV) OOA, were identified. HOA stands for hydrocarbon-like OA, a surrogate for urban primary OA, while "Other OA" comprises primary OAs other than HOA that have been identified in several studies, including biomass-burning OA (BBOA).



Craig Jones

Tectonics of Foundering Lithosphere, Sierra Nevada, CA

FUNDING: NATIONAL SCIENCE FOUNDATION EARTHSCOPE AND CONTINENTAL DYNAMICS PROGRAMS

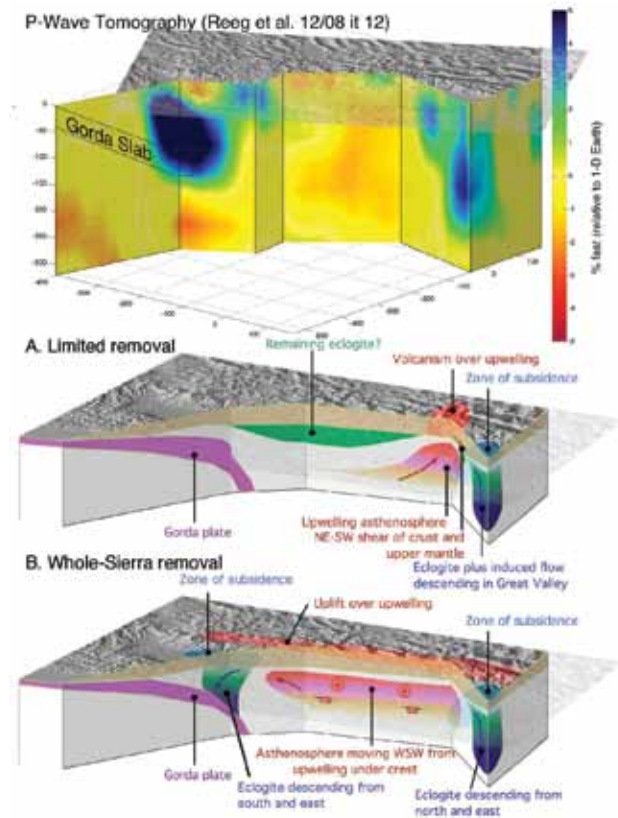


In contrast with oceanic tectonics, continental tectonics are diffuse and occur in places and with styles not easily anticipated from plate kinematics. One potential cause is the antibuoyant mantle lithosphere under continents and the potential that it could detach and sink into the mantle. The Sierra Nevada of California might overlie lithosphere that foundered in the past 10 million years. Jones and colleagues at CU-Boulder and several other universities are analyzing data from the Sierra to

understand the dynamics of this process.

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

The removal of mantle lithosphere may drive enigmatic deformation in continents, but hypotheses for the impacts of such an event were largely based on theory. Previous geophysical data allowed for two possibilities in the Sierra: that only some of the dense layer was removed from part of the range, leaving explanation for most of the elevation of the Sierra to another cause (A in the figure) or that uplift of the range was caused by convective removal of a dense layer at the base of the crust (B in the figure). Inversion of the arrival times of P-waves from distant earthquakes were used to image variations in seismic wavespeed under the Sierra and much of surrounding California (top panel),



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

revealing elements of both ideas. To the right (south), low-speed material (oranges) appears under the southern Sierra to the northeast of the high wavespeed "drip" under the San Joaquin Valley, consistent with case A. Far to the north, high-wavespeed material with a subducting slab is also tied to shallow high-wavespeed material under the Sierra, suggesting some Sierran material being entrained with the downgoing slab. (The bulk of the slab does not show up in this section, owing to coverage from available seismometers). The analysis of density variations indicates that the high-wavespeed bodies (in blue) are denser than if the seismic variation was solely due to temperature. This indicates that some or all of the garnet-rich lithologies are still present under the Sierran foothills and in the "drip" seen at the right of the image, indicating that the process is still underway.

William Lewis, Jr.

Lakes of the World



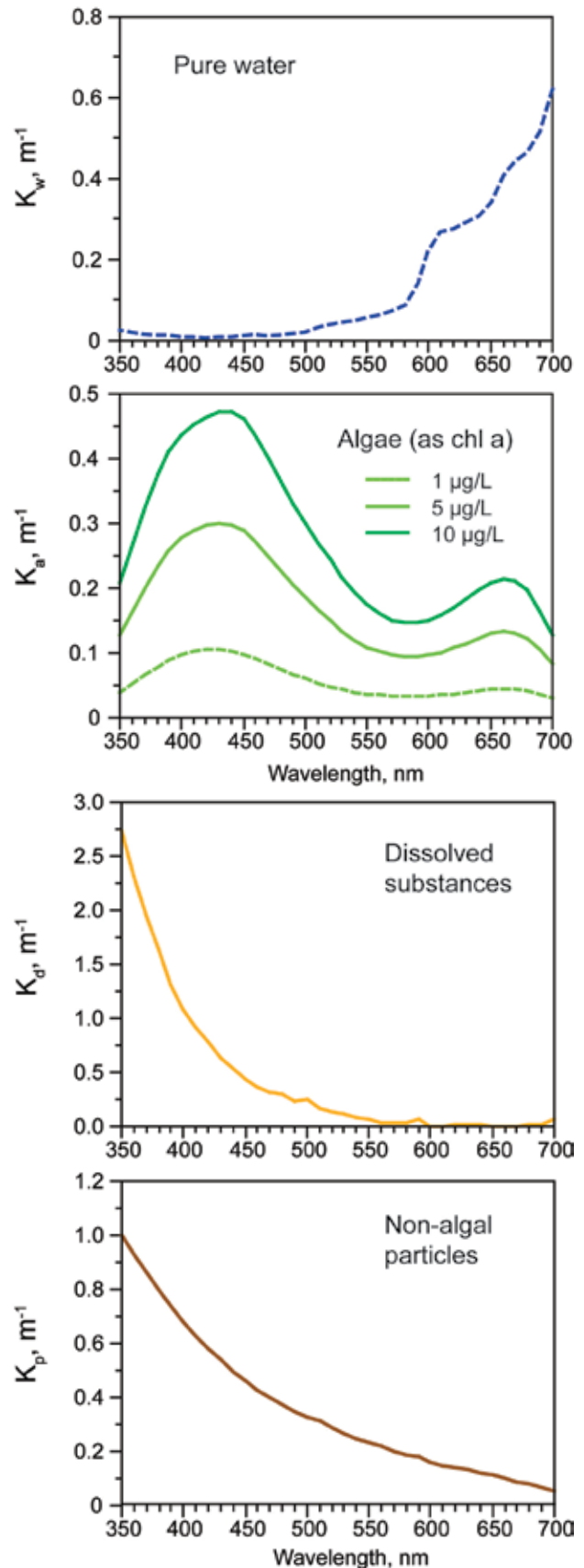
Reports on the global status of ecosystems are commonplace now as there is much interest in the influence of various ecosystem types on the carbon cycle and the response of the ecosystems to human influence. These reports routinely include world oceans and world terrestrial ecosystems, but not lakes. Lakes account for only a few percent of the world's terrestrial surfaces, and therefore may seem inconsequential. Because most of the waters that drain to the oceans from

the continents pass through lakes prior to reaching their destination, the effects of lakes on transport of carbon and other substances is of great practical importance.

One problem in establishing a global view of lakes is that the importance of small lakes is difficult to quantify. Use of frequency distribution methods has recently suggested that the total number of lakes globally is about 304 million, and that small lakes account for as much area as large lakes, contrary to earlier expectations. The definition of lake frequency distributions and latitudinal distributions of lakes by use of geographic information system (GIS) technology pave the way for modeling of lake functions globally. The Center for Limnology is participating in this effort through the estimation of worldwide primary production (photosynthesis) of lakes.

While the most productive lakes are as much as 10-percent efficient in converting solar irradiance to organic matter, most lakes are much less efficient than this (often below one percent). A quantitative estimate of the factors that determine lake production worldwide is underway at the Center for Limnology, by use of quantifiable climate influences and factors that must be approached through a knowledge of frequency distributions of factors that control the transparency of inland waters and the availability of nutrients of inland waters (figure at right). The end product will be presented at the International Congress for Limnology in Cape Town, South Africa in August 2010.

Factors affecting light attenuation in lakes. At a given wavelength, the total attenuation coefficient (K_t) is the sum of attenuation coefficients for pure water, dissolved substances, algal particles, and non-algal particles.



Peter Molnar

Tibet and the Asian Monsoon System



I devoted a part of my research effort in FY10 to synthesizing evidence that pertains to the growth of the Tibetan Plateau and to the Asian monsoon, in modern and geologic time. (Molnar et al. 2010).

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 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.

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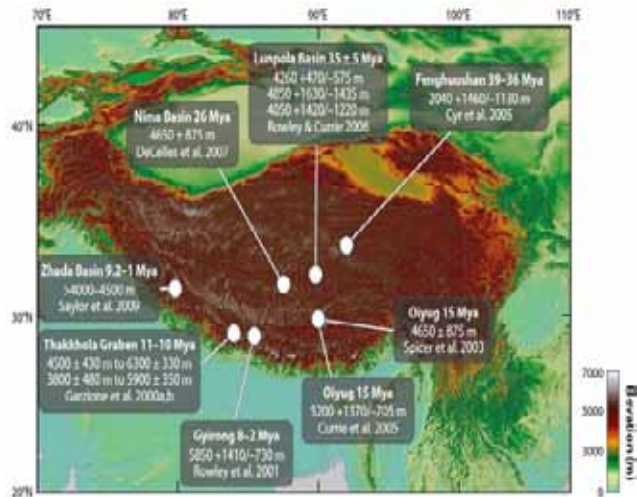


Figure 1: Topographic map of Tibet showing estimates of paleoaltimetry.

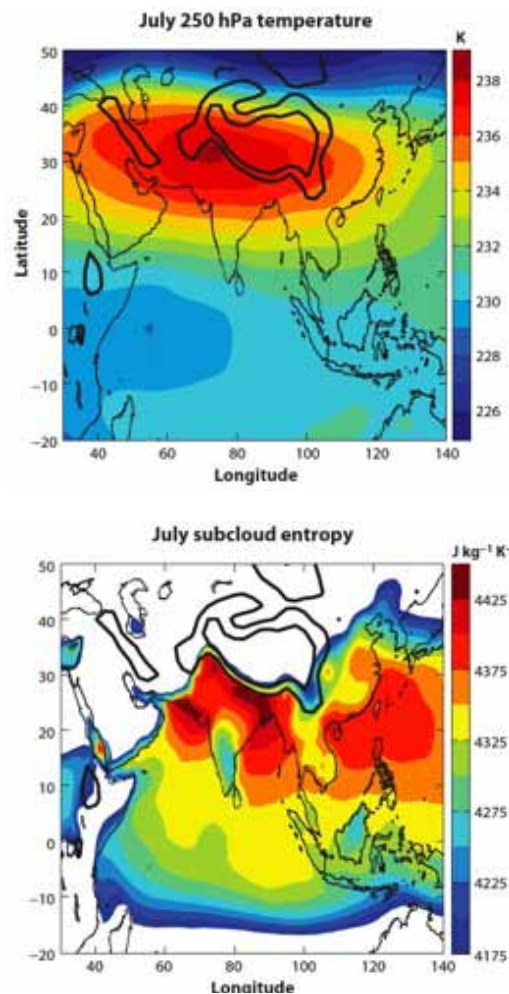


Figure 2: (top) Upper-tropospheric temperature (250 hPa) over Asia in July; the maximum overlies northern India and Pakistan, not the Tibetan Plateau. (bottom) The moist entropy in July on a terrain-following model level within 50 hPa (about 500 m) of the surface. All quantities are means for 1979–2002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



STEVE MILLER/CIRES

Instruments on the AmeriFlux tower at Niwot in Ridge in Colorado.

Russell Monson

Forest Carbon Cycle Studies

FUNDING: NATIONAL SCIENCE FOUNDATION,
DEPARTMENT OF ENERGY



For the past 11 years, we have been studying carbon fluxes between forest ecosystems and the atmosphere in the mountains of Colorado. Our aim is to understand the principal controls over, and magnitude of, the exchange of carbon dioxide from trees and soils in forest ecosystems, and their response to interannual climate variation. In the past few years, we have combined tower flux measurement systems and aircraft sampling to conduct these studies. We have shown that these forest

ecosystems are highly affected by year-to-year variation in the winter snowpack, which has been diminishing over the past 50 years throughout the western United States. Lower snowpacks cause the forests to be water stressed during the middle of the summer, reducing their productivity, and

thus reducing their potential to extract CO₂ from the atmosphere. The influence of reduced snowpack is a systematic component of climate change in the western United States, and is expected to continue in the face of future warming trends.

In the past year, we noticed that mountain pine beetles have infected our experimental forest near Niwot Ridge, CO. The beetles have the potential to further stress the forest, and even further reduce the rate by which the forest extracts CO₂ from the atmosphere. We have initiated studies of the impact of beetle infestation on the cycling of carbon within the soil, and the potential for beetle infections to increase the rate of CO₂ loss from the ecosystem. This increased CO₂ loss will likely be due to increased death of trees and their associated needles, which will increase the deposition of litter to the soil. We are conducting a series of studies using the stable isotopes of carbon (¹³C and ¹²C), to discern rates of soil carbon cycling and its coupling to climate change, and we are using one of the radioactive isotopes of carbon (¹⁴C) to determine shifts in the mean age of soil carbon as a result of the beetle infection.

Given the widespread distribution of mountain forests in the western United States, their dominant role in sequestering atmospheric carbon in this part of the country, and stresses such as winter warming accompanied by reduced snow and mountain pine beetle outbreaks, we can expect the terrestrial carbon sink in the western United States to continue to weaken in the future. We are currently trying to adopt methods of model-data assimilation, combined with predictions of regional climate change using general circulation models, to better understand the connections between these stresses and CO₂ uptake by these forest ecosystems.

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 3.4 mm/year since 1993 (Figure 1). My current research focuses on determining the causes of this change and relating

the satellite record of sea-level change to the longer-term record from tide gauges.

A relatively new technique has been developed that allows the direct measurement of the continental water contributions from space. The Gravity Recovery and Climate Experiment (GRACE) satellite mission has precisely measured temporal variations in Earth's gravitational field since 2002. As the melting of ice in mountain glaciers and ice sheets, in addition to other runoff, adds water mass to the oceans, GRACE has demonstrated the ability to directly measure this change in mass. GRACE can also determine the relative contributions of different areas on the continents. At seasonal frequencies, GRACE ocean-mass estimates have been shown to compare quite well with estimates from satellite altimetry corrected for thermal expansion using shipboard measurements. The seasonal variations in ocean-water mass are due to the seasonal exchange of water with the continents, and thus GRACE measurements are expected to make their greatest impact on studies of the global water cycle. However, eventually GRACE should help explain the differences we have seen between the altimetry and ocean-temperature measurements (Figure 2), since in theory, these are due to changes in global ocean mass.

The biggest advance we made in the past year was a better understanding of the rapid changes occurring in Greenland, and their contribution to sea-level rise. This is largely due to the GRACE mission, which shows Greenland and Antarctica contributing 0.6 and 0.5 mm/year to sea level rise, respectively. Of the observed 3.4 mm/year global averaged sea-level rise, approximately one-third is now thought to be due to the warming of the oceans (thermal expansion), one-third due to the melting of ice in mountain glaciers, and the rest due to other exchanges of freshwater with the continents, including ice melt from Greenland and Antarctica. The total rise is significantly

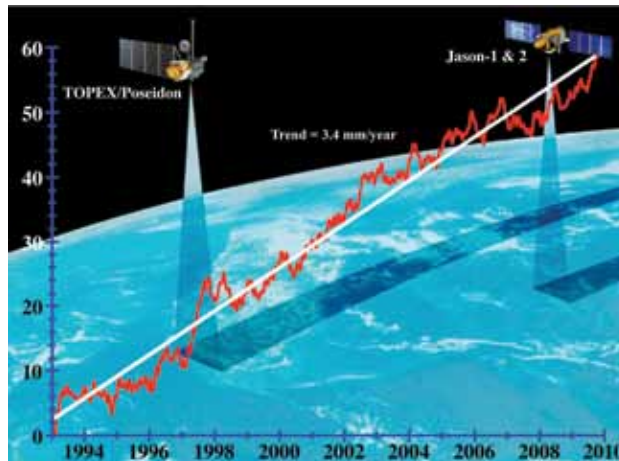


Figure 1: Global mean sea-level variations from a combination of TOPEX/Poseidon, Jason-1, and Jason-2 altimeter data (seasonal variations removed, 60-day smoothing applied).

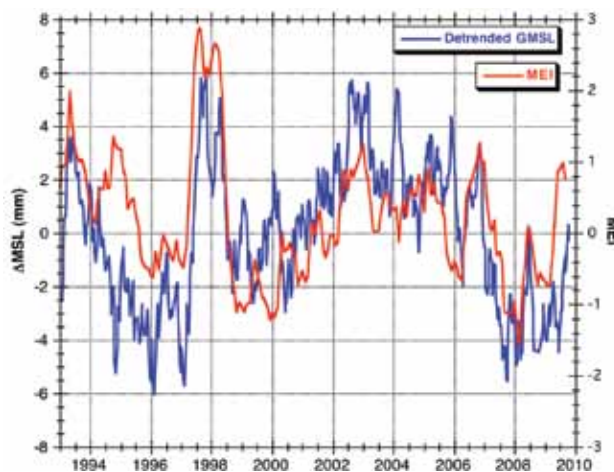


Figure 2: Detrended global mean sea level from satellite altimetry versus the Multivariate El Niño-Southern Oscillation (ENSO) Index (MEI). The ENSO-related global mean sea-level variations are believed to be related to changes in land/ocean precipitation.

greater than has been observed during the last half of the 20th century from tide gauges (about 1.8 mm/year). A substantial part of our future work will involve helping assemble the sea-level chapter of the Intergovernmental Panel on Climate Change Fifth Assessment Report (IPCC AR5) due in 2013.

Satellite altimeter and gravity measurements are expected to have major roles in the formulation of the IPCC AR5. Satellite altimetry has conclusively shown that sea-level rise has been greater during the last 17 years than during the last century. The record of ice-mass changes from the GRACE mission (eight 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 lengthens, it is expected that satellite gravity missions will play a role equal to satellite altimetry in diagnosing the magnitude of sea-level change and its causes.

David Noone

Water and Carbon Cycle Studies in Colorado at the NOAA Tall Tower

FUNDING: CIRES, NASA JET PROPULSION LABORATORY, NATIONAL SCIENCE FOUNDATION



The exchange of water and carbon between the atmosphere and the land surface remains poorly understood, particularly in regions of complex terrain and in the case of stable nighttime boundary layers. We are using the stable isotope chemistry of water to evaluate hydrological air-land exchanges of water and energy and to use this to trace the transport of CO₂ in the boundary layer. Limitations in knowledge of CO₂ transport in the boundary layer is the leading source of error in

global model estimates of CO₂ fluxes, and understanding water is critical to resolving regional water recycling and the surface energy balance.

Variations in isotope rates arise because the abundance of heavy isotopologues (HDO and H₂¹⁸O) relative to normal water (H₂¹⁶O) changes during evaporation and condensation. Lighter H₂O molecules preferentially evaporate, heavier HDO and H₂¹⁸O molecules preferentially condense, and lighter molecules diffuse faster than the heavier ones. In this regard, the isotopic composition can be used for identifying surface water sources and tracking the fate of that water as it moves through the boundary layer.

High-resolution profile measurements of water, the isotopic composition of water, and CO₂ concentration were made at the NOAA Boulder Atmospheric Observatory (BAO) tall-tower facility in Colorado (Figure 1). Measurements were made by placing instruments on the elevator and controlling the ascent and descent every 15 minutes, leading to a total of 311 profiles (Figure 2). During an observation period that followed a storm, melt and evaporation of about one inch of snow shows the isotopic composition unambiguously tracks the fate of the water as it was transported from the surface through the surface layer during the daytime and that there is a significant advective sink. Nighttime conditions were very stable, leading to strong surface trapping of water vapor and also restricting transport of near-surface CO₂. The experimental results are of particular interest because of the extremely weak transport during times of the very stable nighttime boundary layer, which is poorly modeled even in state-of-the-art climate models. Our analysis shows that this is associated with a broad failure of simple turbulence theory, which is

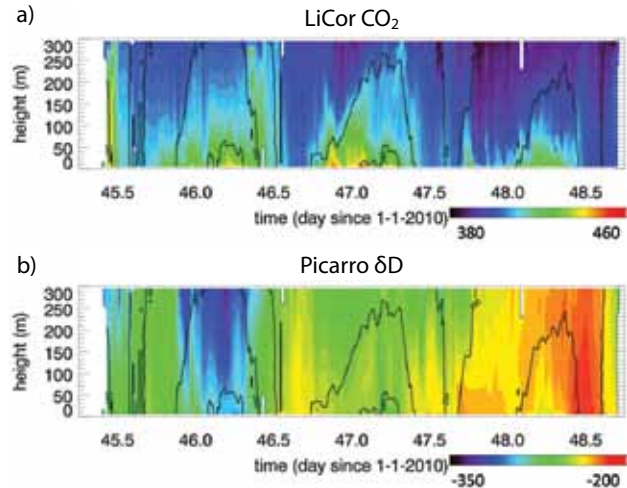


Figure 1: Profile measurements of a) HDO/H₂O water isotope ratio (as δD) and b) CO₂ during 15-18 February 2010 at the NOAA Boulder Atmospheric Observatory. Daytime snowmelt and evaporation are seen in the δD of water, and the restriction of trace gas transport is seen at nighttime in the CO₂.



Figure 2: The instrument package on the elevator ascending the 300-m NOAA Boulder Atmospheric Observatory tower.

of the type typically found in global- and regional-scale models. To this end, improving the representation of the evolution of our observed water isotope and CO₂ profiles provides a clear way to improve models.

Roger Pielke, Jr.

The British Climate Change Act: A Critical Evaluation and Proposed Alternative Approach

FUNDING: NATIONAL SCIENCE FOUNDATION



The United Kingdom's Climate Change Act of 2008 recommends reducing carbon emissions by at least 80 percent by 2050 and 34 percent by 2022, but these goals are just too ambitious to be met, according to a research paper I published in 2009 in the journal *Environmental Research Letters*.

The paper argues that not only is the 2008 Act certain to fail, both in the short and long term, it is also fundamentally flawed in its design. I

argue that the Act begins with a target and then only later do policy makers ask how that target might be achieved, with no consideration for whether the target implies realistic or feasible rates of decarbonization.

Both the 2022 interim and 2050 targets require rates of decarbonization far higher than those ever achieved by

any large economy to date and would require seemingly impossible feats. For example, the UK would need to achieve a carbon efficiency equal to that of France—a relatively carbon-efficient economy due to reliance on nuclear power for electricity generation—in the next five years. Achieving this would require Britain to deploy some 30 new nuclear plants during this time to replace existing power stations fueled by coal and natural gas. I argue that this is just not going to happen, a perspective that was endorsed by the member of the UK Parliament who heads its climate change committee. My paper was the subject of a question posed to each of the three leading political parties in a national debate over energy policy, part of the 2010 parliamentary elections.

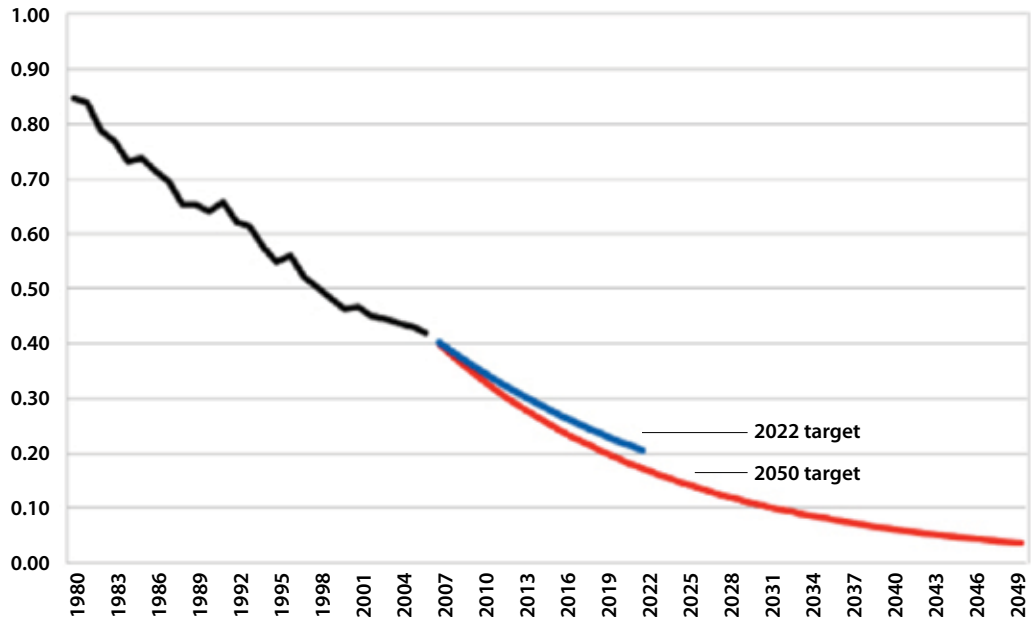
I reached my conclusions by analyzing the targets in the Act using several different approaches and considering projections of future UK population, economic growth, and technology. The calculations show that the UK would have to achieve annual decarbonization rates of more than five percent, a figure that no country has ever attained. In other words, the amount of carbon dioxide emitted by each individual in the UK would need to be reduced by as much as 85 percent in 2050 and 35 percent in 2022, from 1990 levels.

I suggest that setting targets and timetables for different energy sectors and expanding carbon-free energy supplies would be a step in the right direction.

I have conducted similar analyses for Japan and Australia, with similar results, underscoring the need for alternative approaches to achieving emission reduction targets. My new book, *The Climate Fix*, will be published in 2010—and it presents a comprehensive critique of climate policy and suggests a new way forward.

HISTORICAL AND IMPLIED DECARBONIZATION OF THE UNITED KINGDOM ECONOMY ASSUMING 2.0% ANNUAL GDP GROWTH FOR 2022 AND 2050 TARGETS

Past rates of decarbonization of the UK economy, 1980-2006, and implied rates of decarbonization assuming 2% annual GDP growth for the 2022 (blue) and 2050 targets (red). To be on pace to meet the 2022 target, the UK would have to be as carbon efficient as France by no later than 2015, implying a level of effort equivalent to deploying 30 new nuclear power plants.



Balaji Rajagopalan

with graduate student Erin Towler

Climate Variability, Source Water Quality, and Utility Planning

FUNDING: NATIONAL WATER RESEARCH INSTITUTE RESEARCH FELLOWSHIP AND U.S. ENVIRONMENTAL PROTECTION AGENCY SCIENCE TO ACHIEVE RESULTS (STAR) FELLOWSHIP



Climate variability and change affect the hydrologic cycle, which influences the quality of drinking source waters. Shifts in water quality can limit the use of source waters, affecting treatment and management decisions. The confluence of economic growth, increasing demands, and decreasing water supply and quality due to climate fluctuations makes it imperative to develop tools for sustainable development and management of water resources.

Efforts are underway to incorporate climate information into water-availability planning, but little has been done to extend this to water quality. To address this urgent need, we are developing an integrated set of tools that translate climate information into water quantity and quality.

Water quality is often evaluated in terms of thresholds set by regulatory agencies or identified as limits to particular treatment options. Thus, probabilities of threshold exceedances are important for decision making. Examples of our work to inform planning decisions at seasonal and interdecadal time scales are briefly described below.

1) Water Quality Forecasting. To improve efficiency, water utilities require skillful water quality forecasts—and although seasonal climate forecasts have improved, that has not yet led to improved seasonal water quality forecasts. We developed a local logistic regression approach to generate ensembles of water quality variables conditioned on seasonal climate forecast. We demonstrated the useability of the approach for a water utility in Oregon, whose managers sought to understand turbidity exceedances.

2) Understanding Extremes. Large-scale climate drives hydrologic extremes and consequently water quality extremes. We developed a nonstationary generalized extreme value model to estimate the probability distribution of hydrologic and water-quality extremes. The method was used to project extremes under future climate change, for the same Oregon water provider (Figure 1).

3) Planning for New Water Sources. New water source development is the most common solution to meet increasing demand, and it involves significant capital investment. We developed an integrated stochastic framework with simulation techniques to generate paired projections

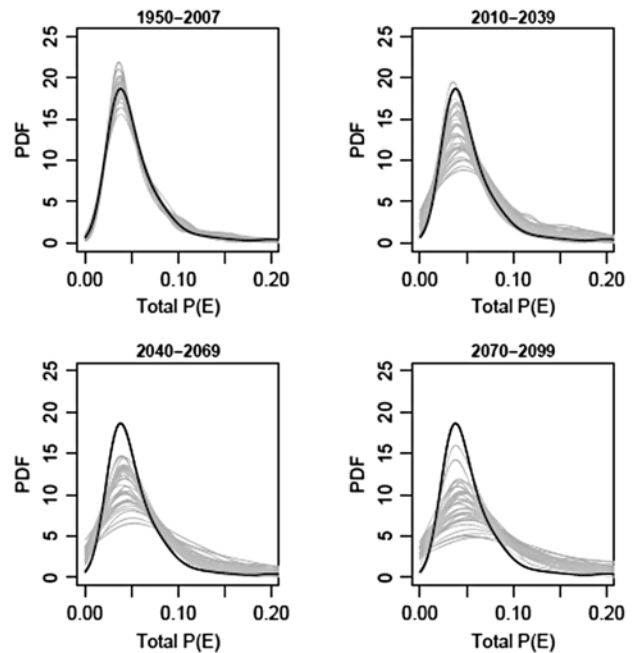


Figure 1: Probability of turbidity threshold exceedance at an Oregon water utility, for varying turbidity thresholds and seasonal climate forecasts.

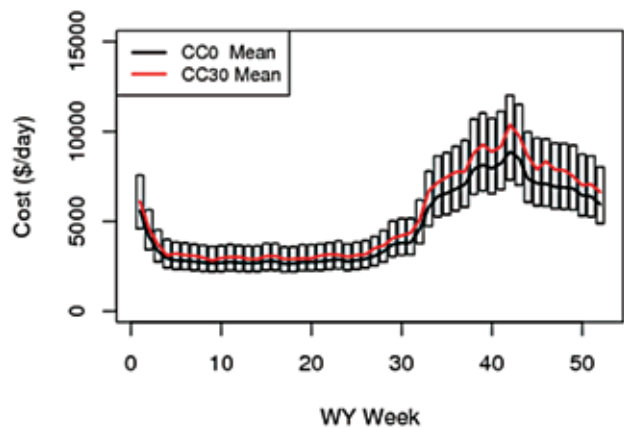


Figure 2: Range of weekly costs (boxes) and mean costs for CC0 (black, historical climate) and CC30 (red, a 30-percent reduction in average streamflow) scenarios.

of streamflow and water quality under a range of climate scenarios. The framework was demonstrated on a municipal water provider in Colorado that is developing a new water source with variable salinity.

4) Evaluating Approaches. When developing or blending in new water sources, utilities need to evaluate the relative costs of necessary treatment. We propose an approach to assess the potential treatment and residential costs associated with blending, under climate uncertainty. Figure 2 shows one way to present and evaluate options. With the proposed blending strategies, a 30-percent reduction in annual flow due to climate change means a 12-percent treatment cost increase and a 22-percent increase in residential cost.

Our work is described in two papers in press at *Water Resources Research*, and a third in review at *Water Research*.

Prashant Sardeshmukh

Critical Influence of the Pattern of Tropical Ocean Warming on Regional Climate Trends Around the Globe



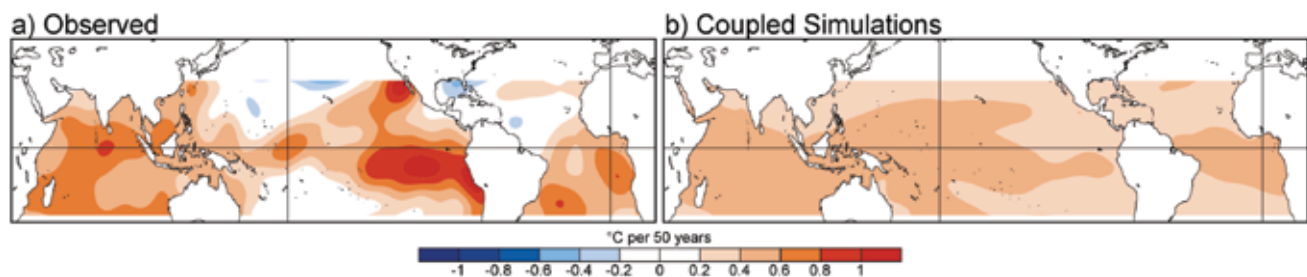
Climate models are now sufficiently advanced that they can reasonably simulate the globally averaged as well as some continental-scale aspects of recent climate change, and provide important guidance on future changes on these scales in response to anthropogenic changes in radiative forcing, as summarized in the 2007 Intergovernmental Panel on Climate Change (IPCC) report. This has led to increased interest and confidence in simulations and predictions

of climate changes on even smaller sub-continental scales, that could be different and more severe than the globally averaged or continental-scale changes.

To assess the extent to which such confidence may be justified, we compared 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 the state-of-the-art IPCC coupled atmosphere-ocean models with prescribed 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 prescribed observed sea-surface temperature (SST) changes 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. 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 Serreze

Winds of Change in the Arctic

FUNDING: NATIONAL SCIENCE FOUNDATION, NASA



Part of my work over the past year has focused on understanding how seasonal and spatial characteristics of recent Arctic air temperature anomalies in the lower troposphere (the 925-hPa level) are related to wind patterns, and how relationships with winds are being modulated by changes in sea-ice concentration, sea-surface temperature, and snow cover. The focus is on the period 1979-2009 in contrast with the most recent decade (2000-2009), during which the Arctic has

undergone strong warming and sea ice loss. The primary objective is to provide a better understanding of why the Arctic is warming at a much faster rate than the rest of the northern hemisphere, a process known as Arctic amplification. While much of this work has involved analysis of gridded fields of atmospheric data, it has also meshed with other projects including fieldwork in the Arctic to assess changing snow and sea-ice conditions.

Along with the expected pattern of opposing temperature anomalies for northerly and southerly winds (winds blowing from the north and south, respectively), there are prominent temperature anomaly signals linked to onshore versus offshore flow. For example, northerlies in summer, blowing off the cold Arctic Ocean, yield cold anomalies over northern Eurasia that can extend several hundred kilometers inland from the coast. While onshore westerlies yield above-average temperatures over northwestern Eurasia and the Barents and Kara seas, continental easterlies yield an opposing anomaly pattern.

Positive temperature anomalies (e.g., warming trends) for the decade 2000-2009 encompass most of the Arctic and are present for all wind directions. That is, northerlies, southerlies, easterlies, and westerlies are all warmer than they used to be. While this general warming points to the effects of radiative forcing linked to rising greenhouse gas concentrations, influences of recent shifts in atmospheric circulation, reduced sea-ice extent, and rising sea-surface temperature are also prominent. For example, reduced winter ice extent between Svalbard and Novaya Zemlya (islands on the Atlantic side of the Arctic), while likely



MARK SERREZE

CIRES Fellow Mark Serreze digs a snow pit to study snow layers in the Brooks Range of Alaska.

maintained in part by anomalous southerly winds, provides for a surface heat source that leads to positive 925-hPa temperature anomalies (again, meaning warming) for all wind directions. Influences of ice loss and sea-surface temperature change are especially noticeable in autumn. Part of the spring signal of warming appears to be linked to reductions in snow cover over land.

Temperature anomalies with respect to wind direction are further contrasted for years with high and low September sea-ice extent. Results suggest that through transports by the atmosphere, temperature anomalies linked to anomalous open water areas can influence much of the Arctic Ocean and penetrate far into the Eurasian continent.

Anne Sheehan

Imaging the Roots of the Rocky Mountains: The Bighorn Arch Seismic Experiment

FUNDING: NATIONAL SCIENCE FOUNDATION
EARTHSOPE PROGRAM



With colleagues from Texas A&M University, the University of Wyoming, the University of Texas at El Paso, and Colorado College, I am currently conducting a large seismic imaging experiment centered on the Bighorn Mountains in Wyoming. The Bighorn Arch Seismic Experiment (BASE) is a flexible array experiment integrated with Earthscope transportable seismic array (USArray).

The goal of BASE is to develop a better understanding of how crustal basement-involved foreland arches form and what their link is to plate tectonic processes. To achieve this goal, the crustal structure under the Bighorn Mountain Range, Bighorn Basin, and Powder River Basin of northern Wyoming and southern Montana are being investigated with both structural geology and seismology. BASE incorporates seismic studies through the use of broadband and short-period seismometers, active- and passive-source "Texan" instrumentation, and structural geology of the Bighorn Mountains. The three-phase seismic deployment includes 39 broadband seismometers (15 months); 185 short-period seismometers (including three, five-element mini-arrays for six months); and 1,850 active-source and 800-passive source Texan instruments (two weeks). The passive-source experiment began in the summer of 2009 and the active-source experiment will take place in the summer of 2010.

The novel combination of these approaches and anticipated simultaneous

data inversion will give a detailed structural crustal image of the Bighorn region at all levels of the crust. The density of the sampling will allow us to make seismic reflection-style images that penetrate the crust. Four models have been proposed for the formation of the Bighorn foreland arch: subhorizontal detachment within the crust, lithospheric buckling, pure shear lithospheric thickening, and fault blocks defined by lithosphere-penetrating thrust faults. Each of these models results in a specific resolvable crustal structure. Combining information from these models with our results will lead to our final goal: a complete four-dimensional (including temporal) lithospheric-scale model of arch formation. This, in turn, will advance our understanding of the mechanisms accommodating and driving basement-involved arch formation as well as continental lithospheric rheology. More information on the project can be found at www.bighorns.org.

Additional funding has been obtained in collaboration with Los Alamos National Laboratory from the National Nuclear Security Administration and the U.S. Air Force Research Laboratory for expanding the experiment for source-discrimination studies. We will assess the performance of regional seismic discriminants as they are applied to earthquakes, contained single-fired explosions, delay-fired explosions, and mining collapses using the unprecedented spatial sampling presented by the BASE dataset. The U.S. Air Force funding supports expansion of the active-source experiment to include additional single-fired shots, including our own single-fired shots at mines in close proximity to delay-fired shots, and it funds the deployment of three, five-element mini-arrays.



CIRES graduate students Henry Berglund and Kevin Befus at Bighorns broadband seismic station west of Kaycee, WY.

Robert Sievers

Aerosol Vaccines

FUNDING: AKTIV-DRY, LLC; CIRES INNOVATIVE RESEARCH PROGRAM; THE CU BUTCHER FUND; FOUNDATION FOR THE NATIONAL INSTITUTES OF HEALTH (AS PART OF THE GRAND CHALLENGES IN GLOBAL HEALTH INITIATIVE CREATED BY THE BILL AND MELINDA GATES FOUNDATION); AND THE NATIONAL INSTITUTES OF HEALTH



The Global Health Group of CIRES is led by myself and Stephen Cape, with the participation of CIRES graduate students David McAdams and J'aime Manion and undergraduate student Nisha Shah. We made continued progress in the development of needle-free delivery systems for vaccines and pharmaceuticals that take advantage of microparticles for inhalation immunization, or, following compression into small pellet lozenges, can be

administered sublingually (under the tongue).

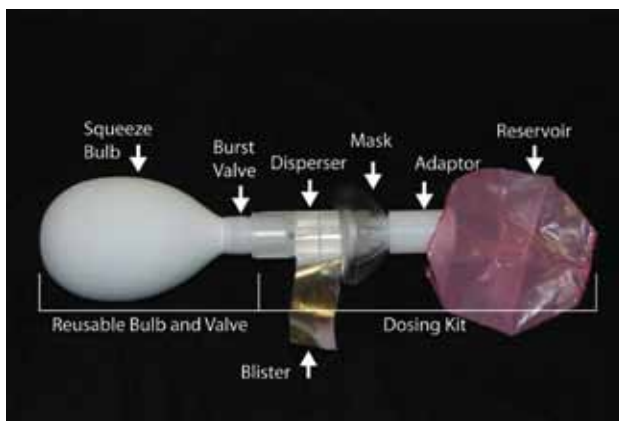
Sievers has served as principal investigator for five years, leading a team from Aktiv-Dry LLC, the Serum Institute of India, Sristek (in India), the U.S. Centers for Disease Control and Prevention, the Johns Hopkins University, CU-Boulder (headed by Stephen Cape), the University of Kansas, BD Technologies, and the National Jewish Medical and Research Center.

1) Our team has reformulated the injectable Edmonston-Zagreb live attenuated measles virus vaccine, replacing sorbitol with myo-inositol to create an inhalable aerosol measles vaccine. Our patented CAN-BD® process was used to produce micronized measles vaccine dry powder with residual moisture levels of 0.3-1.3 percent. The dry powder vaccine is stable for at least two years at 2-8°C and shows less than 1 log loss of virus infectivity at 37°C for seven days.

2) Our team has learned that inhaled myo-inositol powders and the new dry powder aerosol vaccine are not toxic in two animal models. Our team also determined that, 14 months after groups of Rhesus macaques were immunized by at-liberty inhalation of the new vaccine aerosols through facemasks, they were fully protected from infection when challenged with wild-type measles virus.

3) The team has developed two simple, low-cost, active dry powder inhalers.

4) Plans have been made to start Phase I human clinical trials in the summer of 2010 after Indian regulatory approval is received. Presently, several hundred children die each day in India from measles-related disease. Ten percent of all preschool deaths in Indian children are still



PHOTOS/AKTIV-DRY

caused directly and indirectly by measles. In the improved vaccine developed at CU-Boulder, the dry aerosolized and inhaled microparticles rapidly dissolve in the aqueous film in respiratory tracts, so no purified water for injection is needed. The dry powders are individually sealed in peelable blister packs or rupturable capsules to avoid bacterial contamination sometimes encountered when using multi-dose vials.

Work has also begun to synthesize and compress microparticles into wafers for oral and sublingual delivery. Aerosols of kanamycin and other tuberculosis antibiotics were also synthesized and characterized in 2009.

Konrad Steffen

with graduate students Daniel McGrath, William Colgan, Thomas Phillips, and Nicolas Bayou

Greenland Climate Network and Swiss Camp Climatology

FUNDING: NASA CRYOSPHERE, NATIONAL SCIENCE FOUNDATION OFFICE OF POLAR PROGRAMS



The Greenland Climate Network (GC-Net) was established in spring 1990 with the intention to monitor climatological and glaciological parameters at various locations on the Greenland Ice Sheet over several decades to study the climate variability. The first automatic weather station was installed at the Swiss Camp on the western slope of the Greenland Ice Sheet in spring 1990, followed by four automatic weather stations in 1995, four in 1996, five in 1997, four in 1999, one in 2002

and 2003, and the latest one at the European/U.S. deep-ice-core site in northwestern Greenland in 2006. The long-term objectives for the Greenland weather station network are to measure daily, annual, and interannual variability in accumulation rate, surface climatology, and surface-energy balance at selected locations on the ice sheet, and to measure near-surface snow density at the GC-Net locations for the assessment of snow densification, accumulation, and metamorphosis.

GC-Net data requests from the beginning of 2009 to the present came from 184 individual users for surface process studies, model validation, and satellite intercomparison. The web interface allows us to capture the email and affiliation of all GC-Net users, including a short description of their use of the Greenland Climate data. Data requests are processed on a UNIX 4-processor workstation and datasets are transferred on a FTP site for direct downloading.

The mean annual air temperature at Swiss Camp is -12.3°C (1991-2009), with the coldest monthly temperature in February (-32°C) and the warmest monthly temperature in July ($+1.8^{\circ}\text{C}$). Summer mean monthly temperatures above freezing occurred in 1995 and from 1997 to the present. The mean annual temperature has increased by 4.0°C (about $2^{\circ}\text{C}/\text{decade}$) using a linear regression model as shown in Figure 1. The temperature minimum in 1992 was the result of the aerosol loading caused by the Mt. Pinatubo eruption. The linear regressing model at 95-percent confidence shows that the Pinatubo cooling and the subsequent warming from the mid 1990s were outside the 95-percent confidence level. The warming that occurred since 2000 to present shows approximately the same trend as the 19-year time series. The warmest mean annual temperatures were -10.0°C and -10.3°C in 2009 and 2006, respectively.

Radiation has been monitored continuously at Swiss Camp since 1993. The largest monthly mean net radiation

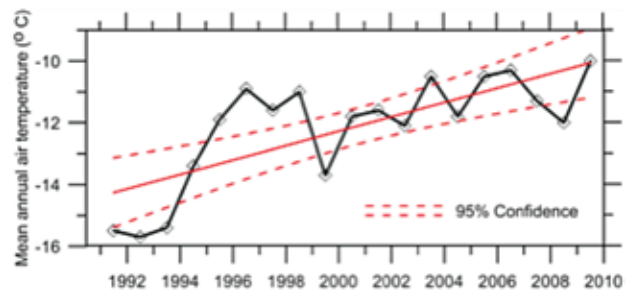


Figure 1: Interannual variability of monthly mean air temperatures (1991-2009) at the Swiss Camp, located at the equilibrium-line altitude on the western slope of the Greenland Ice Sheet.

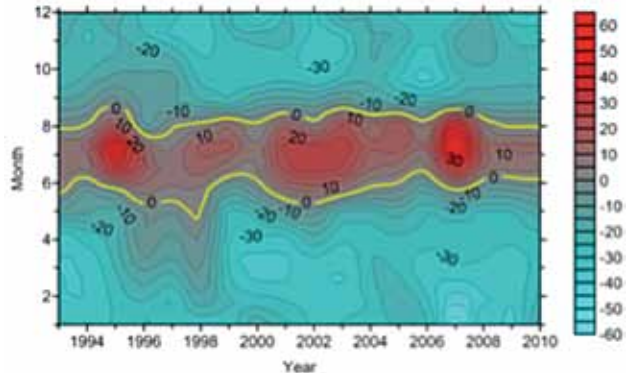


Figure 2: Interannual variability of monthly net radiation (W/m^2) at the Swiss Camp (1993-2009).

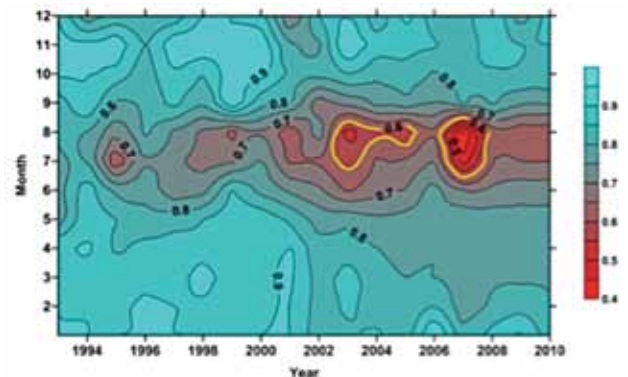


Figure 3: Interannual variability of monthly mean albedo at the Swiss Camp (1993-2009).

is found in the summer of 2007 ($> 60 \text{ W}/\text{m}^2$), coincident with air temperatures above freezing, indicating a strong albedo-feedback mechanism at the equilibrium line altitude (Figure 2). Most of the annual snow cover melted and the bare ice surface was exposed, reducing the monthly albedo value to 0.4 (Figure 3).

It is worth discussing the three anomalous periods of 1995, 1998, and 2001-2009 (Figure 2). The summer season is characterized by a positive net radiation flux, which is indicative of the length of the melting season. High net radiation values can either be the result of low albedo values (i.e., 2003-2009, Figure 3), reduced cloudiness (increase in insolation), or increase in atmospheric temperatures (increase in long-wave radiation). The mean summer net radiation has been higher during the new millennium ($30 \text{ W}/\text{m}^2$) compared to the previous decade, with the exception of record high values in 1995, as a result of increased atmospheric temperatures leading to increase in surface melt (albedo reduction).

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 sub-visible 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 infra-

red 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.

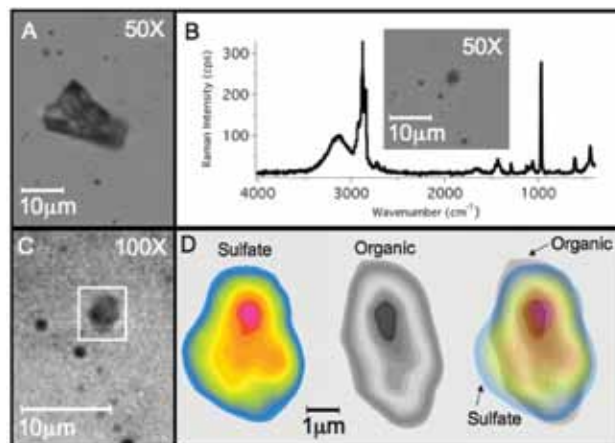
Work in our laboratory to date has shown that the chemical composition and morphology of the nucleating particles is more important than the particle size in controlling ice nucleation.

In addition to laboratory studies on well-defined particles generated with known composition, additional studies are probing heterogeneous ice nucleation on samples collected in the field. Graduate student Kelly Baustian has participated in two field experiments at Storm Peak Laboratory in Steamboat Springs, CO, collecting particles for analysis using our Raman technique. Here we examine unknown samples to determine which particles are the best nuclei, followed by a detailed chemical analysis of those particles that nucleate ice. These studies are giving us new insight into atmospheric ice nucleation.



MARK ZONDLO

Cirrus clouds over Boulder.



Depositional ice-nucleation experiment conducted on ammonium sulfate particles coated with palmitic acid. A) The first ice particle that nucleated ice, B) Raman spectrum of the particle that nucleated ice showing characteristic sulfate and organic bands, C) Detailed image of particle that nucleated ice, and D) Compositional map of the ice-nucleating particle showing regions of sulfate and organic. The morphology of the nucleating particle is complex with regions of the particle exterior containing both organic and ammonium sulfate. Particle such as this nucleated ice at low saturation ratios, similar to pure ammonium sulfate, presumably because of the ammonium sulfate in the outer layers. From PNAS, 107, 2010.



CIRES graduate student Kelly Baustian at Storm Peak Laboratory, collecting samples for ice-nucleation studies using Raman microscopy.

William Travis

The Catastrophe Effect: Extreme Events and Society

FUNDING: NATIONAL SCIENCE FOUNDATION, NOAA



Social science theory struggles with extreme natural events: should we examine social responses as extensions of individual and collective behavior under “normal” conditions, or should we recognize a separate realm of behavior evoked by extremes and catastrophes? In many ways this parallels a debate in the natural sciences: are extremes simply the tails of well-known distributions, or are they manifestations of unique conditions or perhaps the tails of radically different

distributions of natural phenomena? Human interaction with natural variability is highlighted by impacts of, and responses to, extreme events. This shows up, for example, in natural hazard insurance data. Colorado crop insurance premiums and payouts would roughly balance out over the 15 years of the current program if it weren't for one extreme year: 2002 (Figure 1). One year also dominates the recent wildfire record (2006). Perhaps we should separate out a realm of extremes or catastrophes, and analyze those effects as a special population rather than as the extreme end of a continuum. This allows us to assess damage trends and social vulnerability to the more typical droughts or hurricanes, say, while recognizing that the rare, catastrophic event, such as the 1930s Dust Bowl or Hurricane Katrina, may yield quite different physical and social effects. That is, society may well become less sensitive to “typical” droughts and hurricanes through typical mitigations such as larger reservoirs and better building codes, but these adjustments are inevitably overwhelmed by the most extreme events, which we would call catastrophes. Somewhere in the continuum, we reach a point where additional investment in protection and control systems becomes markedly inefficient, perhaps unfeasible.

Are we becoming more or less vulnerable to climate hazards? Is it possible that adapting to particular hazard standards, such as 100-year floods, sets society up for truly catastrophic losses from events that surpass the standard? Does it always hold, as prescribed in many climate adaptation programs, that adapting better to the current climate, especially to its extremes, yields better adaptation to future climate change? For example, as urban water systems are adapted to drought, might they become more or less vulnerable to climate change? Is there a “levee effect,” whereby adjustment to frequent, lower-intensity hazards sets up the potential for truly catastrophic loss

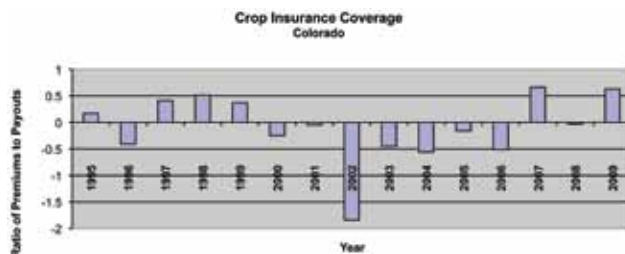


Figure 1: Crop insurance premiums and damages roughly balance except for one extreme drought year, 2002. Data source: Federal Crop Insurance Corporation.



U.S. DEPARTMENT OF AGRICULTURE

The 1930s Dust Bowl remains the driest period in the U.S. climate record.



NOAA

Hurricane Katrina, though not the most intense storm to hit the United States, is the most expensive U.S. hurricane on record.

in rarer events? Is Colorado becoming more or less vulnerable to drought? How might we respond if global warming pushed the climate past a tipping point so that extreme, abrupt climate change occurred? These are some of the questions about extreme events and society that colleagues and I pursue at the CIRES Center for Science and Technology Policy Research.

Greg Tucker

Tectonics and Topography in Taiwan

FUNDING: NATIONAL SCIENCE FOUNDATION

Taiwan's rugged mountains are among the fastest growing on planet Earth. Taiwan owes its geologic vigor to



plate tectonics: a collision between the Eurasian plate and a massive undersea ridge known as the Luzon Arc beginning about five million years ago has thrust rocks upward to build the island. The collision continues to this day, with the result that earthquakes are perennial hazards to the island's 23 million residents. In 1999, a particularly powerful earthquake struck the west-central region of Taiwan, killing 2,400 people and leaving more than 100,000 homeless.

Earthquakes are not the only natural hazards in Taiwan. Its steep relief and wet, typhoon-prone climate make it one of the most rapidly eroding landscapes on the planet. Much of that erosion occurs in the form of floods and landslides; a tragic landslide in August 2009, for example, buried an entire village.

Taiwan's ferocious geological and meteorological activity has drawn a great deal of scientific interest. Our project is focused on understanding how rivers cope with this unusual mix of earthquakes and typhoons, and on what Taiwan's rivers can reveal about processes in the crust below. Recent Ph.D. graduate Brian Yanites, together with Greg Tucker, CU-Boulder professor Karl Mueller, and a team of researchers from Taiwan and New Zealand, undertook a study of the Peikang Shi, a powerful river that slices across a series of active faults on Taiwan's western flank. The river valley is lined by numerous bedrock terraces, which represent preserved segments of ancient floodplain that were left behind as the river continued to slice through the rocks below. By determining the age of these terraces using the method of optically stimulated luminescence dating, the team was able to estimate the rates of river incision over periods of thousands of years. The dates revealed a distinctive spatial pattern of river incision: just upstream of certain faults, the river has been slicing much more rapidly than in other locations, implying that the faults are tectonically active. The results provide useful new information for understanding geologically recent patterns of seismicity and rock deformation. Not surprisingly, the data also revealed a correlation between the rate of incision and the river's hydraulic power.

What was more surprising was the manner by which the river appears to adjust its hydraulic power. In some stretches, variations in power occur because of changes in the river's width: a narrower channel leads to higher fluid stresses along the bed. In others stretches, however,



Brian Yanites collects a sample for optically stimulated luminescence dating by pounding a hollow tube into a fluvial sand deposit.



PHOTOS/GREG TUCKER

This bridge over the Peikang River has been partly buried as a result of earthquake- and typhoon-triggered landslides, which fed massive volumes of sediment to the river following the 1999 Chichi earthquake.

increased hydraulic power is associated with a steeper gradient rather than a narrower channel. This finding prompted us to develop a new mathematical model to explain why bedrock-incising rivers "choose" a particular combination of width and channel gradient. The model appears to explain not only the Taiwan data, but also recent data from bedrock-incising rivers in various locations around the globe.

Veronica Vaida

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

FUNDING: NATIONAL SCIENCE FOUNDATION



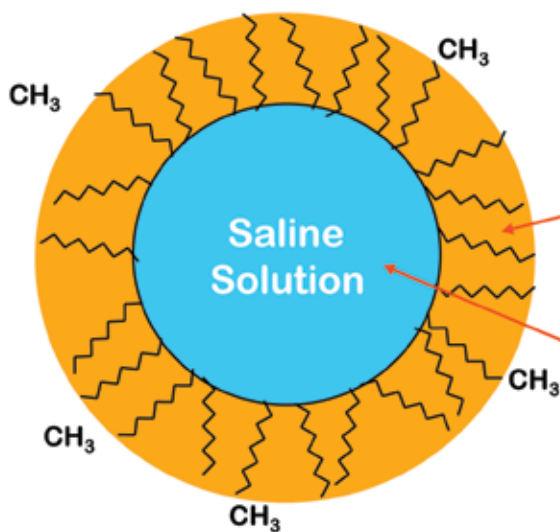
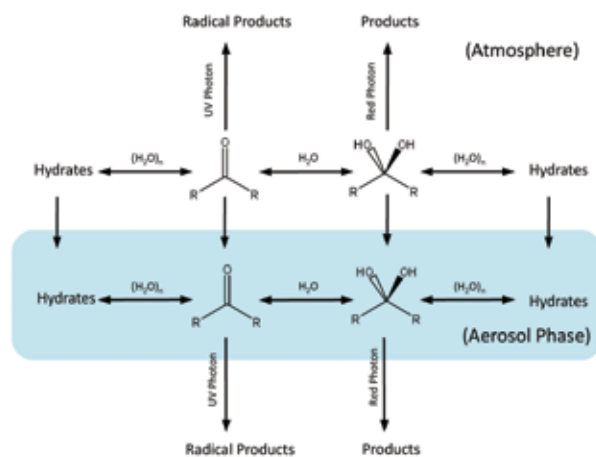
The Sun is the ubiquitous energy source for chemistry on Earth as well as for determining the planet's temperature and climate. My experimental program has proposed and investigated new sunlight-initiated chemical reactions, which occur very fast and sequester the energy from solar radiation into high-energy chemical bonds. Especially challenging to understand are processes occurring in water environments, such as the surface of water and of aqueous atmospheric

aerosols, yet recent experimental and theoretical results from my research group and our colleagues point to significant changes in chemistry in the presence of water. Photochemical reaction mechanisms depend on phase and environment. Fundamental chemical processes in aqueous environments, at the water-air interface and in/on aqueous aerosols are investigated to explore the differences of

chemistry in such environments. The fundamental results obtained are necessary for inclusion in atmospheric models of aerosol processes.

This work derives its intellectual merit from its fundamental molecular approach and its broader impact from the widely acknowledged importance of organic species, water, and aerosols for climate and global change.

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



10⁶ surfactants, polar heads in, hydrocarbon tails out = 25 Å thick

core containing 10⁹ waters together with minerals & small organics

Rainer Volkamer

Airborne Observations of Reactive Trace Gases in the Free Troposphere

FUNDING: NATIONAL SCIENCE FOUNDATION



Oceans cover 70 percent of the Earth surface, yet the open ocean marine atmosphere is one of the most poorly probed atmospheric environments of our planet. In the tropics, deep convective clouds form and provide a mechanism to inject boundary-layer air into the uppermost free troposphere (15 km). The vertical distribution and potential climate relevance of gases such as glyoxal (CHOCHO) or iodine oxide remains poorly characterized, partly because of the lack

of measurement techniques capable of measuring these gases from aircraft. Glyoxal is a short-lived gas that forms climate-cooling secondary organic aerosol (SOA). Iodine oxide forms by destroying tropospheric ozone, and can nucleate new particles.

My research group has designed and assembled a prototype Airborne Multi-Axis Differential Absorption Spectroscopy instrument (CU AMAX-DOAS) that measures glyoxal, iodine oxide, bromine oxide, nitrogen dioxide, formaldehyde, and other gases sensitively and selectively with a single, portable instrument directly in the open atmosphere, by aircraft. Five telescopes mounted in a pylon below the wing observe scattered solar photons in the zenith, nadir, slant forward and backward, and forward viewing directions (Figure 1), and are coupled via optical fiber to a set of two spectrometer/charged couple devices detector systems located inside the aircraft fuselage. The instrument was first deployed in January 2010 aboard the NSF High-performance Instrumented Airborne Platform for Environmental Research aircraft (Gulfstream V). During a first science flight from Hawaii to the tropical Pacific Ocean south of Hawaii (Figure 2), the CU AMAX-DOAS measured, for the first time, elevated concentrations of glyoxal (Figure 2 inset), formaldehyde, and iodine oxide

CU AMAX-DOAS on the NSF GV



Figure 1: Pylon mounted below the wing contains sensors that measure glyoxal, iodine oxide, bromine oxide, nitrogen dioxide, formaldehyde, and other gases.

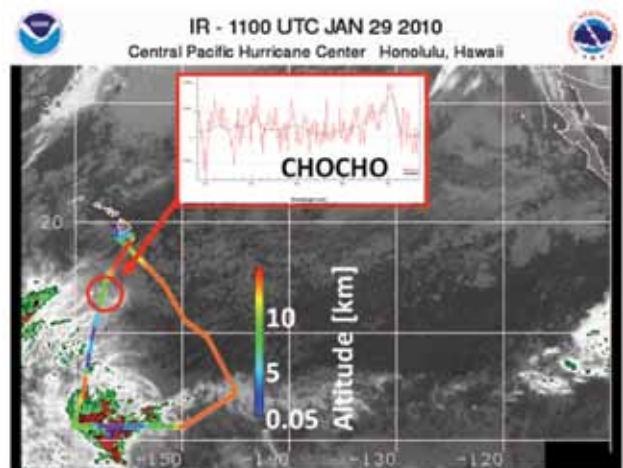


Figure 2: Measurements from the first flight from Hawaii to the tropical Pacific Ocean. CHOCHO is glyoxal.

inside the boundary layer. The vertical distribution was measured into the free troposphere. The presence of these gases more than 5,000 km from any land is surprising because of their very short atmospheric lifetimes (on the order of seconds to hours), and indicates previously unrecognized open ocean sources for hydrocarbons and reactive halogen species. Ours are the first observations of glyoxal in the remote free troposphere.

John Wahr

Applications of Time-Variable Gravity Measurements from GRACE

FUNDING: NASA, JET PROPULSION LABORATORY, NATIONAL SCIENCE FOUNDATION



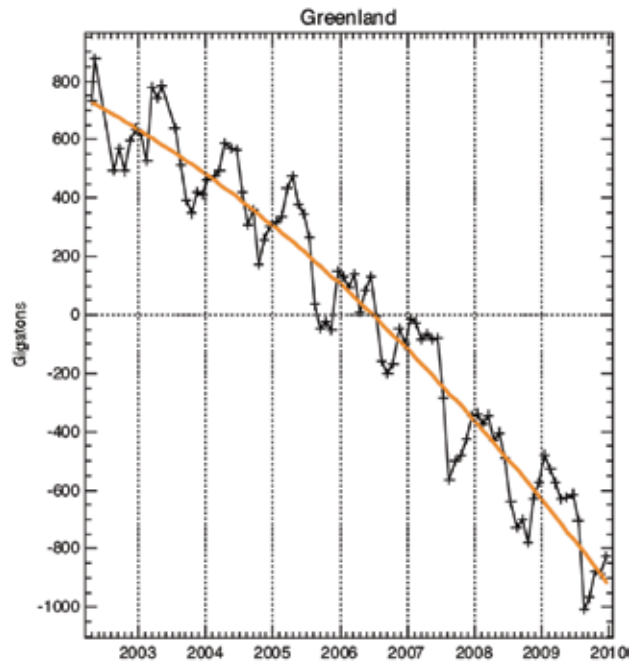
The Gravity Recovery and Climate Experiment (GRACE) satellite mission, launched by NASA and the German Space Agency in March 2002, is providing global maps of the Earth's gravity field to astonishing accuracy every month. Because the Earth's gravity field is caused by its mass distribution, time-variations in gravity as determined from 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.

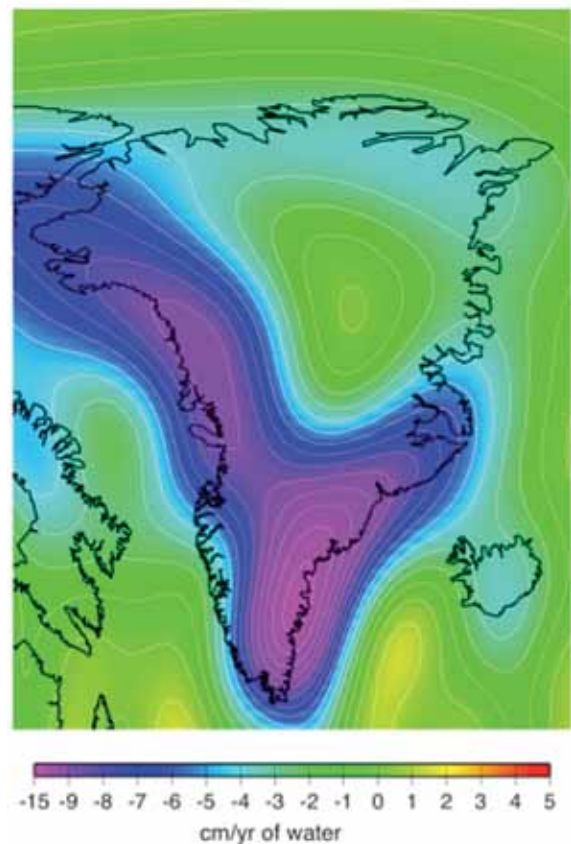
We have been using these data to look at a number of geophysical signals, particularly those that involve the storage of water (including snow and ice) on continents and in the polar ice sheets.

For example, because of its large effective footprint and its sensitivity to mass, GRACE offers the best available method for measuring the total mass balance of the polar ice sheets. The top figure at right shows monthly GRACE results (black line; the orange line is a smoothed version) for the mass variability summed over the entire Greenland Ice Sheet, between April 2002 and December 2009. The trend of the best fitting straight line is about $260 \text{ km}^3/\text{yr}$ of ice volume lost per year, which generates enough meltwater each year to cover all of Colorado to a depth of 90 cm. There is a notable downward curvature to the results, indicating that the mass loss rate has been increasing during this time period. The lower figure shows how this mass loss rate is distributed across Greenland, as determined from the GRACE solutions. By far the largest rates occur in the southeast (note the break in the color scale), where dramatic acceleration of outlet glaciers and accompanying ice thinning has been observed over the last few years. But mass loss has also been occurring up along the western ice sheet margin, particularly within the last 2-3 years. There appears to have been a modest mass gain in the northern interior, presumably associated with increased accumulation rates there.

For other land areas, GRACE recovers changes in the total stored water: the sum of water on the surface, in the soil, and beneath the soil layer. Before GRACE, there was no practical way of measuring total water storage at regional- to global-scales.



Mass variability summed over the entire Greenland Ice Sheet, monthly Gravity Recovery and Climate Experiment (GRACE) results (black line; the orange line is a smoothed version) April 2002 and December 2009.



Distribution of mass loss rate across Greenland, as determined from the GRACE solutions.

Carol Wessman

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

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



Forest ecosystems are vulnerable to a range of disturbances that shape their structure, composition, and function, and consequently affect issues ranging from climate change to economics and social stability. Climate change, as well as ongoing human-forest interactions (i.e., forest management), is expected to yield forest disturbances of greater frequency, extent, intensity, and variety. We have a poor understanding of forest responses (especially regeneration) to multiple

disturbances. Under climate change, compounded interactions among multiple disturbances may be unprecedented and unpredictable. We are studying the roles of large-scale disturbance interactions, historical contingencies, and ecological resilience in ecosystem dynamics in a long-term study of a subalpine ecosystem.

This study focuses on important drivers of forest regeneration at two scales: landscape (e.g., recent disturbance history, disturbance pattern) and local (e.g., biotic competition, microenvironment). Our study area in northern Colorado's Routt National Forest experienced several catastrophic, large-scale disturbances over a short period. The region, currently undergoing epidemic spruce and mountain pine beetle infestations, experienced a record-setting windstorm in 1997 (causing blowdown) followed by salvage logging and a regional wildfire in 2002. Historical records of such disturbance complexes are rare, and lack information on the processes important to ecosystem recovery.

This year, we found that successional processes are significantly different among disturbances, suggesting longer-term consequences for landscape structure. Areas that experienced a blowdown prior to fire are experiencing very little to no conifer regeneration, suggesting that fuels present in the blowdown contributed to increased fire severity. In contrast, blowdown areas that were logged are recovering well, comparable to forests that had no pre-fire disturbance. Our analyses show that pre-fire disturbance history interacted with both burn severity and time, implying that patterns of disturbances on the landscape may be affected spatially by previous disturbances, and have lasting temporal effects through seedling recruitment. This



PHOTOS/JANE PALMER/CIRES

CIRES Ph.D. student Brian Buma in a burned blowdown plot in the Routt National Forest.



Conifer recovery in a burned logged-blowdown site.

year we also examined Normalized Difference Vegetation Index (NDVI) time-series data from NASA's MODerate Resolution Imaging Spectrometer (MODIS) sensor to determine whether 250-m resolution NDVI can be used to identify landscapes with drastically different recovery patterns. Results indicate that spring data can differentiate among recovery patterns in forest recovery, suggesting that MODIS NDVI can provide regional information on forest response to disturbance.

Tingjun Zhang

Degrading Permafrost Across Eurasian Permafrost Regions

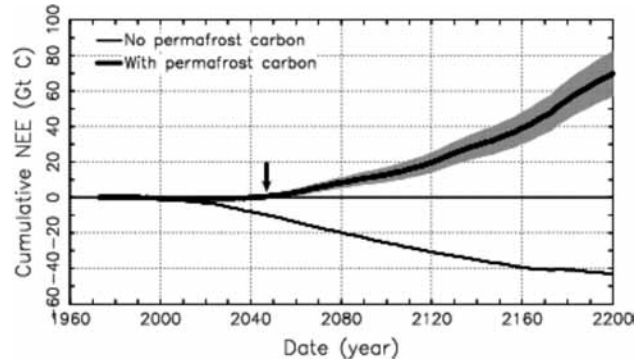
FUNDING: NSF OFFICE OF POLAR PROGRAMS, ARCTIC SYSTEM SCIENCE PROGRAM



Estimates of the total amount of carbon stored in permafrost range from 950 to 1,672 gigatons (Gt). Although there are large uncertainties in these estimates, permafrost carbon is roughly 1.3 to 2.3 times the total carbon currently in the atmosphere. It has been observed that permafrost is warming and thawing worldwide due to the effect of increased greenhouse gases in the atmosphere. As permafrost degrades, portions of permafrost carbon start to thaw and micro-

bial decay resumes, increasing respiration fluxes to the atmosphere. This will, in turn, increase concentrations of atmospheric greenhouse gases, amplify the rate of climate warming, and further accelerate permafrost degradation, resulting in a positive permafrost carbon feedback (PCF) on climate. However, little is known of PCF. In this study, we use model projections to estimate PCF timing and strength.

By 2200, we predict a 10-percent reduction in permafrost area and a 5- to 50-percent increase in active layer depth. This prediction is on the lower end of potential permafrost degradation in the next two centuries. An irreversible tipping point in Arctic carbon balance signalling the start of PCF could occur during the middle of the 21st century (top figure). The estimated cumulative permafrost flux to the atmosphere by 2200 varies between 101 and 127 Gt C. The 10-percent reduction in permafrost area accounts for 62 percent of this permafrost carbon flux. The PCF tipping point is delayed relative to increases in atmospheric



Cumulative net ecosystem exchange (NEE) over the global permafrost domain with/without permafrost carbon with uncertainty (grey) showing a tipping point during the middle of the 21st century.



KEVIN SCHAEFER

Permafrost sampling on the North Slope of Alaska during the summer of 2009.

temperature, possibly explaining why observed increases in atmospheric CO₂ lag behind temperature after glacial terminations. Qualitative evaluations of various sources of uncertainty indicate the actual PCF tipping point and strength uncertainties are greater than our current estimates. Nevertheless, the PCF is strong enough to warrant inclusion in projections of future climate and in international strategies to reduce fossil fuel emissions.



A. SLATER/NSIDC

Matthew Sturm and CIRES Fellow Mark Serreze set up magna-probes to measure snow depth in Alaska.

SCIENTIFIC CENTERS

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

Center for Limnology

The Center for Limnology supports research and graduate education related to biogeochemistry and metabolic functions of aquatic ecosystems. During 2009, 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 (Figure 1). 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 2). 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

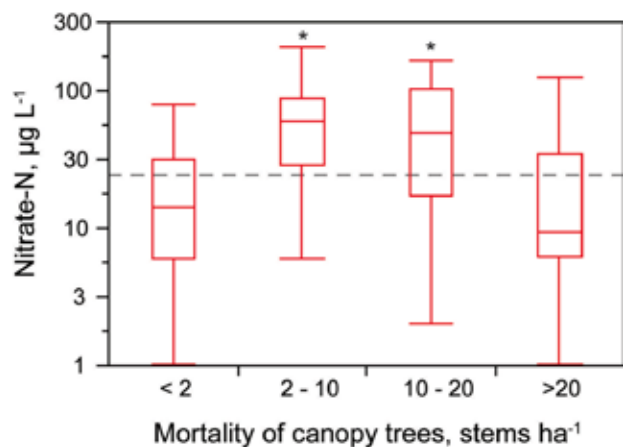


Figure 1: Effect of tree mortality on nitrate concentration in stream water. For 60 montane watersheds in Colorado, nitrate concentrations were similar in undisturbed watersheds and watersheds with the highest level of tree mortality; nitrate concentrations were elevated slightly in watersheds with intermediate levels of tree mortality.

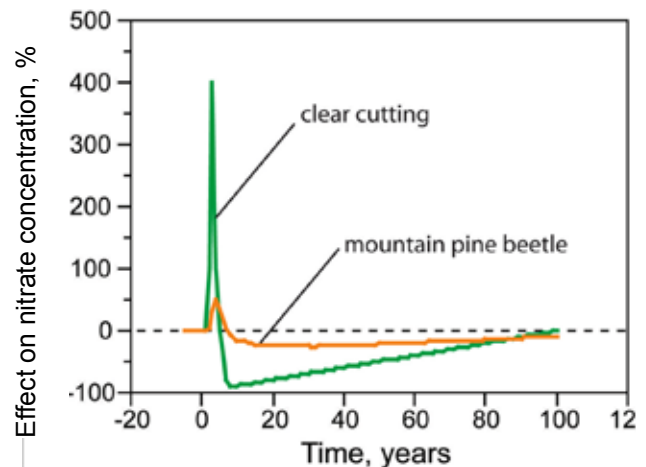


Figure 2: Predicted changes in stream-water nitrate concentration following clearcutting and tree mortality associated with mountain pine beetle.

working on the biogeochemical effects of pine beetle infestation.

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.

Initial results from Detmer's studies show that lakes without fish have a much stronger representation of large invertebrates such as mayfly larvae. When fish are present, large invertebrates are strongly suppressed by fish predation (Figure 3). Detmer believes that the shift from strong populations of large invertebrates to more cryptic populations of small invertebrates is accompanied by a change in the relative dependence of lake food webs on external carbon subsidies coming from leaves and other organic matter generated outside the lake. He is investigating this hypothesis by use of stable isotope signatures, which may differ for different carbon sources.

In 2009, we continued the study of Little Gaynor Lake, a natural waterbody in Boulder County that receives most of its water supply through slow flow of alluvial waters rather than surface flows. The lake is slightly saline and supports large populations of bluegreen algae (cyanobacteria). Populations reach such high densities that the lake appears to support a density of algae that is unmatched by any waterbody for which abundances have been reported in the literature. The Center receives some biofuels research funding to investigate the manner in which the stability of these algal populations can be maintained, as well as measurements of their lipid content. A surprise came in 2008 when one genus of algae disappeared and a second genus replaced it. The characteristics of the second population are much the same as the first: a monoculture of high-density algal cells. Causal analysis is in progress.

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.



PHOTOS/MORGAN HEIM/CIRES

Figure 3: Predator (brook char, above) and prey (crustaceans, below) in Rocky Mountain National Park lakes.

Center for Science and Technology Policy Research

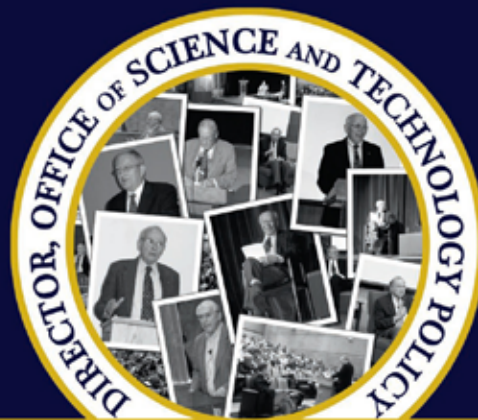
The Center for Science and Technology Policy Research (CSTPR) was established within CIRES in 2001 to focus on research, education, and outreach at the interface of science, technology, and the needs of decision makers in public and private settings. The Center also works at the intersection of the environment 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.

At the center of much of our work lie 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 resources, and adapt to environmental change.

Current projects include studies of how urban water managers respond to shortages, alternative approaches to limiting greenhouse gas emissions to the atmosphere, Colorado's vulnerability to drought, the role of non-governmental organizations in ecosystems management, and how the media portray climate change issues. Our work is reported via research articles, books, and several outreach methods, including a regular newsletter, research briefings, faculty blogs, news media, and frequent seminars and workshops.

Recent highlights include publication of a collection of essays and other commentary based on the Center's presidential science advisors lecture series; release of the *Handbook on Useable Science* from the Science Policy Assessment and Research on Climate (SPARC) project; a workshop on "Reconciling the supply of and demand for research in

Presidential Science Advisors: Perspectives and Reflections on Science, Policy and Politics



Roger Pielke
Roberta A. Klein
Editors

 Springer

Presidential Science Advisors: Perspectives and Reflections on Science, Policy and Politics edited by Roger Pielke, Jr. and Roberta A. Klein (May 2010, Springer). For the past 50 years, a select group of scientists has provided advice to the U.S. President, mostly out of the public eye, on issues ranging from the deployment of weapons to the launching of rockets to the moon to the use of stem cells to cure disease. The role of the presidential science advisor came under increasing scrutiny during the administration of George W. Bush, which was highly criticized by many for its use (and some say, misuse) of science. This edited volume includes the reflections of the presidential science advisors from Donald Hornig, who served under Lyndon B. Johnson, to John Marburger, who served under George W. Bush, on their roles within both government and the scientific community.

the science of science and innovation policy," held in Oslo, Norway; and new research publications on carbon sequestration and land use, media coverage of global warming, de-carbonizing the global economy, and societal response to extreme climate change.



Above, participants at the September 2009 workshop on “Linking science to societal benefits: Why, how and when?” held at Linköping University’s Centre for Climate Science and Policy Research in Linköping, Sweden.



The new Handbook on Useable Science, from the Science Policy Assessment of Research on Climate, addresses the challenge of producing usable science, defined as science that meets the changing needs of decision makers. We present concrete examples from diverse areas such as earthquake research to materials science, and offer specific recommendations for organizations and individuals interested in becoming more effective at producing usable science. These include understanding and connecting with potential users of science in setting the course of research policies, developing creative incentives and evaluation metrics, and recognizing innovative leadership.

Climate Diagnostics Center

The mission of the Climate Diagnostics Center (CDC) is to improve our understanding of global climate interactions to improve regional climate predictions, and to train the next generation of climate scientists in advanced climate system diagnosis and prediction. CDC's goal is to establish the causes of regional climate variations around the globe on time scales of weeks to millennia, by 1) applying newly developed diagnostic techniques to global observations and model simulations; 2) developing new observational datasets and performing new climate model integrations as needed for this purpose; and 3) developing new techniques to diagnose and reduce model 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 2009-2010, CDC published 26 peer-reviewed papers on topics that included:

- Techniques for removing El Niño-Southern Oscillation (ENSO) related variations from the historical climate record to better isolate climate change signals
- A demonstration using the newly developed CDC/NOAA 20th Century Reanalysis (20CR) dataset that the 1918/19 El Niño event, which coincided with the "Great Influenza Epidemic," may have been much stronger than previously thought
- Global air-sea thermal coupling and related non-Gaussian sea-surface temperature (SST) variability
- The importance of air-sea coupling in the evolution of ENSO and the tropical Madden-Julian Oscillation (MJO)
- Interannual ENSO variability forced through coupled atmosphere-ocean feedback loops
- The changing hydrology of the Colorado River Basin



and the American Southwest

- Representation of regional trends in the climate models used in the Intergovernmental Panel on Climate Change Fourth Assessment Report (IPCC AR4)
- Summer precipitation variability over South America as simulated by the IPCC AR4 models
- The simulation of cloud, precipitation, and radiation in climate models
- Reconciling non-Gaussian climate statistics with linear predictable dynamics
- Oceanic influences on recent continental warming

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

- Providing leadership in the international Global Climate Observing System Surface-Pressure Working Group, to promote the development of long-term, high-quality surface-pressure datasets
- Completing production of a global atmospheric circulation dataset for 1891-2008, using only daily surface pressure observations and an ensemble-Kalman-filter-based data assimilation system, and making the dataset widely available through a web interface. More: see: http://www.esrl.noaa.gov/psd/data/gridded/data.20thC_Rean.html.
- Starting production of version two of the global atmospheric circulation dataset, extending it back to 1871 using a longer and improved surface-pressure database and an

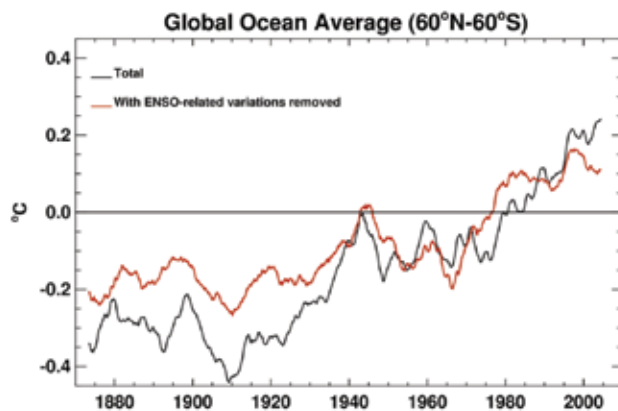


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improved model for assimilating those data. The improved model included better specifications of time-varying CO₂ and aerosol radiative forcings over the assimilation period. This effort will extend our ability to quantify climate variability over the historical record, provide uncertainty estimates for climate change detection, and aid attribution efforts to inform climate policy decisions.

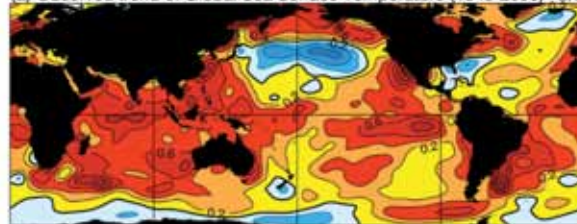
■ Developing and releasing a new experimental forecast product (jointly with NOAA ESRL's Physical Sciences Division) for subseasonal tropical forecasts based on a coupled linear inverse model of weekly tropical SSTs and outgoing longwave radiation variations. More: see <http://www.cdc.noaa.gov/forecasts/clim/>.

CDC researchers recently reached some surprising conclusions concerning the contributions of ENSO-related variations to observed 20th century climate trends. In a study published recently in the *Journal of Climate*, we stressed that isolating such contributions is challenging for several reasons, including ambiguities arising from how ENSO itself is defined. In particular, we argued that defining ENSO in terms of any single index and ENSO-related variations in terms of regressions on that index, as done in most previous studies, can lead to wrong conclusions. We believe ENSO is best viewed not as a number but as an evolving dynamical process for this purpose. Specifically, we identified ENSO with the four dynamical eigenvectors of tropical SST evolution that are most important in the observed evolution of ENSO events over several months, and used this definition to isolate the ENSO-related component of global SST variations on a month-by-month basis in a 136-yr (1871-2006) global SST dataset. The analysis showed that ENSO-related trends

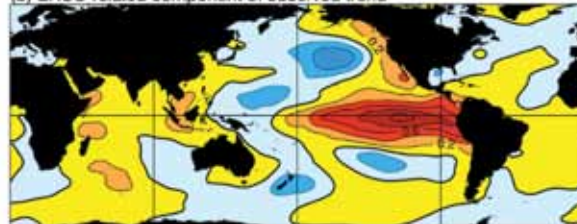


Time series of observed global ocean average surface-temperature anomaly (black curve) and its El Niño-Southern Oscillation-unrelated component (red curve). A 10-yr running mean has been applied to both series. Anomalies are relative to 1949-2004 climatology.

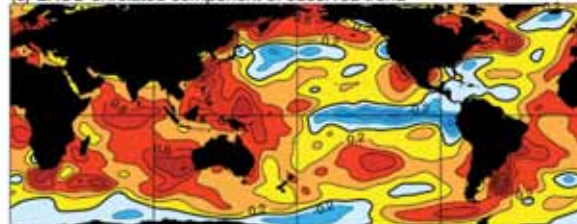
(a) Observed trend of Global Sea Surface Temperature (1949-2006) °C/50 yr



(b) ENSO-related component of observed trend

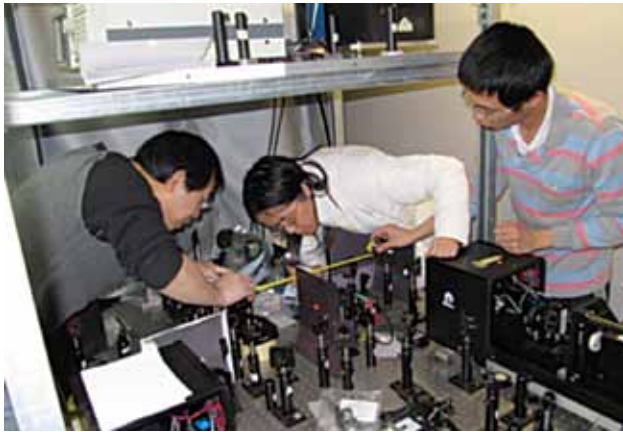


(c) ENSO-unrelated component of observed trend



Global maps of linear sea-surface temperature (SST) trends during 1949-2006 of a) the full SST anomalies, b) the ENSO-related anomalies, and c) the ENSO-unrelated anomalies. The contour interval is 0.2°C change per 50 years, and the zero contour is thickened.

have contributed substantially to the 136-yr SST trends in all ocean basins, and accounted for nearly 40 percent of the trend in globally averaged SSTs. The ENSO-unrelated component of the SST trends, obtained by removing the ENSO-related component, shows a particularly striking strong cooling trend in the eastern equatorial Pacific region of largest ENSO-related SST variability. These results have large implications for our understanding of how the global climate system in general, and the tropical climate system in particular, may be responding to anthropogenic and other climate forcing.



Wentao Huang, CIRES Fellow Xinzhao Chu, and Weichun Fong working on lasers for McMurdo Station, Antarctica.

The Earth Science and Observation Center

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 FY10, 20 graduate students, and four research associates. 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 dataset, 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 fall, between 1.5 and 2.0°C in 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 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.

Land Surface Effects on Climate

We continue to examine the impact of surface hydrology



Field team on the Larsen C Ice Shelf during summer 2009 field campaign.

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, wildland-urban interface) will increase the complexity of disturbance impacts and forest recovery. Our ongoing study of several catastrophic disturbances in a northern Colorado sub-alpine 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 pre-fire disturbances (1997 catastrophic blowdown, 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



KONRAD STEFFEN

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 sized river basins (about 3,000 km²) confirmed the presence of self-similarity in networks, thus supporting the hypothesis. This is the first time the theory has been put to test on medium-sized basins (about 32,000 km²), 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

Three resonance-fluorescence lidars are being developed by the Xinzhao Chu research group within ESOC. First, we are developing the NSF Major Research Instrumentation Fe-resonance/Rayleigh/Mie Doppler lidar for advancing the middle atmosphere physics and chemistry. Excellent results have been achieved in development of a state-of-the-art pulsed alexandrite ring laser and in optical heterodyne detection for laser diagnosis. Secondly, we are deploying an Fe Boltzmann lidar to McMurdo, Antarctica to measure middle and upper atmosphere for three years. This lidar was developed by Chu and her colleagues more than 10 years ago and is being upgraded for deployment in November 2010 to complete an observational chain in Antarctica. Thirdly, the CAREER lidar is being developed



Regeneration in a site experiencing (chronologically) severe blowdown, salvage logging, and fire—all within five years.

by graduate students for educational and science study purposes. In addition, a proposal to the European Space Agency for spaceborne Na Doppler lidar is in progress.

Water Cycle and Climate

Appreciating the changing relationships between the Earth's water cycles and climate are central to adapting to environmental change. We seek to improve understanding of the mechanisms which control the exchange of water between 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. Recently we have evaluated the rate at which evaporation of melting snow is mixed into the free troposphere using new measurements of the isotopic composition of water vapor and CO₂ concentration at the 300-meter tower at the NOAA Boulder Atmospheric Observatory in Colorado. The data show that state-of-the-art climate models inadequately capture the gas transport and offer guidance as to how the models can be improved. This work complements the group's larger effort to use remote-sensing data and other in situ measurements with models to understand interactions between the global water cycle and climate.

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. We are also actively involved in NASA's Deformation Ecosystem Structure and Dynamics of Ice mission. A new area for us this year is in detection of potential geothermal heat sources using high-resolution thermal infrared data from Landsat, MODIS, and ASTER. We partnered with Flint Geothermal, LLC on a \$5 million grant.

National Snow and Ice Data Center

The National Snow and Ice Data Center (NSIDC) supports research into Earth's frozen realms: the snow, ice, glaciers, ice sheets, and frozen ground that make up the cryosphere. NSIDC manages and distributes scientific data, creates tools for data access, supports data users, performs scientific research, and educates the public about the cryosphere.

NSIDC is reducing the distance between its users and its data holdings, with a new infrastructure that supports users finding and browsing actual data holdings online. Powered by the NSIDC Searchlight engine, the beta-release Advanced Data Search online tool delivers data downloads immediately, with the user in control of on-the-fly output reformatting, reprojection, and subsetting. Searchlight represents a suite of fundamental architectural changes that allow NSIDC to develop even more capabilities to help researchers work with cryospheric data.

Access to data at NSIDC also improved greatly as a result of a substantial archive-technology shift and data migration by the NSIDC Distributed Active Archive Center (DAAC). The DAAC operates NASA's Earth Observing System Data and Information System (EOS-DIS) Core System (ECS), which archives and distributes data from NASA's Earth Observing System (EOS) satellite programs. Previously, the DAAC employed a StorageTek Powderhorn robotic tape library for storage and retrieval of all Earth science data products within the ECS. NSIDC transitioned the ECS at NSIDC to an online disk archive, conducting a massive migration of data from hundreds of tapes to the online archive, performed with zero data loss. The archive now contains approximately 60 terabytes of EOS data, consisting of 8.5 million data files. The new system speeds fulfillment of data requests and provides direct access to many more datasets online.

Scientists today who study polar sea-ice conditions

rely on satellite records reaching back to 1979. But soon, NSIDC data scientists hope to extend the look back by another decade or more. Researchers at NSIDC and NASA have shown that Earth-observing satellite data from the 1960s can be made to yield new information, adding substantially to the view of Earth's climate history. A team at NSIDC worked with the Lunar Orbiter Image Recovery Project (LOIRP) at NASA Ames Research Park to search NASA archives for the original Nimbus tapes containing raw images and calibrations. The team's first goal was to read and reprocess the data at a higher resolution, removing errors resulting from the limits of the original processing.

These tasks proved more challenging than expected, due to truncated data, missing algorithms, and other issues. But the result was a global image of the Arctic from Nimbus II, captured on 23 September 1966, in higher resolution than ever seen before from this type of data. This date falls around the time that Arctic sea ice would have reached its end-of-season minimum extent, demonstrating the possibility of reprocessing the entire available time series and supporting new scientific study of past conditions on Earth. This proof-of-concept research was supported by an Innovative Research Program seed grant from CIRES.

NSIDC researchers contributed to the United Nations Climate Change Conference in Copenhagen. NSIDC scientist Shari Gearheard spoke at the Inuit Circumpolar Council official side event, "Using Traditional Knowledge in Climate Change Decision Making," and participated in "Inuit and Arctic Indigenous Peoples Day." NSIDC Fellow Richard Armstrong, though not attending the conference, participated in a six-person task force that produced *Melting Snow and Ice: A Call for Action*. The report on the status of Earth's glaciers and ice caps was released at Copenhagen and commissioned by Nobel Peace Prize laureate Al Gore and Norway's Minister of Foreign Affairs Jonas Gahr Støre.

Inuit forecasters equipped with generations of environmental knowledge are helping scientists learn something new about Arctic weather. A study published in the journal *Global Environmental Change* brings together two worlds, combining indigenous environmental knowledge with the practice of statistical weather analysis.



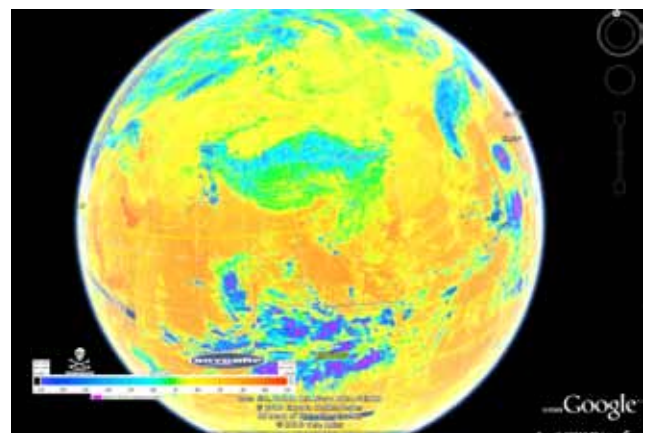
ANDY MAHONEY

NSIDC researcher Shari Gearheard, front row, fourth from left, poses with members of the international Siku-Inuit-Hila (Sea Ice-People-Weather) project on the sea ice near Qaanaaq, Greenland. Gearheard's research integrates local observations and knowledge with scientific data and observations to deepen understanding of climate change.

The study, a collaboration between Shari Gearheard and CIRES Fellow Roger Barry at NSIDC, and CIRES senior scientist Betsy Weatherhead, shows that including the observations and stories of the Inuit into climate research can not only provide valuable insights into asking the right scientific questions, but helps researchers find new ways of answering them.

In a related development, the NSIDC-hosted Exchange for Local Observations and Knowledge of the Arctic project released its first product: the Sanikiluaq Sea Ice Project website. Sanikiluaq is one of the southernmost Inuit communities in Nunavut, Canada, located on the Belcher Islands in Hudson Bay. To help document changing sea-ice conditions around the islands, members of the Sanikiluaq Sea Ice Project interviewed three hunters. The product website presents the resulting videos and maps describing each hunter's observations.

NSIDC researchers provided ongoing analysis and satellite data to the public and research communities via Arctic Sea Ice News and Analysis (<http://nsidc.org/arcticseaicenews/>). This heavily-visited site continues to fill a key role in keeping the public and media informed of the current status of Arctic sea-ice conditions, which have shown strong sensitivity to climate warming.



NSIDC/NASA

NSIDC data scientists rescued imagery from NASA's earliest Earth science satellites, with the potential to extend the look back on Earth's climate by 10 years. Because of archaic formats and deteriorating media, the satellite imagery were inaccessible to researchers and on the verge of being lost forever. On 23 September 1966, NASA's Nimbus II satellite acquired the temperature data shown in this image of Asia, overlaid on Google Earth. Blues and greens indicate cooler temperatures, and yellows and reds indicate warmer temperatures. The warm waters of the Persian Gulf are clearly seen in contrast with the cold temperatures of the Himalayas.

WESTERN WATER ASSESSMENT

- Dealing with Drought — Adapting to a Changing Climate
- Treeflow.info Web Portal
- Forests, Climate, and Change
- 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 multi-disciplinary teams of experts in climate, water, law, and economics, the WWA team works with decision makers across the Intermountain West to produce useful information about climate variability and climate change. In the West, many of the impacts of climate change will be delivered through changes in the hydrologic cycle, affecting water resources. To address these issues, the WWA has focused on building relationships and networks with water-resource decision makers, and has subsequently used these interactions to develop practical research programs and useful informational products.

FY10 was an exciting one for the WWA research team. WWA refocused its research and decision-support products so that all WWA projects fall within 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 legacy projects and newer initiatives were well received by our stakeholder community, and several major endeavors emerged as particularly important efforts.

Dealing with Drought — Adapting to a Changing Climate

Specific WWA accomplishments in FY10 include the “Dealing with Drought—Adapting to a Changing Climate” workshop series presented in three locations around Colorado. These workshops built on themes and information from both the 2008 WWA-Colorado Water Conservation Board *Climate Change in Colorado* report and the October 2008 Colorado Governor’s Conference on Managing Drought and Climate Risk. More than 80 participants attended, representing diverse sectors and interests affected by drought and climate. The primary objectives of these workshops were to improve the climate literacy of the participants, provide input into the ongoing update of the state drought plan, document participants’ understanding of climate change in Colorado, and address concerns and questions among this group of stakeholders about climate change. Workshop objectives were achieved through pre- and post-workshop evaluations, instructional presentations, breakout discussions, and the distribution of climate and drought information in printed form.

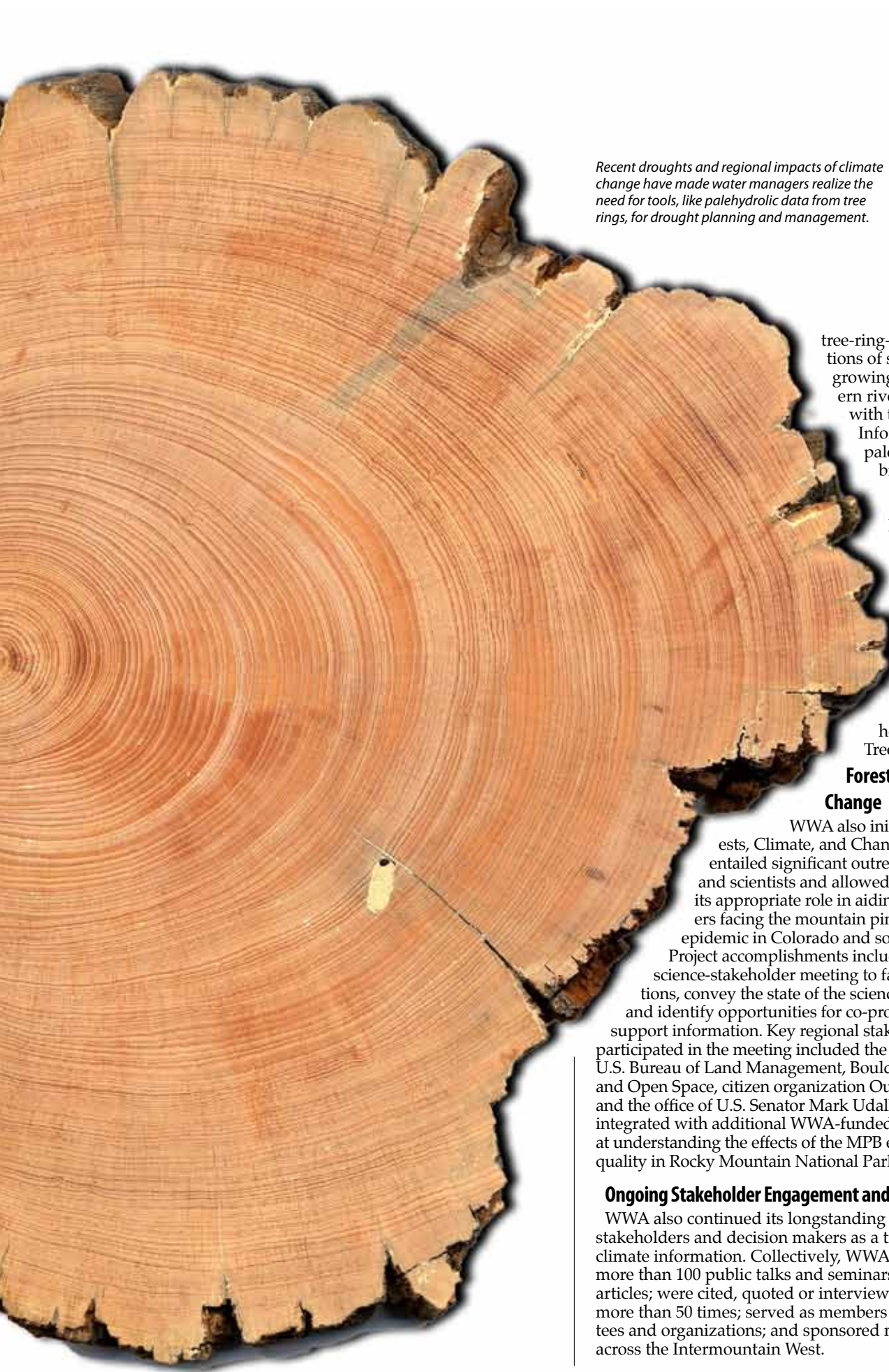


Mountain pine beetle.

MORGAN HEIM/CIRES

Treeflow.info Web Portal

WWA, in collaboration with researchers from the Climate Assessment for the Southwest (CLIMAS), also developed a web portal to access paleohydrologic records (<http://treeflow.info>), which was publicly announced to stakeholders in September 2009. Paleohydrologic data and information from tree rings are increasingly recognized as valuable tools for drought planning and water-resource management. The recent severe and prolonged drought and a growing awareness of the regional impacts of global climate change, coupled with an increased demand for water that far exceeds demands during the drought of the 1950s, have made water managers in the western United States realize the need for new tools for drought planning and water management. The development of high-quality



Recent droughts and regional impacts of climate change have made water managers realize the need for tools, like paleohydrolic data from tree rings, for drought planning and management.

tree-ring-based reconstructions of streamflow for a growing number of western rivers has coincided with this realization.

Information from the paleo record, combined with future projections, may yield the most likely range of future scenarios for planning purposes. To meet the growing demand by resource managers for a clearinghouse of such information, WWA helped develop the TreeFlow web portal.

Forests, Climate, and Change

WWA also initiated the “Forests, Climate, and Change” project, which entailed significant outreach to stakeholders and scientists and allowed WWA to assess its appropriate role in aiding decision makers facing the mountain pine beetle (MPB) epidemic in Colorado and southern Wyoming. Project accomplishments included hosting a science-stakeholder meeting to facilitate connections, convey the state of the science on MPB impacts, and identify opportunities for co-producing decision-support information. Key regional stakeholders that participated in the meeting included the U.S. Forest Service, U.S. Bureau of Land Management, Boulder County Parks and Open Space, citizen organization Our Future Summit, and the office of U.S. Senator Mark Udall. This project was integrated with additional WWA-funded research aimed at understanding the effects of the MPB epidemic on water quality in Rocky Mountain National Park.

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 100 public talks and seminars; published 42 articles; were cited, quoted or interviewed by the media more than 50 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 research conducted at CIRES provides knowledge that helps society to build a sustainable future. In 2009-2010, CIRES Education and Outreach expanded our program in online and distance education in climate-related topics, added to our solar weather offerings, and now leads the NSF-funded “Project Extremes,” which supports graduate students in science disciplines to work with teachers in the classroom. Highlights of recent work are described below.

Climate Science Education

Many teachers would like to teach climate science, but find their intentions frustrated by the difficulty of finding high-quality teaching materials, or by their own lack of background in the topic. Two new projects help to meet these needs: Inspiring Climate Education Excellence (ICEE) and Climate Literacy Energy Awareness Network (CLEAN).

CLEAN is developing a collection of 500 “cream-of-the-crop” learning resources aligned with the *Essential Principles of Climate Change* and National Science Education Standards. A team of collectors, climate scientists, and educators will review thousands of climate learning resources. Those that meet the highest standards of quality and are aligned with the *Essential Principles* will be included in the collection. As a National Science Digital Library “Pathways” project, CLEAN will make climate and energy education resources more visible and useful for educators, and will build a community of people interested in these topics. The first set of reviewed resources will be available November 2010.

Since 70 percent of educators who teach climate and energy topics in the classroom go to 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*. A workshop was held 10-16 June 2010, and from that a suite of online

“I have a strong basic understanding, but just need more data and evidence to share with students, and better inquiry-based activities to use in the classroom.”

Teacher respondent to ICEE needs assessment



PAT CORKERY/UNITED LAUNCH ALLIANCE

Scientists are comparing the data stream from the Solar Dynamics Observatory to a firehose of information.

modules and a full online course will be developed for those seeking more in-depth experience.

Two new online courses have been developed by CIRES Outreach and are offered as part of the CU-Boulder Sustainable Practices certificate program: “Climate Literacy for Educators” and “Effectively Communicating about



PHOTOS/CIRES

Crest View Elementary school teacher Erin Shea-Bower of Boulder, CO, works with a student on a science project developed by graduate student Phillip Taylor. Shea-Bower says that she learns from Taylor, too. "The more knowledge I have, the more excited I am."

Climate and Energy."

CIRES Outreach is also delivering professional development workshops via tele-videoconferencing to other states and across Colorado, with participation by CIRES researchers.

A series of webinars and workshops has been offered through 2009-2010 for graduate students and scientists to learn how to communicate about climate change. The "Effectively Communicating Climate Change" workshop was conducted, for example, at: the NASA Langley Research Station; during the State of the Arctic conference; at Colorado State University; at a NOAA Climate Operations course; for the NOAA Great Lakes Regional Collaboratory; and for the National Weather Service Central and Western regions.

Graduate Student Education

CIRES Outreach leads an NSF-funded grades K-12 program to place science graduate students in diverse classrooms within the Boulder Valley School District. 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. In a related project, middle school teacher Ian Schwartz wrote a popular blog while conducting research in

"The ability to tune a science message on the fly to each of the audiences is a skill that I could only have learned by being involved in this program."

**Phillip Taylor,
Project Extremes Fellow**

Antarctica's dry valleys with three Fellows, and while active, it was the second most popular website at CIRES.

Sun-Earth Connections

The Solar Dynamics Observatory (SDO) launched February 2010, and as the lead education team for one instrument onboard, CIRES Outreach provides teacher

professional development and classroom kits. In partnership with CU's Laboratory for Atmospheric and Space Physics, a journalist workshop was held prior to launch. The SDO is sending back a firehose of new data, which will be incorporated in new learning activities.

A NASA grant held by a CIRES scientist supports a project in geomagnetism in which students learn about Earth's magnetic field and navigation through hands-on and outdoor activities. Through an after-school academic program, students come to understand that solar variability affects our modern way of life.

VISITING FELLOWS

With partial sponsorship by NOAA, CIRES offers visiting fellowships at the University of Colorado at Boulder. Every year, CIRES awards several fellowships to visiting scientists at many levels, from postdoctoral to senior. These fellowships promote collaborative and cutting-edge research. Since 1967, about 255 people have been visiting fellows at CIRES, including previous CIRES Director Susan Avery and current Director Konrad Steffen.

Allen Robinson

Sabbatical

Ph.D., University of California, Berkeley

Project: Integrating laboratory, field, and modeling studies to close the organic aerosol mass balance



Allen Robinson is a Professor at Carnegie Mellon University in Pittsburgh, PA. Robinson's main interests are associated with the atmospheric transformation of emission from combustion systems, focusing on organic aerosols and regional climate. While at CIRES, he is working with Jose-Luis Jimenez and Joost de Gouw and their groups to conduct experimental and theoretical

studies of secondary organic aerosol formation and evolution. Experimental work includes portable smog chamber studies to investigate the gas-particle partitioning chemical evolution of biomass-burning emissions at the Fire Science Laboratory in Missoula, MT. The data are being used to develop new parameterizations for the chemical evolution of organic aerosols in biomass-burning plumes. In addition, measurements of low-volatility organic vapors are being made in Los Angeles during the California Nexus (CalNex) campaign, to investigate the sources of this material. Modeling efforts are focused on implementing and testing new secondary organic aerosols in chemical transport models.

Sponsor: Jose-Luis Jimenez and Joost de Gouw

Allyson Eller

Postdoctoral

Ph.D., Cornell University

Project: Characterizing VOC emissions from hybrid poplars under current and future CO₂ conditions



Allyson Eller is working jointly in the NOAA Chemical Sciences Division's Tropospheric Chemistry group and CU-Boulder's Ecology and Evolutionary Biology Department. She is investigating how rising carbon dioxide may affect the volatile organic compound (VOC) emissions from different hybrid poplar genotypes.

Hybrid poplar is already widely planted in the timber industry and is likely to be planted even more extensively if it becomes a source of biomass for the biofuel industry. A number of the VOCs emitted by plants participate in the chemistry that produces tropospheric ozone, which can have serious impacts on regional air quality. Eller is working to characterize the VOC emissions from several common commercial genotypes of hybrid poplar under current and elevated concentrations of carbon dioxide to determine the likely impact of larger poplar plantations on regional air quality now and in the future.

Sponsors: Joost de Gouw and Russell Monson

Stephanie Jenouvrier

Sabbatical

Ph.D., University of Pierre and Marie Curie, Paris, France

Project: Antarctic seabird population responses to future climate changes



Stephanie Jenouvrier from the Woods Hole Oceanographic Institution is working on the ecological impact of climate change. Her main interests are to understand and predict the population responses of Antarctic seabirds to present and future climate changes, and to compare responses among other seabirds species.

While at CIRES, she is working with Julienne Stroeve and Mark Serreze at the National Snow and Ice Data Center and Marika Holland at the National Center of Atmospheric research to obtain past and future climate data to project the population responses of penguins and petrels to climate change.

In Antarctica, seabird species are sensitive to changes in sea-ice conditions because sea ice affects their food resource or their habitat. For instance, winters with exten-

sive sea ice enhance krill abundance, and seabirds mainly feed on fish species that depend on krill and other crustaceans. Sea ice affects the demographic traits of penguins and petrels, and thus their population dynamics.

Most of the climate models used in the Intergovernmental Panel on Climate Change Fourth Assessment Report (IPCC AR4) project that sea ice will shrink in future global warming scenarios. This may strongly affect Antarctic species, as Jenouvrier et al. (2009) showed for the emperor penguin in Terre Adélie. Indeed, the median population size of the emperor penguin is projected to decline from approximately 6,000 to 400 breeding pairs by 2100 if winter sea ice extent declines at the rates projected by IPCC AR4 models.

Sponsor: Mark Serreze, Julienne Stroeve, and Marika Holland

Justin Langridge

Postdoctoral

Ph.D., University of Cambridge, UK

Project: Optical properties and direct radiative impacts of atmospheric aerosols



Justin Langridge's CIRES research focuses on the optical properties of atmospheric aerosols and, in particular, the nature of light absorption by organics in the particle phase.

Aerosol particles affect the climate system in a number of important ways, one of which is by directly interacting with solar radiation. The relative extent to which aerosols absorb versus scatter incoming

radiation determines, in part, whether they lead to net warming or cooling of the atmosphere. Combustion-derived soot has traditionally been considered the sole light-absorbing, and thus positive forcing, component of ambient aerosols. However, this assumption has recently been cast into doubt by the discovery of the widespread abundance of additional light-absorbing carbonaceous material in atmospheric particles, generically termed brown carbon. At present the optical properties and climate forcing importance of brown carbon aerosol are poorly understood.

Langridge is examining the absorption properties of brown carbon through field and laboratory studies using newly developed spectroscopic instrumentation.

Sponsor: Michael Hardesty

Molly Larsen

Postdoctoral

Ph.D., University of California, Los Angeles

Project: Photochemistry of atmospherically relevant small organic molecules



Molly Larsen is working in Veronica Vaida's laboratory to examine the photochemistry with red sunlight of atmospherically relevant organic molecules, such as small organic acids and alcohols. Molecular oxygen and ozone in the upper mid-stratosphere absorb most of the ultraviolet light in the solar spectrum so it is the lower-energy visible photons that are available for most of the photochemical

processes in the Earth's lower atmosphere. The question under study is if visible light-exciting vibrational overtone transitions of acids and alcohols could play an important role in the chemistry of these organic molecules, which would lead to secondary organic aerosol (SOA) formation. While the oxidation of these small molecules by O_3 and OH are known to be important in the degradation of SOA precursors, current aerosol models ignore the photochemistry of particles and underestimate the SOA mass by two orders of magnitude. Larsen's research findings on the low-energy photochemistry of small organic molecules will be used as input to atmospheric models.

A related aspect of Larsen's research focuses on how interactions with water can enhance the photochemical reactions described above. Theoretical results show that water can catalyze these photoreactions by lowering the energy of the transition state in the reaction. Interactions with water can also shift and broaden the absorption spectra of these molecules, greatly affecting their interactions with the solar spectrum. Since these small organic molecules are taken into aerosols in the atmosphere, understanding their photochemistry in the liquid phase, in the ice phase, and at the liquid/water interface is necessary for understanding their atmospheric relevance. Larsen's research focuses on examining the visible-light-initiated photochemistry in these three atmospherically important phases, and on how water can influence atmospheric reactions.

Sponsor: Veronica Vaida

Adrian McDonald

Sabbatical

Ph.D., University of Wales

Project: Constraining parameterizations of small-scale variability in middle atmosphere climate models



Adrian McDonald is a senior lecturer at the University of Canterbury in New Zealand. Adrian's main interests are associated with the dynamics and chemistry of middle atmosphere (the region between 10 and 90 km above the Earth's surface), particularly over the Antarctic, and the effect of the middle atmosphere on Antarctic surface climate. While at CIRES, he

is working with Xinzhao Chu and her group on understanding the temporal and spatial variability in the middle atmosphere associated with internal gravity waves. Understanding this variability and deriving data on gravity-wave motions is important because these processes are too small to be resolved by most climate models, but have significant impacts on the mean circulation in the middle atmosphere, which in turn feeds back on surface climate. The work uses data from the Chu group lidar instruments and satellite observations from the Constellation Observing System for Meteorology, Ionosphere and Climate (COSMIC) radio occultation to derive improved constraints for parameterizations used in climate models.

Sponsor: Xinzhao Chu

Scott Bates

Postdoctoral

Ph.D., Arizona State University

Project: Surveying the diversity and biogeography of fungi in arid land soils and biological soil crusts



Microbes play essential roles in soil processes, including the formation of soil structure, stabilization through the aggregation of soil particles, and, perhaps most importantly, mediating nutrient cycling. In arid lands, microbially driven organosedimentary topsoil assemblages known as biological soil crusts (BSCs) are a critical component of these nutrient-limited and erosion-prone soils. While BSCs are ubiquitous on terrestrial

surfaces of the Earth's arid and semi-arid ecosystems, understanding of the diversity of organisms that are present in BSCs and how the community structure of BSC microbes changes across regions or in response to edaphic factors is still limited. This knowledge gap limits our ability to provide useful data to inform predictive and conceptual modeling of crust cover, global nutrient cycling, or ecological processes in arid lands.

Bates is working with Noah Fierer's research group, which has focused on understanding factors that influence

the structure and diversity of archaeal, fungal, bacterial, and viral communities in the soil environment. In this effort, the Fierer group has pioneered the use of barcoded pyrosequencing, a high-throughput sequencing technique which generates thousands of sequences from hundreds of individual samples, in conjunction with phylogenetically based multivariate statistical methods to gain a comprehensive understanding of the diversity soil microbes and the dynamics that shape these communities. Bates is applying these techniques to the study of microbes in arid-land BSCs, with a special emphasis on fungi, to elucidate factors that influence the formation and spatial variability of these unique communities. In addition to this work, Bates is involved in examining interaction between soil archaea and bacteria, microbes involved in leaf litter decay, as well as potential endosymbiotic bacteria of lichens.

Sponsor: Noah Fierer

Stephen Martel

Sabbatical

Ph.D., Stanford University

Project: Mechanics of geomorphic surfaces and its impact on landscape

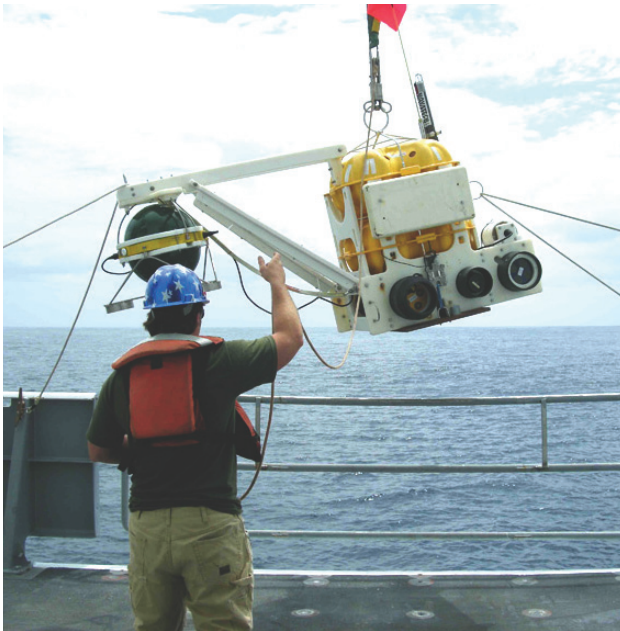


Stephen Martel is a professor at the University of Hawaii. Martel's interests are diverse but center around the mechanics of fracture phenomena in the Earth, especially those that pertain to structural geology, engineering geology, and geomorphology. While at CIRES, he is working with Peter Molnar and Greg Tucker on sheeting joints, fractures that open near to, and nearly parallel to, the topographic surface in rock. These fractures are widespread and play a critical role in landscape development, slope stability, shallow groundwater flow, and weathering of rock. Their cause has remained enigmatic for more than two centuries. Martel is testing a new physically based explanation for these fractures that blends detailed geologic mapping, stress measurements, differential geometry, digital signal processing, and lidar data. Early results indicate that sheeting joints reflect strong compressive stresses parallel to the topographic surface and that topographic shape data can constrain the magnitude of near-surface stresses in areas with sheeting joints.

Sponsor: Peter Molnar

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 2010.



ANNE SHEEHAN

Array studies, tsunami wave propagation

Anne Sheehan, Zhaohui Yang, George Mungov, and Kelly Stroker

In 2009, CIRES Fellow Anne Sheehan and colleagues, including from the Massachusetts Institute of Technology, deployed 30 ocean-bottom seismometers and differential pressure gauges on the Continental Shelf and slope offshore New Zealand. The sensors were originally placed to map the Alpine Fault, but this dense network of sensors also recorded signals for five tsunami-generating earthquakes during their year on the ocean floor. Differential pressure gauges can measure pressure fluctuations of several millimeters in water pressure, making them useful for measurements of tsunami waves in the zone between NOAA's Deep-Ocean Assessment and Reporting of Tsunami (DART) buoys and the coastal tidal gauges currently used to monitor tsunami propagation. The pressure data set collected from the New Zealand ocean-bottom experiment affords the opportunity to reconstruct the entire process of tsunami propagation and transformation from the open ocean through the Continental Shelf to the coast. It also helps bridge the gap between the earthquake source model and the tsunami model, which could help tsunami warning systems more accurately model the size of waves as they approach landfall.

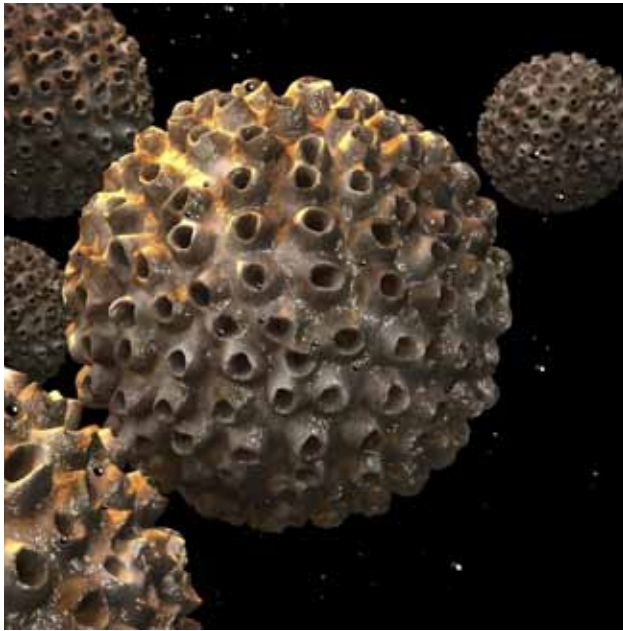


MORGAN HEIM/CIRES

New wind profile measurements for quantifying ozone transport

Michael Hardesty and Christoph Senff

Planes sampling the air with optical scanners and laser systems called lidars have revolutionized the way we understand our skies. Many projects use one of these methods or measure just one component of the air, but CIRES Fellow and NOAA scientist Michael Hardesty, CIRES' Christoph Senff, and colleagues will combine all these technologies into one experiment to produce a three-dimensional view of wind and ozone transport over Central and Southern California. Many regions in California experience high ground-level ozone concentrations and frequently violate national ozone standards. Observations of ozone transport mechanisms are sparse and it is poorly understood when these processes occur and how important they are for ventilating air basins. The team will install an optical scanner on the NOAA Twin Otter to enable simultaneous measurement of wind and ozone profiles, develop supportive software, operate the scanner in conjunction with other instruments during the California Nexus experiment (Doppler lidar, NOAA TOPAZ ozone lidar and CIRES AMAX-DOAS), and analyze ozone and wind data to investigate the mechanisms and pathways for ozone transport.



ISTOCK

New needle-free methods of HPV vaccine delivery of aerosols and dry powders

Robert Sievers and Steve Cape

More than 300,000 women die each year from cervical cancer, a disease caused by certain types of human papilloma virus (HPV) that is especially devastating in developing countries. There is a vaccine for HPV, but right now that vaccine entails needle injections and refrigeration, both factors that limit who can afford, tolerate, or access this important health precaution. CIRES Fellow Robert Sievers and colleague Steve Cape aim to prepare fine dry powders of a new vaccine against HPV that can be packaged in foil laminate blisters for delivery to the respiratory tract using a simple, inexpensive dry powder inhaler (DPI), such as the PuffHaler, which was invented by CIRES scientists and students. Additionally, these dry powders will be processed into thin wafers for sublingual delivery. These innovations will help decrease costs, increase longevity, and help take the sting out of HPV vaccination. The project will also help position CIRES to pursue additional major funding for further development of alternative HPV vaccines and tests of immunogenicity.



ISTOCK

Statistics of ENSO past and present: Comparing climate models with coral reconstructions

Baylor Fox-Kemper, Samantha Stevenson, Helen McGregor, and Steven Phipps

Climate models coupled with field measurements can give an accurate picture of the modern nature of El Niño, but to understand the way it reacts to climate change, scientists need to dig back thousands of years, something that has so far proven challenging. Ancient corals may offer the key to extending the timeline of El Niño's history from decades to millennia. CIRES Fellow Baylor Fox-Kemper and graduate student Samantha Stevenson are teaming up with researchers from the Universities of Wollongong and New South Wales in Australia to look at how the information collected from fossilized corals combined with modeling can shed light on El Niño's past. El Niño-Southern Oscillation (ENSO) strongly influences drought and flooding events in Australia and the United States, thus planners in both regions require good ENSO statistics over decadal and longer timescales. Under likely future forcing and past orbital forcing, ENSO activity is expected to change, but the direction of projected change is not consistent among models, and may not necessarily dominate over natural decadal variability. Researchers will use Stevenson's newly developed wavelet probability analysis toolbox to compare coral paleorecords with continuous, though limited-duration, modern observations. CIRES and collaborators produced the first statistically robust, millennial-scale climate model validation to provide important comparisons between past and present El Niño cycles, while also applying a CIRES-developed model validation tool that could further advance paleoclimate and climate diagnosis research.

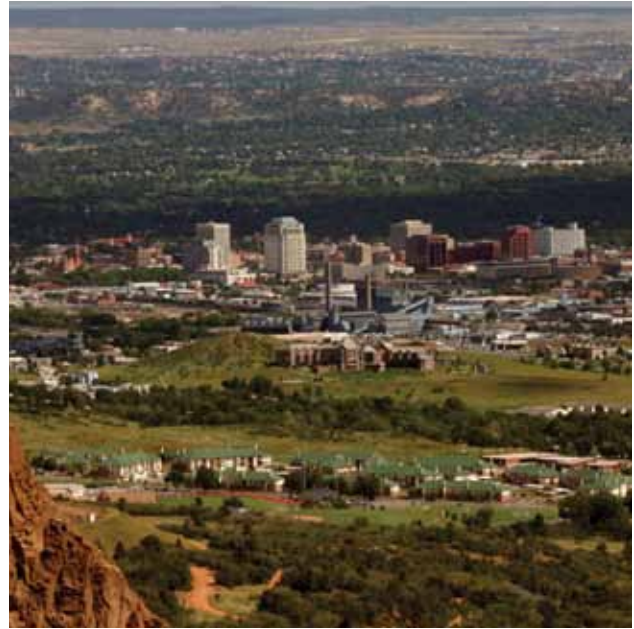


ISTOCK

Measurements of weak absorptions by O_3 and O_3-H_2O clusters using cavity-enhanced spectroscopy

Veronica Vaida, Cora Young, Rebecca Washenfelder, and Gregory Frost

Light from the Sun passes tens of kilometers through the atmosphere before reaching the Earth's surface. Over this long path, even very weak absorptions of the Sun's light by atmospheric gases can be important. These weak absorptions influence the Earth's heat budget and affect measurements made by other instruments monitoring the atmosphere, such as those on satellites. Although most strong absorptions have been measured well, it is difficult to measure weak absorptions in the laboratory. In particular, laboratory measurements have been unable to accurately measure weak ozone absorptions of near UV-light or the absorptions caused by clusters of ozone and water. This has left many questions unanswered about the radiative and chemical processes of atmospheric molecules. CIRES Fellow Veronica Vaida and CIRES/NOAA colleagues Cora Young, Rebecca Washenfelder, and Gregory Frost are developing a laboratory instrument with a super sniffer for ozone that they will use to help answer those questions. This instrument could be adapted to help study other atmospheric gases.



ISTOCK

Phenology of green infrastructure in cities: A window into ecosystem services in urban environments

Carol Wessman, Brian Muller, and Brian Buma

Urbanization has far-reaching impacts on the environment and ecosystem services; however, natural landscapes within mega-urbanized regions can provide services to support environmental and urban planning, including improvement of hydrological systems, disaster risk mitigation, demand for local food and natural amenities, mitigation of climate change effects, amelioration of heat islands, and carbon sequestration. However, the benefits of green infrastructure and associated ecosystem services have not been evaluated systematically for urban environments. CIRES Fellow Carol Wessman and graduate student Brian Buma will use remote sensing to evaluate the performance of green infrastructure under different development regimes in providing different ecosystem services. Wessman and her colleagues will look at the urban growth along the Colorado Front Range, using multiple interpretation strategies to assess landscape change at regional and sample-area scales. Quickbird, LIDAR, and other datasets, will be used to create three-dimensional descriptors of morphological and vegetative structures of urban subdivisions. The project should provide insights valuable to policy makers and researchers seeking to improve quality of life and sustainability in large and dense mega-regions.

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. The ESRL-CIRES Fellowships are awarded on alternate years with the next competition in 2011. 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.

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



Brian Buma

- B.S., 2003, Biology, Western Washington University
- M.A., 2005, Education, Western Washington University
- Ph.D. student in Ecology and Evolutionary Biology
- Academic Advisor: Carol Wessman
- Research Area: Multiple, interacting

disturbances and their impact on successional pathways and alternate stable states in a subalpine forest



Elizabeth Campbell Griffith

- B.S., 2009, Chemistry, University of Maryland
- Ph.D. student in Physical Chemistry
- Academic Advisor: Veronica Vaida
- Research Area: Processing of organics in atmospheric aerosols



Thomas Detmer

- B.A., 2003, Biology, University of Puget Sound
- M.A., 2005, Ecology and Evolutionary Biology, CU-Boulder
- Ph.D. student in Ecology and Evolutionary Biology
- Academic Advisor: William Lewis, Jr.
- Research Area: Research on high moun-

tain lakes' food web dynamics, community composition, and biogeochemical cycling



Christopher Gray

- B.A., 2008, Ecology and Evolutionary Biology, CU-Boulder
- Ph.D. student in Ecology and Evolutionary Biology
- Academic Advisor: Noah Fierer
- Research Area: Quantifying and measuring the controls over volatile organic compound emissions from soils



Mariela Perignon

- B.S., 2007, Earth, Atmosphere and Planetary Sciences, Massachusetts Institute of Technology
- M.S., 2008, Geology, Massachusetts Institute of Technology
- Ph.D. student in Geological Sciences
- Academic Advisor: Greg Tucker
- Research Area: Effects of riparian

vegetation control on the morphology of channels



Ingrid Ulbrich

- B.S., 2000, Environmental Engineering, Massachusetts Institute of Technology
- Ph.D. student in Analytic and Atmospheric Chemistry
- Academic Advisor: Jose-Luis Jimenez
- Research Area: Understand sources and transformations of organic aerosol in urban and rural environments by applying matrix factorization techniques to two- and three-dimensional aerosol mass spectrometric ambient field datasets

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/>

2009 SOARS PROTÉGÉS

Marques Cameron

■ Project: Modeling wildfire behavior and analyzing emissions
■ CIRES Mentor: Lesley Smith

Marcus Walter

■ Project: Re-examination of northeast United States drought trends and characteristics
■ CIRES Mentor: Leslie Hartten

Vanessa Vincente

■ Project: The relationship between sea breezes and rainfall along western Mexico during the North American Monsoon
■ CIRES Mentor: 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/>

2009 UROP PROGRAM RECIPIENTS

Justin Ball

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

Josh Kelly

■ Project: Development of advanced receiver function calculation methods and application to continental collision
■ Faculty or CIRES sponsor: Vera Schulte-Pelkum

Christy Long

■ Project: Infrared and raman spectroscopic characterization of Titan tholins
■ Faculty or CIRES sponsor: Margaret Tolbert

Theme Reports

AMOS: Advanced Modeling and Observing Systems 85

CIRES researchers characterize and predict the state of the Earth system on a variety of scales using direct observations and mathematical techniques for projecting outcomes.

CSV: Climate System Variability 105

Climate directly influences agriculture, water quantity and quality, ecosystems, and human health. CIRES research on this theme addresses climate change that occurs on time scales from seasons and decades to millennia.

GEO: Geodynamics 121

CIRES geodynamics research focuses on the internal processes of the planet, including the properties of the core-mantle boundary, convection within the Earth's mantle, and the effects of convection on the surface of the planet.

PM: Planetary Metabolism 123

Planetary metabolism encompasses the complex web of biochemical and ecological processes that occur within the biosphere and their interaction with the lithosphere, atmosphere, and hydrosphere.

RP: Regional Processes 125

Climate variability and extreme weather events are influenced by topography, watersheds, vegetation, and other geographical features that often impact very specific populations, economic systems, and ecosystems.

IA: Integrating Activities 136

CIRES is committed to working across conventional disciplinary boundaries to produce rigorous, cutting-edge science and technology and to share that knowledge with a broad audience.

Project	Page	Project	Page	Project	Page	Project	Page
CET-01	087	GMD-06	129	NSIDC-01	118	PSD-11	125
CSD-01	085	GSD-01	095	NSIDC-03	118	PSD-12	127
CSD-02	093	GSD-02	132	POLICY-01	136	PSD-13	129
CSD-03	108	GSD-03	096	POLICY-02	139	PSD-15	117
CSD-04	113	GSD-04	103	POLICY-03	139	PSD-16	095
CSD-05	132	GSD-05	096	PSD-01	110	PSD-17	095
CSD-07	123	GSD-07	092	PSD-02	111	SWPC-01	099
CSD-08	130	NGDC-01	087	PSD-03	116	SWPC-02	100
CSD-09	134	NGDC-02	088	PSD-04	107	SWPC-03	090
CSD-10	136	NGDC-03	099	PSD-05	120	SWPC-04	091
GMD-02	100	NGDC-04	108	PSD-06	115	WWA-01	136
GMD-03	105	NGDC-05	121	PSD-07	120	WWA-02	137
GMD-04	112	NGDC-07	124	PSD-08	086	WWA-03	137
GMD-05	113	NGDC-08	089	PSD-10	100	WWA-04	139

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 LEAD: MICHAEL HARDESTY, NOAA RESEARCH
CIRES LEAD: RICHARD MARCHBANKS

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.

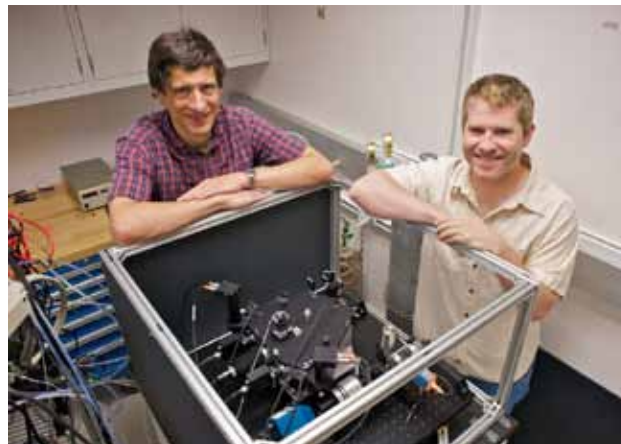
Milestone 1. Assess the capability of the single-particle albedo instrument by acquiring ambient data.

For the past few years a new type of instrument has been designed and constructed with the ultimate goal of successful field deployment. The Aerosol Scattering-To-Extinction Ratio (ASTER) instrument represents an important new measurement method; it simultaneously measures light scattering and extinction to determine the climatically important single-scattering albedo value for individual aerosol particles. This method also provides a measure of particle size, which has implications for climate.

Development was completed this year, and the instrument was thoroughly tested in the laboratory to determine its capabilities and areas for future improvement. This year's work culminated in the deployment of ASTER in the 2010 California Nexus (CalNex) campaign on climate and air quality.

The instrument proved successful in that it measured ambient aerosol single-scattering albedos and optical sizes in nearly continuous operation over the course of the campaign. The end of the campaign coincided with the end of this year's milestone period, so full data analysis

is forthcoming. However, some initial results have come out of the preliminary data. One example is the presence of a highly absorbing (dark in color) mode of aerosols that may have sources in fossil fuel combustion or biomass burning. This absorbing mode will be further analyzed as a function of the ASTER-determined particle size and compared with data from other instrumentation measuring particle composition. This will help determine how the aerosol optical (and thus climate) properties depend on particle size and chemical composition.



WILL VON DAUSTER/NOAA

Dan Murphy, left, and Todd Sanford with the ASTER instrument.

Milestone 2. Assess the capability of a new space-based Doppler wind lidar to measure wind profiles in the lower troposphere.

Work continues in the United States and Europe to develop a satellite capability to measure tropospheric winds globally from space. The European Space Agency plans to launch a satellite in 2012 that will use a Doppler lidar to obtain zonal winds every 200 km, while a similar U.S. satellite is in the early planning stages. Because of the long measurement range, wind measurements from space will require significant averaging to improve signal-to-noise ratios. The impact of averaging over small-scale wind structures in the lower troposphere on the representativeness of the space-based measurement and the potential introduction of biases have not been investigated for actual wind fields, especially over the oceans, where low-level wind data are scarce.

Using data gathered during a cruise off the coast of South America during the fall of 2008, the structure of boundary-layer wind fields was studied on scales smaller than the 200-300-km satellite measuring length. Of particular interest was the apparent difference in wind structure between clear sky and cloudy or partially cloudy conditions. The observations (from the Variability of the American Monsoon Systems [VAMOS] Ocean-Cloud-Atmosphere-Land Study [VOCALS]) indicated that both wind speed and direction were slightly different when stratocumulus clouds were present. Wind speeds were about 0.25 m/s lower, on average, under stratocumulus conditions and slightly more southerly in direction (Figure 1). This has potential implications for space-based measurements because the satellite will, in general, not sample beneath clouds, introducing a potential bias into the measurement. Additional aspects of averaging impacts, such as the introduction of spatial and vertical uncertainties due to aerosol weighting of the returns, are currently being investigated.

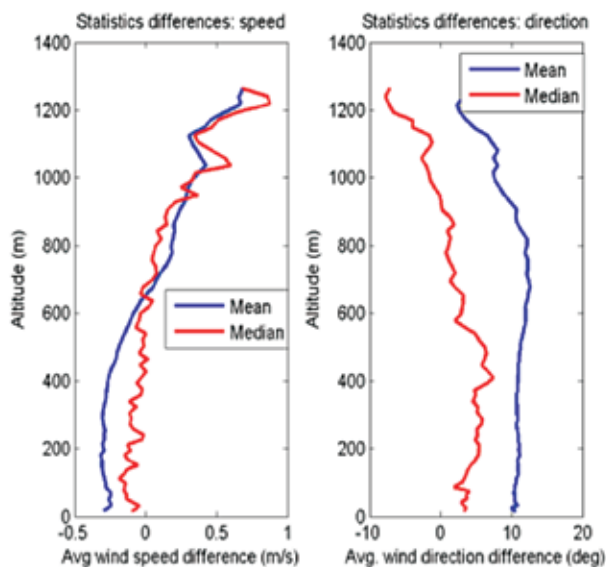


Figure 1: Difference in wind speed and direction in winds measured beneath low-level clouds and under clear conditions, showing slightly reduced speed and more southerly direction when clouds are present.

Milestone 3. Develop and test a new, fully-automated instrument to measure ozone on board a high-altitude, long-duration unmanned aircraft system.

A new, fully automated ozone ultraviolet (UV) photometer has been developed and fully tested for operation on board the NASA high-altitude, long-duration Global Hawk unmanned aircraft system (UAS). The instrument was flown successfully on board the Global Hawk during the first inaugural Global Hawk mission, Global Hawk Pacific (GloPac) in the winter of 2010. The instrument worked well during GloPac, and obtained ozone data of high precision and accuracy. The longest single-flight duration was more than 28 hours. Ozone data have been obtained over a large geographic area, covering latitudes spanning 26°N and 85°N and altitudes spanning the ground up to 20 km. The measurements provide an important scientific dataset and a successful demonstration of the capability to make measurements of high precision and accuracy in remote regions of the globe, for flights of unprecedented duration.

Milestone 4. Evaluate fast response, state-of-the-art instrumentation suitable for airborne measurements of nitrate (NO₃)/dinitrogen pentoxide (N₂O₅).

During the summer of 2007, CIRES researchers participated in an intercomparison campaign at the SAPHIR (Simulation of Atmospheric Photochemistry In a large Reaction chamber) in Jülich, Germany, to assess the performance and accuracy of instruments for measurements of the nocturnal nitrogen oxides, NO₃ and N₂O₅. These compounds are relevant to air quality and climate through their roles in chemical transformations of oxides of nitrogen (NO_x), volatile organic compounds (VOCs), ozone (O₃), and aerosol, yet the factors governing their atmospheric abundance are poorly understood for lack of observational data. The 2007 campaign included about 10 research groups from the United States, Europe, and Japan. Results showed that the NOAA instrument based on pulsed cavity ring-down spectroscopy agreed well (within 10 percent) with a standard based on differential optical absorption spectroscopy for NO₃. Comparisons with other N₂O₅ instruments based on various techniques also showed excellent agreement. No artifacts due to environmental variables, such as water vapor, reactive VOCs, or aerosol loading, were apparent in the NOAA data. A paper describing the calibration methodology for this instrument was published in 2008, and papers describing the intercomparisons are currently in preparation. Additional papers describing the scientific studies of organic aerosol production from NO₃ reaction with biogenic VOCs as part of this study have also been recently published.

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

PSD-08 Sensor and Technique Development

FEDERAL LEAD: CHRIS FAIRALL, NOAA RESEARCH
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. Deploy roving calibration standard on two ships.

The system has been successively developed and deployed on two research vessels.

Milestone 2. Test new ruggedized fast carbon dioxide sensor for permanent installation on NOAA research vessel *Ronald Brown*.

The system has been developed, modified, and deployed in several cruises including the Southern Ocean Gas Exchange Experiment (GasEx-III). FY10's activity also included the data analysis and further collaboration between the NOAA/CIRES team and Columbia University Lamont-Doherty Earth Observatory on the design and deployment aboard NOAA research vessel *Ronald Brown* of the CO₂ measurement system.

Milestone 3. Complete designs for installation of the ESRL Physical Sciences Division W-band radar on the NOAA P-3.

The W-band radar has been successively developed, deployed, and tested aboard the Woods Hole Oceanographic

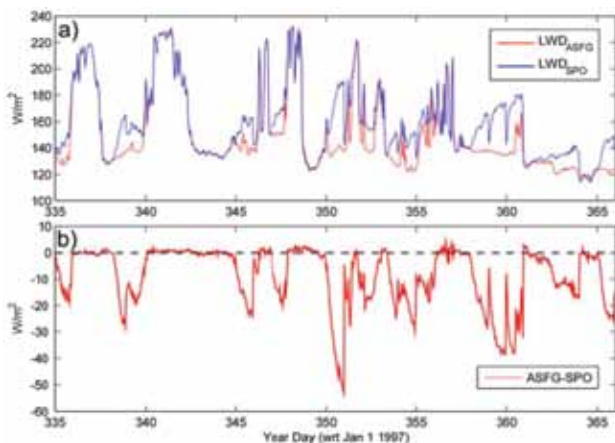
Institutions' research vessel *Atlantis* during the California Nexus field campaign in May-June 2010. Current activities include working on a mounting platform for deployment on the NOAA P-3 aircraft.

Milestone 4. Submit for publication a paper describing special problems of Arctic flux measurements.

A manuscript is in process describing the difficulties of making quality radiation measurements in the riming conditions of the Arctic. Dramatic changes are being observed in the Arctic, with significant surface warming, reduction of Arctic sea ice, and thawing of permafrost. Making accurate measurements of radiative fluxes over the entire Arctic pack ice and Arctic terrestrial regions during all seasons over many years is crucial for understanding the mechanism(s) causing the observed changes, which are likely to have dramatic effects on regional and global climate, and even on global commerce. Because of riming effects on the radiometers, such measurements are currently not possible except at year-round, manned stations with AC power.

Over the pack ice, the atmosphere is nearly always saturated with respect to ice, likely because of the presence of leads as a moisture source. In the wintertime, supersaturation with respect to ice occurs frequently, with the likely additional reason that there are very few ice nuclei. Because of these conditions, riming often forms on many surfaces, including radiometer domes. Experience from both Arctic terrestrial and pack ice sites reveals the following tendencies: 1) The radiometer most likely to be rimed is the upward-facing pyranometer measuring shortwave downward radiative flux (SWd) at an automated DC-powered site. The least likely is the downward-facing pyrgeometer measuring longwave upward radiative flux (LWu) at an AC-powered site. At terrestrial sites, certain wind directions showed preferential riming or no riming (e.g., at Alert, Canada, unrimed domes reliably occurred with a southwesterly wind direction, which is a downslope direction from the interior of the Ellesmere Island). Occasions of snow or freezing rain covering the radiometer domes were also noted.

The impact of the riming on pyrgeometer data is illustrated in the figure.



The time-series of the hourly LWd at the AC-ventilated Surface Heat Budget of the Arctic Ocean (SHEBA) Atmospheric Surface Flux Group (ASFG) site and the nearby DC-ventilated SHEBA Project Office (SPO) site for December 1997 and the difference (ASFG minus SPO) between them.

Differences in LWd tend to occur for low values of LWd, which typically occur during clear skies allowing radiative cooling of the radiometer domes to cause riming. When the pyrgeometer is rimed, it measures the longwave radiation (temperature) of the rimed dome, which tends to have a higher radiative temperature than the clear sky. Differences of up to 50 W/m² occur, and the December monthly mean difference is -9.6 W/m². Note that the periods of negative errors generally lasted no more than 24 hours, as cleaning of the SPO radiometers typically occurred near 23 UTC each day (local midday). Some days (e.g., YD359), the riming recurred within an hour after cleaning. The riming problem was even worse at the Atlanta automated site about 2.4 km from the SHEBA ASFG site. The Atlanta radiometers were ventilated with DC-powered fans and cleaned manually once per week or less. The Atlanta radiometer rarely measured the clear-sky low values of LWd throughout the SHEBA winter. Clear-sky periods showed positive LWd errors of up to 70 W/m², and the four-month mean LWd difference is 24 W/m². The LWd error at the manned SPO site is a little over 6 W/m² during the same time period.

CET-01 Remote Hydrologic Sensing

THIS PROJECT IS INACTIVE

AMOS-02 Data Management, Products, and Infrastructure Systems

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

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

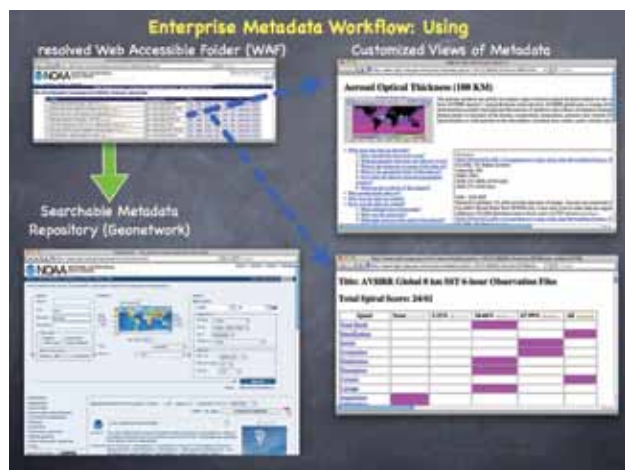
FEDERAL LEAD: RAY HABERMANN, NOAA NESDIS
CIRES LEAD: RICHARD FOZZARD

NOAA Goals 2 and 3: Climate and Weather and Water

Project Goal: Develop methods and processes for integrating multiple types of observations (gridded satellite products, in situ measurements) using new 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 that provide integrated access to data quality information using international standards.

By leveraging more than a decade of experience authoring geospatial metadata—structured dataset discovery, quality and usage documentation—and by working with NOAA’s NGDC and external partner data managers, a powerful, usable system has been developed for authoring, discovering, and viewing metadata in the new ISO 19115 standard format. Tools are provided to convert older FGDC metadata into the ISO format. This new system is being deployed and actively used for a number of collections of NOAA datasets: the Comprehensive Large Array-data Stewardship System, NOAA Observing Systems Architecture, National Climate Data Center, and the Office of Climate Observations. The system will be improved and use expanded during the coming years.



The workflow of metadata authoring: 1) Creating XML for metadata records and components—reusable pieces of records (e.g., contacts). 2) Storing metadata in a version control system and database of components. 3) Exposing the records on the Web in an “unresolved” Web Accessible Folder (WAF). (i.e., the unresolved records contain only references [xlinks] to the reusable components. 4) Resolving all referenced components and exposing the complete records to the Web in a “resolved” WAF.

Product: <http://www.ngdc.noaa.gov/metadata/published/iso>, and <http://www.ngdc.noaa.gov/geonetwork>

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

Using spatial databases developed by NGDC, Open Geospatial Consortium standard tools (e.g., Web Mapping Service, Figure 1, and ArcGIS, Figure 2) are used to allow scientists and the general public to interactively visualize remote-sensing data. The images and maps are generated dynamically from databases updated and archived in near-real-time.

To further aid dataset interpretation, ways are provided for drilling down into dataset metadata and documentation, such as specifications of individual in situ measurement stations.



Figure 1: An interactive map created from spatial databases of earthquake and tsunami events. Note that many other data layers are available for overlaying, to examine the relationships between many natural hazard events.

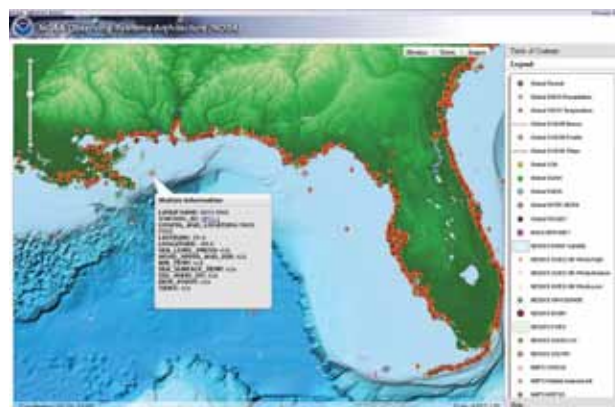


Figure 2: NOAA’s Observing Systems Architecture ArcGIS map showing detailed metadata for a National Weather Service Coastal Marine Automated Network buoy in the Gulf of Mexico.

NGDC-02 Marine Geophysics Data Stewardship

FEDERAL LEAD: SUSAN McCLEAN, NOAA NESDIS
CIRES LEAD: BARRY EAKINS

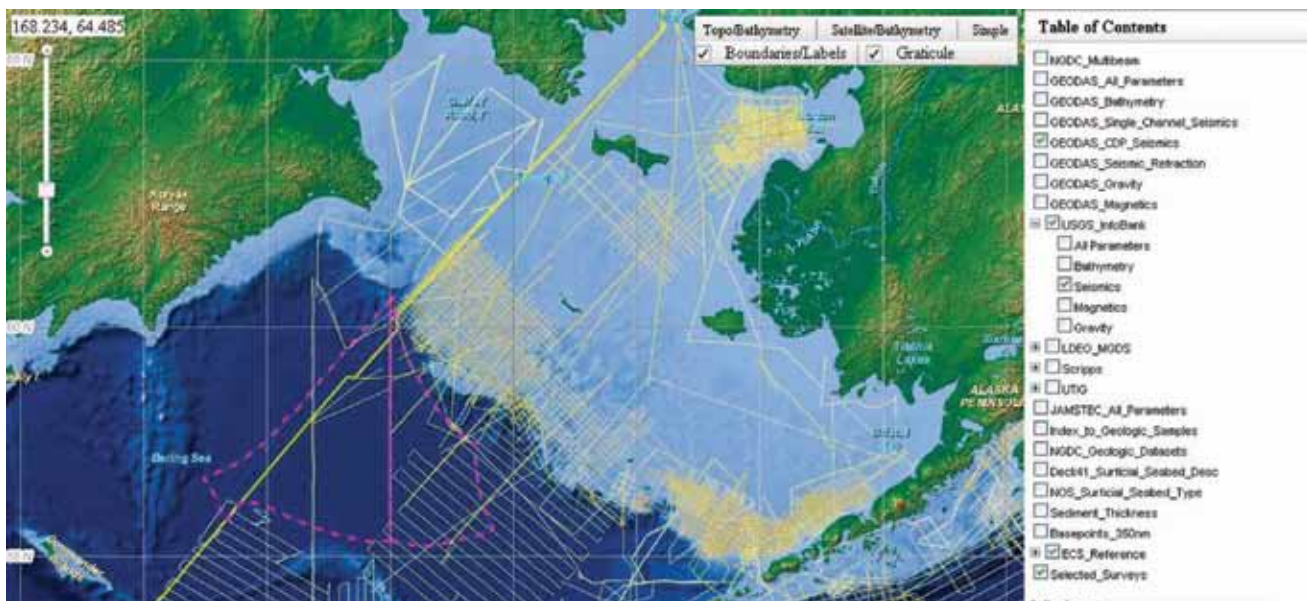
NOAA Goals 1 and 4: Ecosystems and Transportation

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 marine geophysical data from the worldwide oceanographic community.

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

NGDC provides long-term archive, stewardship, and delivery of data to scientists and the public by using standard metadata, spatially-enabled databases, robotic tape archive, and standards-based web services. Since July 2009, 136 multibeam swath sonar surveys (1,821,755 nautical miles) and 41 trackline (bathymetry, magnetics,



A screen grab of the interactive web map illustrating the Extended Continental Shelf Dynamic Inventory. The yellow lines represent seismic data collected in and around the Bering Sea, off Alaska.

gravity, and seismic reflection) surveys (146,622 nautical miles), throughout the world's oceans, have been added to the archive by NGDC and CIRES staff. National and international organizations contribute to and retrieve marine geophysical data from the spatially-enabled, interactive, web-accessible databases.

Marine geophysical data archived at and delivered by NGDC are currently supporting two specific, ongoing U.S. mapping efforts: the Extended Continental Shelf (ECS) project, and the Integrated Ocean and Coastal Mapping (IOCM) program. Data collected and identified as relevant for the ECS project will be used to define the maximum extent of the U.S. continental shelf. CIRES and NGDC staff have built a dynamic inventory of these data based on a geo-spatial database with an interactive web map (figure above). The map shows the spatial coverage of all available marine geophysical surveys from a variety of sources and includes tools for identifying relevant surveys and for querying the ECS database. Scientists on the ECS team can record information for individual surveys (e.g., navigational quality, suitability for the ECS project, etc., and also descriptive comments) and identify potential gaps in the available data for future survey planning.

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

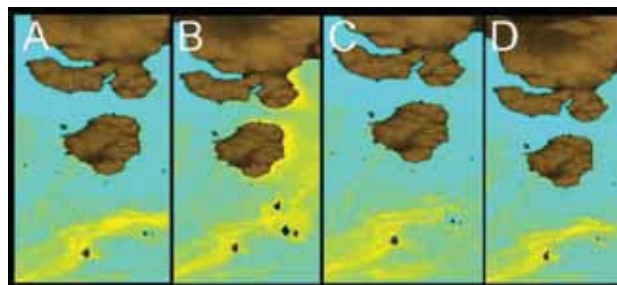
FEDERAL LEAD: SUSAN MCLEAN, NOAA NESDIS
CIRES LEAD: BARRY EAKINS

NOAA Goals 1, 2, 3, and 4: Ecosystems, Climate, Weather and Water, and Transportation

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

Milestone 1. Produce a pilot study on the effects of different gridding algorithms on integrated bathymetric–topographic DEMs, and their impacts on coastal inundation that result from hazard modeling for a specific at-risk community.

The pilot project “Assessment of the sensitivity of tsunami inundation modeling to gridding methodologies used in building high-resolution digital elevation models (DEMs),” was completed. Results showed that different gridding methods involving distinct methods of interpolation produce unique DEMs that result in differences in wave height and run-up times when modeling a tsunami event. This study supported our hypothesis that changing the gridding methodology alone, while using the same data, will produce unique DEMs that affect tsunami inundation results. Knowledge of how gridding methods affect inundation modeling will benefit those building and using high-resolution DEMs and ultimately the coastal emergency managers who rely upon the results of inundation models to conduct hazard assessment and prepare communities for tsunami and storm-surge events.



Differences in tsunami inundation modeling run-up heights by using DEMs constructed using different gridding methods. A) Base comparison model. B) Spline tension (multi-beam system software). C) Triangulation (GMT software). D) Spline tension (generic mapping tools software). Impacts were observed by changing gridding method, choosing different software, and adjusting software gridding parameters.

As a result of the pilot study, NOAA has funded a two-year project to more fully constrain the effects of gridding technique on DEMs, and how to quantify their impact. This

is part of a larger NOAA effort to incorporate error estimations into tsunami forecast and warning products. An incoming CIRES graduate student affiliated with the CU Department of Geography will begin work on this research project in FY11.

Milestone 2. Produce six to nine seamless, integrated bathymetric–topographic DEMs of select U.S. coastal communities sufficient for tsunami forecast and warning, and coastal inundation mapping.

During FY10, NGDC and CIRES staff developed 17 high-resolution digital elevation models (DEMs) covering 12 U.S. coastal communities. Each DEM is accompanied by a detailed NOAA Technical Report covering the data used, DEM development and quality assurance procedures, appropriate use, and partners. These integrated bathymetric–topographic DEMs are used by NOAA’s Tsunami Warning Centers to support NOAA’s tsunami forecasting and warning efforts, and by NOAA’s state partners in the National Tsunami Hazard Mitigation Program for coastal tsunami inundation mapping and hazard mitigation. The DEMs of American Samoa were used by NOAA’s Center for Tsunami Research to model maximum run-up height of the deadly tsunami of 29 September 2009.

A new methodology was developed to efficiently and quickly generate multiple DEMs of the same community, each referenced to a different vertical datum. This significantly expands the user-base for the DEMs with minimal cost in additional time and effort. A base DEM is built referenced to the North American Vertical Datum of 1988 (NAVD 88). Conversion grids are then built that model the relationship between NAVD 88 and other datums in the area, typically tidal related. Once the base DEM is built, additional DEMs can be created in a short period of time. For example, a recently built NAVD 88 DEM for the Santa Monica, CA region was converted to mean low water within days of the Chilean earthquake in February of 2010. This enabled researchers in California to analyze actual tsunami run-up data to modeled results since the tsunami arrived in Southern California at low tide.

Products: Caldwell et al. 2010, Carignan et al. 2009 a and b, Eakins and Taylor 2010, Friday et al. 2009 and 2010, Grothe et al. 2010 a and b, Lim et al. 2010 a and b, and Medley et al. 2009 a, b, and c.

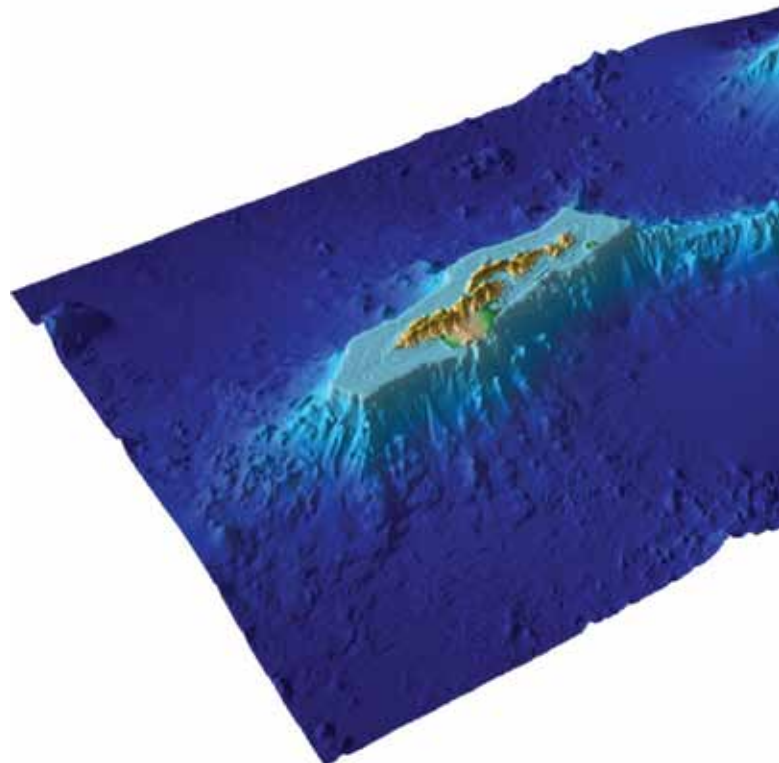
SWPC-03 Information Technology and Data Systems

FEDERAL LEAD: STEVEN HILL, NOAA SWPC
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). Enhance the GOES-O data processing systems and deploy to operations. Provide project management assistance when necessary. Begin transition of this system to support GOES-P telemetry streams and product development. Continue to provide analysis and

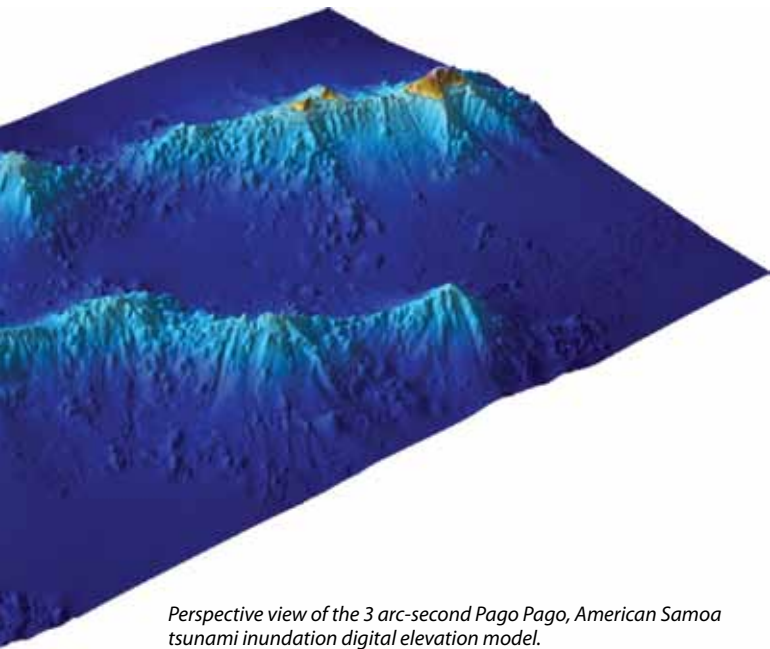


technical support to algorithm development, instrument checkout, and data verification.

A 14-person team of developers and administrators was led successfully by CIRES and SWPC to deploy the GOES O-series GDS into the SWPC’s National Critical Systems (NCS) operational environment. The deployment required the team to enhance, test, and document many different facets of the GDS’ functionality within a tight schedule. The deployment’s scope additionally included bringing several new NCS infrastructure components online for the laboratory: a more modern Microsoft SQL Server Relational Data Store than is already in place, a more secure network domain, and another Microsoft Active Directory. The fact that the team was comprised of individuals from several of SWPC’s project teams required detailed, cross-branch coordination of deployment activities. In the end, the deployment occurred ahead of schedule and with no problems for the laboratory, other operational projects, or the GOES GDS.

Milestone 2. Assist SWPC efforts to modernize data processing and distribution systems that are currently hosted on legacy systems. Provide development, transition, and mentoring support for contracts to outsource modernization efforts. Implement specific portions of the modernization that will not be outsourced. Improve legacy replacement systems that now exist and support new modernization projects as they are identified.

The Air Force Weather Agency-International Space Environment Service Message Decoder project was assisted



Perspective view of the 3 arc-second Pago Pago, American Samoa tsunami inundation digital elevation model.

by re-factoring legacy database schemata into modernized entity relational data models. All data were successfully normalized and all pertinent procedures to support data loading were developed. Relational tables on the new Microsoft SQL Server 2008 database system were prototyped, and systems support for high-bandwidth traffic was tested.

Milestone 3. Aid in new model development and transition to operational products. Enhance newly developed product software as requested. Continue to support the identification of new models and products, as well as assist in refining the organizational workflow processes by which those new models and products are developed and deployed.

SWPC CIRES members were instrumental in several new model development projects, facilitating validation and transition to operational products. The D-Region Absorption Prediction project was one such new model where SWPC CIRES staff participated in the design, development, testing, documentation, and deployment of two iteration releases. The team also assisted the Global Positioning System Ionospheric Positioning Correction project through requirements development and prototype implementation.

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

Storage systems were improved through valuable efforts aligned with several projects. Based on customer user re-

porting requirements of the project in Milestone 2 above, a suite of database views was developed to facilitate the aggregation and summarization of data. The Real-Time Ground Magnetometer System was transitioned to the new Microsoft SQL Server 2008 database system, with support from SWPC CIRES team members.

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

Critical support was provided for several operational product generation systems. The GOES-NOP ground data system in support of operational requirements and maintenance was expanded through a disciplined change control process that saw the completion of more than 52 documented change requests. The design, development, and testing of level-1 Solar X-ray Imager (SXI) processor for GOES-NOP was supported, based on what was implemented for the GOES 12 series. Lastly, important legacy system administration service support was continued, as was troubleshooting for system problems and implementation of several legacy system change requests.

SWPC-04 Space Environment Data Algorithm and Product Development

FEDERAL LEAD: STEVEN HILL, NOAA SWPC
CIRES LEAD: MARY SHOULDIS

NOAA Goal 3: Weather and Water

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

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

Delivery of the phase 1 GOES-R algorithms and documentation were completed in December 2009. These six algorithms meet 22 NOAA product requirements including: Time-Series Data Averages, Magnetometer Comparison to Quiet Fields, Magnetometer Conversion to Alternate Coordinate Systems, Energetic Particles Conversion of Differential Flux to Integral Flux, Solar Ultra-Violet Imager (SUVI) Composite Images, and SUVI Fixed / Running Difference Images. Test proxy data and test cases were delivered to validate the algorithms. Research and development of the phase 2 algorithms was started in January 2010, and in May 2010, a preliminary design review was held for four new algorithms. The requirements and preliminary design was approved by NOAA, and detailed research, design, and development are now underway.

The development and testing of the Space Environmental Anomalies Expert System, Real-Time (SEAESRT) product to ingest real-time GOES particle data and Kp magnetometer indices to derive satellite anomaly hazard quotients and display the quotients as a function of time and local time on the SWPC website is nearly complete. The SEAESRT product will enable the satellite community to better plan satellite maneuvers and maintenance, provide situational awareness, and aid anomaly assessment.

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

Development of an algorithm to detect magnetopause crossings in real time is being researched and developed using the GOES-R magnetometer and energetic particle data for operational use at the SWPC. Magnetopause crossings at geosynchronous orbit can have serious effects on satellites that depend on magnetic torque coils to adjust for satellite momentum changes caused by solar radiation pressure and can signal changes in magnetospheric current systems having major impacts on ground-based electric power systems. Research into the best method to detect these events is ongoing.

The goal of current risk reduction research for the Space Environment In Situ Suite (SEISS) instrument data is to reduce time-averaged data to quantities that are useful for SWPC forecasters. This effort involves the development of moments from the GOES-R energetic particle data. Moments succinctly describe the magnetospheric electron and ion distribution functions. They are a critical component of geospace models for predicting geomagnetically-induced currents in power grids. They also indicate satellite failures due to surface charging, and deep dielectric charging and satellite degradation due to surface dose.

Solar Ultraviolet Imager (SUVI) thematic maps are a completely new data product born of GOES-R risk reduction research and fulfill a longstanding need for more automated solar-image-analysis tools. A robust Bayesian classification algorithm has been verified in research and is being tailored to meet specific SWPC operational needs. Planned SUVI data products that are expected to use these thematic maps as input include bright region reports, flare location reports and coronal hole boundaries.

GSD-07 High Performance Computing Systems

FEDERAL LEAD: LESLIE HART, NOAA RESEARCH
CIRES LEAD: CRAIG TIERNEY

NOAA Goals 2 and 3: Climate and Weather and Water

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

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

Several technologies have been investigated to better understand their suitability for the NOAA scientists. Here, suitability is defined as not only technology suitable but also suitability in terms of manageability and resiliency. From this investigation, the following recommendations were made for NOAA:

- 1) Intel Westmere processors would provide more value than Advanced Micro Devices Magny-Cours processors to support next-generation hurricane modeling and other weather and climate simulations, and
- 2) Nvidia graphics processing units (GPU) provide better performance and a more robust ecosystem to support next-generation model development.



Nvidia graphics processing unit.

Milestone 2. Complete technical investigation on alternative hierarchical storage management technologies.

This project was suspended due to a change in priorities and funding availability.

Milestone 3. Evaluate (and implement if robust) available technologies to support true system-level checkpoint restart for user applications.

Successful identification and implementation of technologies that would allow for system-level checkpointing would increase the overall usefulness of the high-performance computing systems at NOAA. While some technologies are evolving that could become useful soon (Berkeley Lab Checkpoint/Restart and other virtualization technologies), none currently meet the necessary criteria for adoption for production computing, namely stability, minimal impact on performance, and robustness.

Milestone 4. Complete feasibility study of extending existing Parallel HPC file systems in use on HPCS throughout ESRL's Global Systems Division (GSD) laboratory.

During FY10, other research groups within GSD Boulder, CO laboratories have been engaged. These groups are only starting to develop needs that would require such expansive data storage archives, based on research conducted by the HPC group. Regarding extending functionality of the HPC parallel filesystems out to the other groups, research and discussion with NOAA security has led to the conclusion that significant technological and security issues would prevent this type of usage at this time.

Milestone 5. Research methods and approaches to implementing distributed HPC file systems in high-latency environments.

This research goal was aligned with Milestone 4, to extend the feasibility of existing parallel filesystems to HPC throughout the GSD laboratory. Given technical challenges and time constraints, research into this topic was not initiated.

Milestone 6. Investigate tools to automate the use of GPU co-processors within existing ESRL Global Systems Division GSD codes.

Investigation into the usefulness of GPUs and their suitability to numerical weather prediction continues. In collaboration with the Aviation Branch of GSD, a perfor-

mance increase of more than 33 times has been demonstrated with the use of GPUs and in-house GPU compilers that convert existing Fortran code into code suitable for the GPU. These results exceed those of commercial tools that are now becoming available.

AMOS-03 Prediction, Model Development, and Evaluation

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

CSD-02 Chemical Transport Model Research

FEDERAL LEAD: MICHAEL TRAINER, NOAA RESEARCH
CIRES LEAD: STUART MCKEEN

NOAA Goal 3: Weather and Water

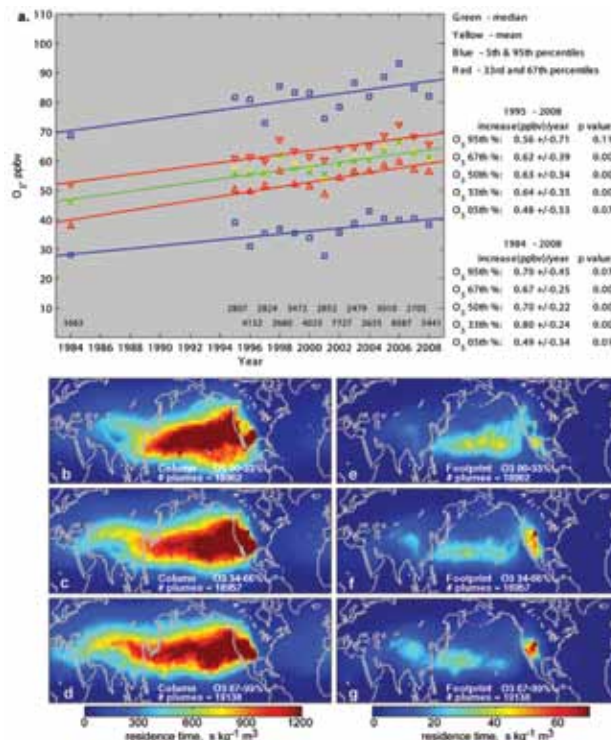
Project Goal: Undertake research that contributes to the ability to forecast regional air quality and improves the understanding of the budget of ozone in the upper troposphere.

Milestone 1. Use the Weather Research and Forecasting with chemistry (WRF-Chem) regional chemical transport model to conduct a detailed study of the California ozone budget throughout the troposphere for March through September 2006. This research will study: 1) the impact of stratospheric intrusions on the mixing ratios of ozone in the mid- and lower troposphere over California during spring and summer, 2) the contribution of lightning nitrogen oxides (NO_x) emissions to free tropospheric ozone production above the southern United States with episodic impact above California during summer, and 3) the photochemical formation of ozone in the lower troposphere due to the photochemical processing of local anthropogenic and biogenic emissions over California.

While exploring the feasibility of this analysis, a fascinating discovery was made, and the focus of the study was shifted to understanding ozone trends above western North America. East Asia has the world's fastest growing ozone precursor emissions, but despite evidence that exported Asian ozone pollution reaches North America, no previous study had found a significant increase in free tropospheric ozone concentrations above the western United States. To explore this apparent contradiction, springtime ozone measurements from many different platforms across western North America were compiled. Springtime ozone mixing ratios during 1995-2008 increased strongly, it was found, and there was some additional evidence that a similar rate of increase in ozone has occurred since 1984. The rate of

increase in ozone is greatest when measurements are more heavily influenced by direct transport from Asia. This result agrees with previous modeling studies, which indicate that global ozone should be increasing due to increasing precursor emissions, especially above western North America, which is sensitive to rising Asian emissions. The observed increase in springtime background ozone concentrations may hinder U.S. compliance with its ozone air quality standard. These results were published in the journal *Nature*.

Product: Cooper et al. 2010



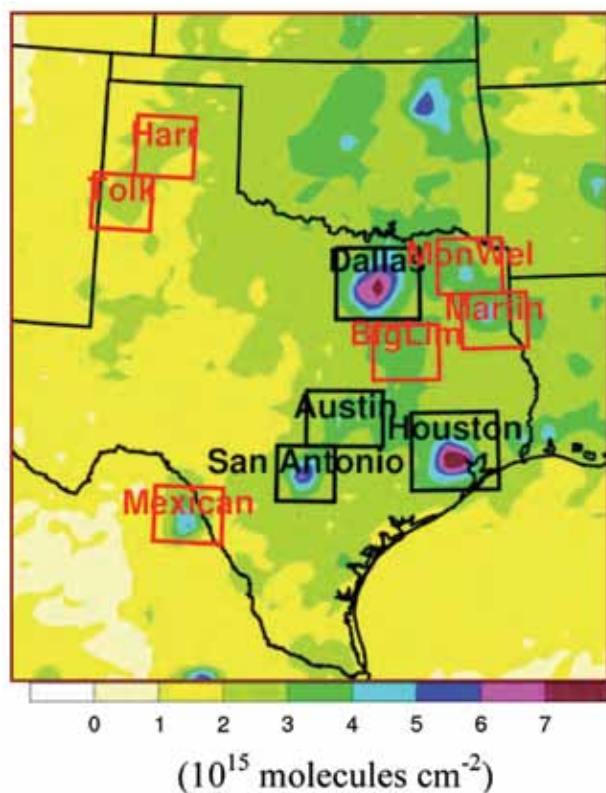
a) Ozone distributions for all data points in the troposphere ($PV < 1.5$ PVU) between 3,000-8,000 m, with sample sizes for each year indicated above the x-axis. Also shown are the ozone rate of increase per year and the p-value of the least squares line fit through the data for 1984-2008 and 1995-2008. Below are the column residence times of the FLEXPART retrorplumes averaged over the 1984-2008 period and associated with ozone values in b) the 0-33rd percentile range, c) the 34th-66th percentile range, and d) the 67th-99th percentile range. Panels e, f, and g correspond to panels b, c, and d, respectively, and show the retrorplume residence times in the footprint layer.

Milestone 2. Examine the feasibility of using satellite-retrieved tropospheric nitrogen dioxide (NO₂) vertical columns in combination with predictions from a regional chemical transport model to evaluate the emission strength of nitrogen oxides (NO_x) from a variety of Texas sources. These comparisons can constrain inventories of important NO_x sources and indicate how their emissions are changing with time. A particular focus will be on NO₂ columns near isolated point sources in East Texas and the urban areas of Dallas and Houston.

Satellite data and atmospheric chemical-transport models were used to see how well the emissions of nitrogen oxides (NO_x) are understood, and to evaluate how NO_x emissions are changing over time. NO_x is a key precursor of ozone pollution. NO₂, the largest component of NO_x, can be detected in the atmosphere using instrumentation on a number of satellites currently orbiting the Earth. The total amount of NO₂ in a column extending from the Earth's surface to the top of the troposphere can be

retrieved from these satellite measurements and can also be simulated by models. Comparisons of NO₂ columns measured by satellites and calculated by models provide an evaluation of NO_x inventories. A critical input to predictive models of the atmosphere, these inventories are the product of a complex amalgam of measurements, estimation methods, and assumptions, so they require independent assessment of their accuracy.

In this study, the spatial distributions and temporal trends in NO_x emissions from polluted areas in Texas were investigated. Texas has a number of areas that regularly violate Federal air quality standards. Observations of tropospheric NO₂ columns retrieved from satellite-based instruments (Ozone Monitoring Instrument [OMI] and Scanning Imaging Absorption Spectrometer for Atmospheric CHartography [SCIAMACHY]) routinely detect strong NO_x plumes from urban, industrial, and power plant sources in Texas (figure below). With the aid of the WRF-Chem, these satellite NO₂ column observations allowed evaluation of the latest bottom-up NO_x emission inventory prepared by the U.S. Environmental Protection Agency. The satellites also provide the opportunity to observe changes in NO_x emissions from 2003-2007, the period that these satellite data were available.



Ozone Monitoring Instrument (OMI) tropospheric NO₂ columns averaged for the period 26 July-6 October 2006. Black boxes represent regions where NO_x emissions are dominated by Texas cities, such as Dallas, Austin, San Antonio, and Houston. Red boxes indicate areas where Texas power plants are the main contributors to NO_x emissions, such as Monticello and Welsh, Martin Lake, Big Brown and Limestone, Harrington, and Tolk. The plume from a power plant located near Piedras Negras, Mexico can also be seen.

The model and satellite NO₂ columns agreed well for several large Texas power plants where NO_x emissions are simultaneously measured directly in the smokestack. The model and satellites were also in good agreement for

Texas cities such as Dallas, where NO_x emissions are dominated by mobile sources. However in Houston, which has large industrial NO_x sources in addition to motor vehicles, the model NO₂ columns were a factor of two higher than the satellite columns. There were relatively small changes from 2003-2007 in summertime satellite NO₂ columns over all areas in Texas with strong NO_x emissions, with differences between the various satellite datasets precluding further evaluation of NO_x trends.

These results suggest that NO_x emissions from Texas power plants and mobile sources are reasonably well understood. However, industrial NO_x emissions in the Houston area may not be well represented in current emission inventories. Within the limits of this analysis, significant changes in NO_x emissions from large Texas sources could not be identified between 2003 and 2007.

A journal article describing these results is currently in preparation.

Milestone 3. Use measurements of ozone, aerosols, and their precursors made during the 2006 Texas Air Quality Study (TexAQ5) and 2004 New England Air Quality Study (NEAQS) field missions in conjunction with a state-of-the-art air quality forecast model to relate uncertainties in particulate matter (PM2.5—pollutants with a diameter of 2.5 micrometers or less) aerosol forecasts to uncertainties in the parameterizations of key chemical and physical processes.

Because PM2.5 aerosol are a public health concern, NOAA and the 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 NWS. Several forecast and research centers are developing PM2.5 forecast capabilities, such as the WRF-Chem model within NOAA/ESRL. Observations from two previous intensive field campaigns, TexAQ5 and NEAQS, have been used to evaluate seven such PM2.5 forecast models. These model evaluations, along with surface network comparisons, have consistently shown that unlike ozone, forecasts of PM2.5 suffer from inaccuracies and biases that limit their usefulness to the public. As a consequence, the projected date for operational deployment of PM2.5 forecasts has been extended from 2011 to 2015.

This work focuses on understanding and quantifying the factors that contribute to the forecast models' inability to adequately predict PM2.5 levels over regional and continental scales. The TexAQ5 verification studies, in particular, addressed many of the processes known to be important factors in determining PM2.5 levels. These include 1) direct emissions of PM2.5 and emissions of PM2.5 precursors from the Houston and Dallas/Fort Worth urban centers, 2) the numerical treatment of vertical transport by boundary layer turbulence and convective transport, 3) the models' accuracy in reproducing the inorganic composition of PM2.5 aerosol, and 4) the formation of secondary organic aerosol (SOA) from anthropogenic and biogenic hydrocarbons. The results of these evaluations have been published in a special issue of the *Journal of Geophysical Research*.

Several modifications to the WRF-Chem model have been undertaken to address the deficiencies found in all models within the field study evaluations. Emission inventories have been updated and modifications to these updated inventories based on NOAA observations have also been produced. Various boundary-layer mixing schemes have been tested and evaluated against NOAA P3 aircraft and NOAA Twin Otter aircraft lidar data. A new state-of-the-art SOA formation mechanism based on the Carnegie-Mellon

volatility basis set approach has been incorporated into the WRF-Chem model. Improvements in the parameterization of PM_{2.5} deposition using recent field measurements have also been included. Though systematic testing and evaluation is still ongoing, this research will lead to recommendations that NWS and other forecast centers can use to improve the currently limited real-time PM_{2.5} forecasts.

Product: McKeen et al. 2009

PSD-16 Raindrop Size Distributions

FEDERAL LEAD: TIM SCHNEIDER, NOAA RESEARCH
CIRES LEAD: CHRISTOPHER WILLIAMS

NOAA Goal 3: Weather and Water

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

Milestone 1. Attenuation-based rainfall algorithms used by high-frequency radars, including the W-band radar on the CloudSat satellite, assume the rainfall is uniform in height. Deviations from this assumed uniform structure will be quantified using rain rate and median raindrop diameter estimates from an X-band polarimetric scanning radar and S-band vertical pointing profilers deployed in support of NOAA-Hydrometeorological Testbed-West.

The vertical profiles of non-attenuated radar reflectivity were studied in tropical stratiform rain events. For these rain events, the typical standard deviations of reflectivity in a vertical profile ranged between 1 and 2 dBZ. Also, the vertical variability of reflectivity did not deviate significantly from a constant mean profile. The vertical variability of non-attenuated radar reflectivities were used to estimate rainfall retrieval uncertainties, assuming that these same profiles were observed with high-frequency cloud radars that measure attenuated radar reflectivities.

Product: Matrosov 2010.

PSD-17 Environmental Monitoring and Prediction

THIS PROJECT IS INACTIVE

GSD-01 Numerical Weather Prediction

FEDERAL LEAD: JOHN BROWN, NOAA RESEARCH
CIRES LEAD: GEORG GRELL

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. Pending evaluation by the National Centers for Environmental Prediction (NCEP) on the readiness of the Rapid Refresh (RR) for real-time operational status, initiate operational implementation of RR.

Work has progressed steadily toward implementing RR at NCEP, but delays in acceptance of NCEP's new IBM Power 6 and an increasing backlog of other operational implementations by NCEP Central Operations has pushed back the date of RR implementation until early in 2011.

This delay has given a little more breathing room for RR

Weather Research Forecast (WRF) model testing (e.g., an upgrade to the WRF V3.2 released in April), and for adding enhancements to the Gridpoint Statistical Interpolation (GSI) analysis needed for optimal performance of the RR.

With the diagnosis and fixing of a few important bugs, there has been considerable improvement in RR performance during FY10. Verification of the RR over the continental United States since December 2009, using conventional statistical measures, has been at least as good as the backup Rapid Update Cycle (RUC) running at ESRL and the operational RUC running at NCEP. Work toward transferring RR code and setting up an hourly RR cycle on the development machine at NCEP is now mostly complete. Barring further delays in NCEP's scheduling of new implementations, there should be no barriers to smooth implementation of the RR into operations early next year.

An esteemed and much beloved colleague, Dezso Devenyi, passed away on 26 November 2009. Dezso was the CIRES supervisor to many in ESRL's Global Systems Division and was a recognized international expert in data assimilation. He is much missed, both as a good friend and for his deep knowledge of data assimilation.

Milestone 2. Conduct and evaluate a summer 2009 convection forecast exercise with other Aviation Weather Research Program Research Teams (Convective Weather, in particular), in which the High-Resolution Rapid Refresh (HRRR) plays a dominant role. The goal of this exercise is to evaluate the potential effectiveness of the HRRR in correctly predicting high-impact aviation weather, particularly convection, 3-10 hours in advance.

Much effort has gone toward the HRRR, sponsored by the Federal Aviation Administration (FAA) as part of a project called Consolidated Storm Prediction for Aviation (CoSPA) in collaboration with the Research Applications Laboratory of the National Center for Atmospheric Research (NCAR), and Lincoln Laboratories of Bedford, MA. Hourly and 15-min HRRR storm-resolving Weather Research Forecast (WRF) model forecasts are provided to NCAR, which blends extrapolation procedures for existing convection with the HRRR forecast to produce a 1-10-h forecast of convection that is based mainly on extrapolation of existing convection for the first 3-4-h blending toward dominance of the HRRR forecast for later periods. The forecast is then packaged, monitored, and distributed to the FAA command center by Lincoln Laboratories.

The principal motivation for this work is to improve forecasts of convection over the continental United States (CONUS) to reduce summertime weather-caused commercial flight delays, particularly at major hubs such as Chicago O'Hare International Airport. The CoSPA forecasts are being used for both strategic (planning for weather problems several hours in advance) and tactical aspects of airspace management.

The HRRR domain was expanded in the spring of 2009 to encompass approximately the eastern two-thirds of CONUS. Twelve-hour forecasts using 3.1-km horizontal grid spacing and 50 computational layers over this domain were made every hour on ESRL's supercomputer, and output distributed to a variety of users. The HRRR is initialized from the Rapid Update Cycle (RUC), using the RUC cloud-hydrometeor initialization procedure, which uses the diabatic Digital Filter Initialization (DFI) to produce a divergent horizontal wind field that has some measure of balance with latent heating as inferred from

the three-dimensional radar reflectivity field. Unfortunately, after the 2009 CoSPA demonstration was over, a serious omission was discovered in a script tied to the radar initialization—the radar-inferred temperature tendency field applied during the forward part of the DFI was being initialized to zero. In spite of this, the 2009 demonstration was considered a success (the diabatic DFI RUC initial conditions contained sufficient information for the forecast to be surprisingly accurate in spite of the bug).

With the success of the 2009 demonstration, the FAA provided more resources for an expanded 2010 demonstration covering the whole CONUS on a 1100 X 1680 horizontal grid at 3.0 km. These resources also allowed these full CONUS-domain hourly HRRR forecasts to be run out three additional hours, to 15 h. Figure 1 shows the domains used for the HRRR, and Figure 2 shows an example of a HRRR forecast from 2010.

Current RR/RUC/HRRR Model Domains

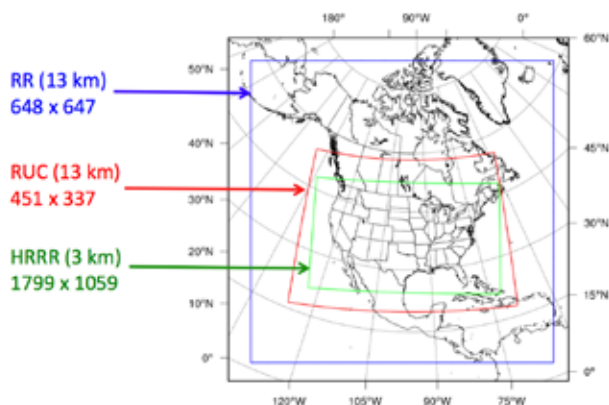


Figure 1: Domains used in the High-Resolution Rapid Refresh and other forecast models.

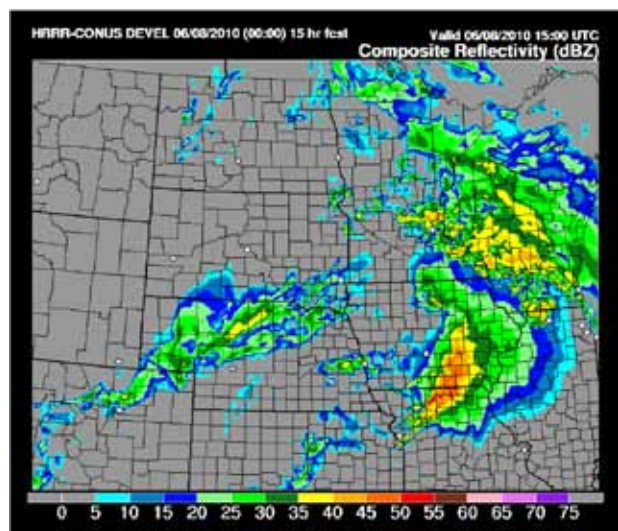


Figure 2: Example of a High-Resolution Rapid Refresh forecast from 8 June 2010.

Milestone 3. Port Flow-following, finite-volume Icosahedral Model (FIM) code, embedded within the Earth System Modeling Framework (ESMF), to the National Centers for Environmental Prediction's (NCEP), and begin pre-implementation testing of FIM as a member of the Global Ensemble Forecast System (GEFS).

Work continued toward rendering the FIM compat-

ible with the NCEP version of the ESMF. During the late spring of 2010, test runs under ESMF were performed at NCEP and compared with runs of identical initial conditions made at ESRL's Global Systems Division. These comparisons verified that the port of the model was successful. NCEP itself is still in the process of developing other aspects of ESMF for NCEP's GEFS—postprocessing, for example—that must be in place before the FIM can become operational as a contributor to the GEFS, so further work is delayed until later in 2010 or early 2011.

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

FEDERAL LEAD: JENNIFER MAHONEY, NOAA RESEARCH
CIRES LEAD: MICHAEL KAY

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. Provide quality assessment reports summarizing version 4 of the Graphical Turbulence Guidance, the Consolidated Storm Prediction for Aviation (CoSpa, the National Ceiling and Visibility Forecast), and the volcanic ash plume forecast products.

Evaluations of the quality of aviation forecast products of convection, turbulence, and ceiling and visibility were completed. The results from evaluations were used by high-level decision makers to determine whether the forecast products were ready for transition to operational platforms at the National Weather Service.

Milestone 2. Demonstrate a Network-Enabled Verification Service (NEVS) prototype for evaluating convective and turbulence forecast quality utilizing Open Geospatial Consortium standards for accessing and distributing quality assessment information in real time. Demonstrate NEVS capabilities for the Developmental Testbed Center.

A NEVS working prototype was completed and demonstrated for high-level Federal Aviation Administration managers. The prototype demonstrated the use of cutting-edge quality assessment concepts that are used to assess forecasts in the context of aviation user decisions, real-time processing of data using automated notifications, and web-based access to the statistical results and displays.

GSD-05 Numerical Prediction Developmental Testbed Center

FEDERAL LEAD: STEVEN KOCH, NOAA RESEARCH
CIRES LEAD: SHAOWU BAO

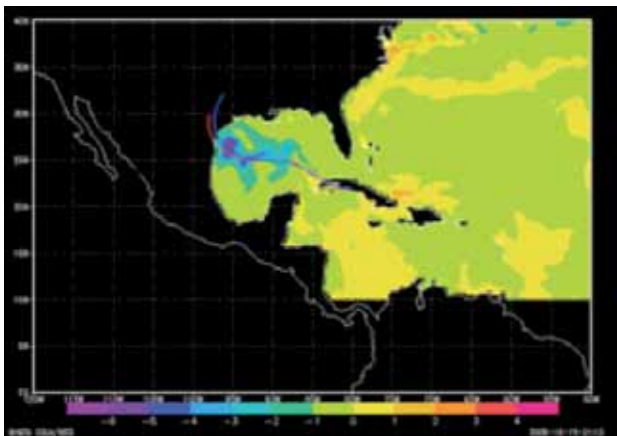
NOAA Goal 3: Weather and Water

Project Goal: Develop and maintain a version of the Hurricane Weather Research and Forecasting (HWRF) modeling system that is to be supplied to the weather research modeling community through the Developmental Testbed Center (DTC).

Milestone 1. Port the ocean and wave modeling components to the HWRF system and verify that results are satisfactory relative to those obtained on the National Centers for Environmental Prediction (NCEP) computer system.

The operational HWRF currently does not have a wave component, although that is planned for future implementation. The ocean component of the operational HWRF model, the Princeton Ocean Model for Tropical Cyclones (POM-TC), was ported and tested in coupled and uncoupled modes on the computer platforms available to the DTC (IBM and Linux). The results are comparable to those obtained in the NCEP computer system. The figure below illustrates the difference in simulated sea-surface temperature (SST) before and after the storm (day 5 minus day 1) for a HWRF simulation conducted by the DTC. The SST reduction reaches a maximum of 6°C. The forecast tracks from the operational HWRF run at NCEP (blue) and the community model run at the DTC (red) are shown. Note that the SST change occurred mostly along and to the right of the cyclone track.

Products: Bernardet et al. 2010 and Bao et al. 2010.



Forecast tracks from the operational HWRF run at the National Centers for Environmental Prediction (blue) and the community model run at the DTC (red).

Milestone 2. Work collaboratively with NOAA's Atlantic Oceanographic and Meteorological Laboratory (AOML) in Miami, FL to include an adaptive movable grid-nesting algorithm capability in the HWRF system.

A collaboration in the code management of HWRF between NOAA's ESRL, AOML, and the NCEP has led to the addition of the movable third nest algorithm developed by AOML to the WRF v3.2 public release code. This development is currently under review by NCEP and, upon successful results, the code will be added to the WRF community code to be available in the next public release. Having the AOML movable third nest algorithm available in the community code is a important step towards getting it tested and, if performance results support it, implemented operationally.

Milestone 3. Complete the documentation describing the atmospheric-only component to the HWRF system.

A Community HWRF *Users' Guide* and HWRF *Scientific Documentation* have been published. The *Users' Guide* was primarily (75 percent) written by ESRL staff, including those from CIRES. The scientific documentation was edited by ESRL (including CIRES), with contributions from authors in four different institutions (University of Rhode Island and NOAA's National Centers for Environmental Prediction, Geophysical Fluid Dynamics Laboratory, and Atlantic Oceanographic and Meteorological Laboratory). These documents are disseminated through the WRF for

Hurricanes website (<http://www.dtcenter.org/HurrWRF/users/>), are available to all Community HWRF registered users, and were distributed during the February 2010 WRF for Hurricanes tutorial. Both the *Users' Guide* and the *Scientific Documentation* cover all aspects of HWRF: the atmospheric model, atmospheric initialization, ocean model, ocean initialization, coupler, and postprocessing.

Products: Bao et al. 2010 and Gopalakrishnan et al. 2010.

Milestone 4. Deliver the first HWRF tutorial to the community as part of the biannual DTC/National Center for Atmospheric Research WRF model tutorials.

The first WRF for Hurricanes tutorial was organized jointly by ESRL, the National Centers for Environmental Prediction, and NCAR, taking place in Boulder, CO in February 2010. The three-day tutorial was sold out to 40 participants from a variety of backgrounds (academia, government, private sector) and countries of origin. The tutorial offered both lectures and hands-on practical sessions. A survey sent out after the tutorial indicated the students thought the tutorial was well delivered and very helpful for their work.

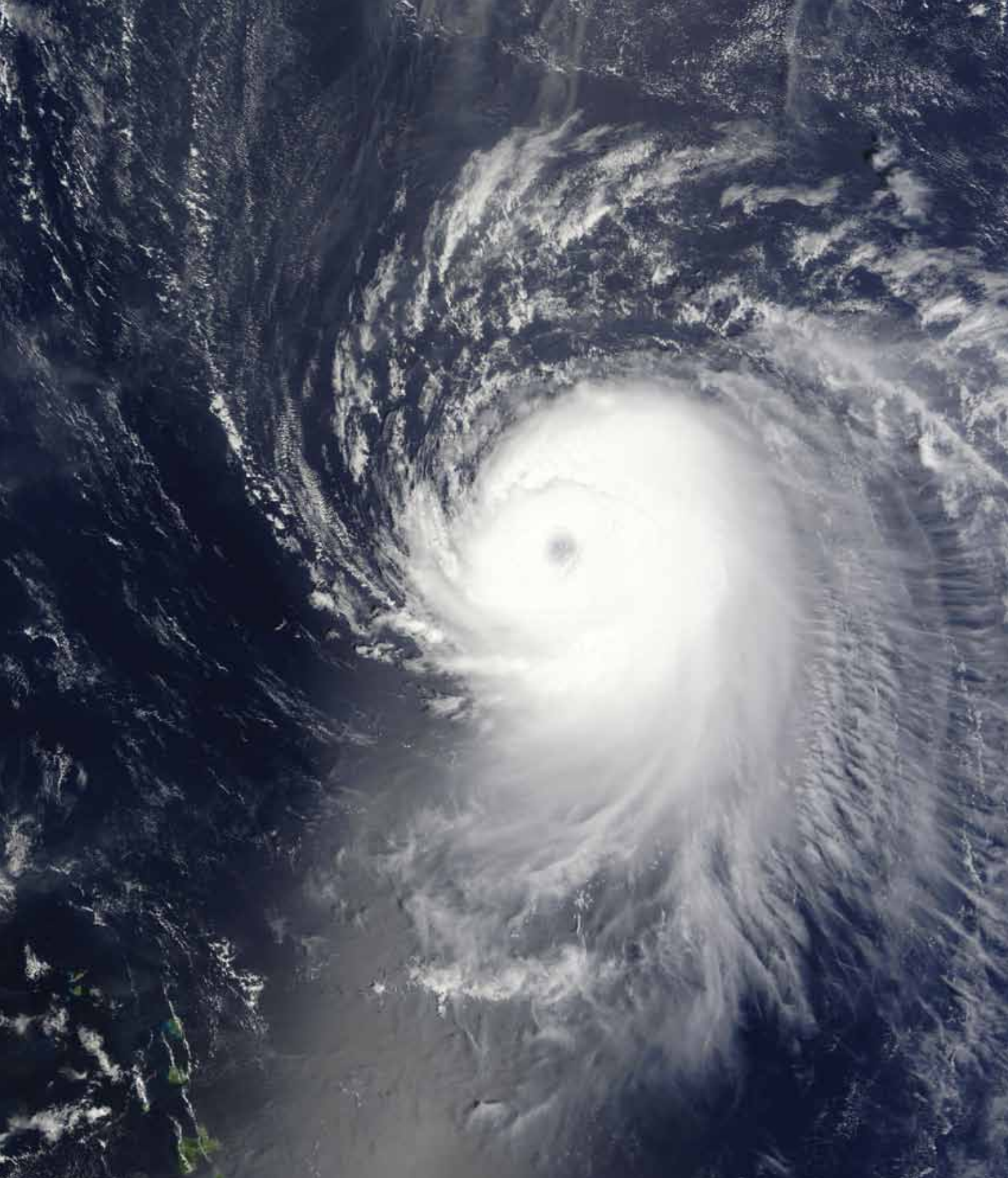
Milestone 5. Develop first draft of the documentation describing the atmospheric, ocean, and wave coupled models components of the HWRF system.

A Community HWRF *Users' Guide* and HWRF *Scientific Documentation* have been published, as indicated in Milestone 3 above. These documents are disseminated at <http://www.dtcenter.org/HurrWRF/users/>, and cover all aspects of HWRF: the atmospheric model, atmospheric initialization, ocean model, ocean initialization, coupler, and postprocessing.

Products: Bao et al. 2010 and Gopalakrishnan et al. 2010.



The HWRF website disseminates the documents of the *Users' Guide* and HWRF *Scientific Documentation*.



Hurricane Ike off the Lesser Antilles.

NASA

NGDC-03 Space Weather

FEDERAL LEAD: ERIC KIHN, NOAA SWPC
CIRES LEAD: JUSTIN MABIE

NOAA Goals 3 and 4: Weather and Water and 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. Run 10 years of physically-driven modeling using the Simulation of the Inner Magnetosphere Model (SIMM) and new data-assimilative version of the code to produce the first long-term archive of this domain.

Ten years of model runs for the SIMM model have been completed and archived. Output from SIMM is available to customers through NGDC data services and archived in the NGDC tape library system.

Milestone 2. Using data generated by southwest Australia (SWA) climate modeling, generate a state-of-the-space-environment report. This will detail changes in Earth's magnetosphere over the solar cycle.

SWA climate model runs for the three primary models (SIMM; the Assimilative Mapping of Ionospheric Electrodynamics; and the Global Ionosphere Thermosphere Model) have been completed for an entire solar cycle. This product was delivered to customers at the U.S. Air Force Combat Climatology Center for generation of a state-of-the-space-environment report. SWA climate models are available to customers through NGDC data services and archived in the NGDC tape library system.

Milestone 3. Generate physical parameters from ionospheric satellites (Defence Meteorological Satellites Program, POES) to be made available to the community through a standard interface. This will allow for much better utilization of a long-term climate archive.

Development of a routine to process POES data is complete. This routine extracts parameters and displays them in a geographic coordinate overlay that emphasizes the spacecraft track. This routine is served through the Space Physics Interactive Data Resource (SPIDR). Space Sensor J4 (SSJ4) data are available online through the NGDC SPIDR virtual observatory or through NGDC data services.

SWPC-01 Solar Disturbances in the Geospace Environment

FEDERAL LEAD: VIC PIZZO, NOAA SWPC
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 (CMEs) from the Sun, can cause substantial geomagnetic effects leading to the crippling of satellites, disruption of radio communications, and damage to electric power grids.

Milestone 1. GOES X-Ray instrument: Implement algorithms to optimize parametric fits to observed data from a sounding rocket solar X-ray spectrometer for new flights, and apply the

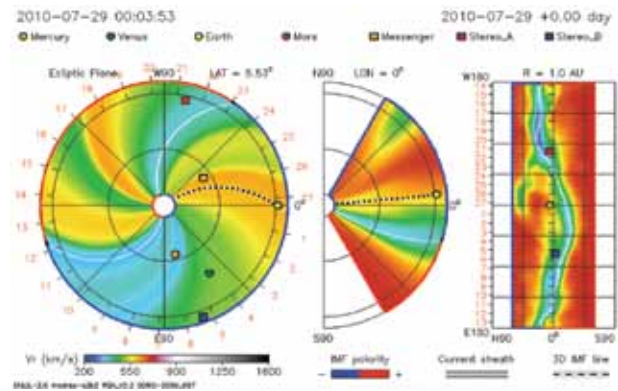
results to operational products and calibration routines.

This milestone is inactive.

Milestone 2. Global Solar Wind Predictions: Continue sophistication of an operational prediction tool based on the Wang-Sheeley-Argge (WSA) source surface model, and include evolving solar wind and tracing of magnetic field lines down to the solar photosphere.

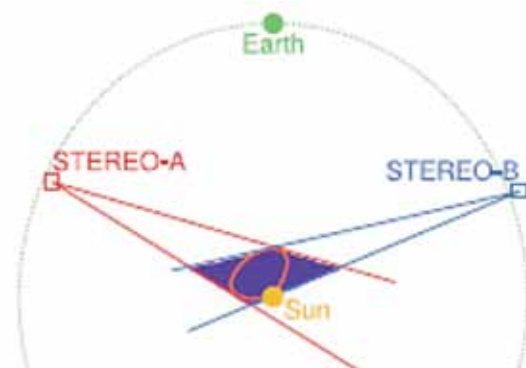
The WSA model has seen further improvements, to the point where it is ready to serve as the input to the WSA/Enlil model, now being transitioned into operations for space weather forecasting at the National Centers for Environmental Prediction. The WSA segment of the model supplies the basis for calculating the structured, ambient solar wind flow, through which coronal mass ejections must pass on their way to Earth.

The figure below illustrates the spiral flow pattern in the ecliptic plane out to the orbit of Earth, as produced from the near-Sun WSA inputs in the right panel. The left panel depicts a view from over the solar north pole, while the center panel shows a meridional cut at the longitude of Earth.



Milestone 3. Coronal Mass Ejection Locator: Finalize development and initiate verification and validation studies of the operational tool based on white-light corona observations from NASA Solar Terrestrial Relations Observatory (STEREO) spacecraft.

The idea is to determine the location, size, and direction of solar coronal mass ejections (CMEs) by taking advantage of the two views of the corona provided by STEREO. One of the two identical spacecraft (A, below) is in an orbit slowly drifting ahead of Earth, the other B, behind. A form of geometric triangulation is used to infer the bulk properties of the CME and its motion near the Sun.



A software tool that enables these determinations to be semi-automated for use with an upcoming operational space weather model has been put together and is undergoing testing at SWPC. CME positions provided by the STEREO observations are an important input to the model, and early tests suggest they will improve its performance measurably.

Milestone 4. Extreme Ultraviolet Imaging Telescope (EIT) waves and dimmings: Investigate possible relationships between CME properties and dimmings observed by EIT and validate with spacecraft observations.

This milestone is inactive.

SWPC-02 Modeling the Upper Atmosphere

FEDERAL LEAD: MICHAEL CRUMLY, NOAA SWPC
CIRES LEAD: TIMOTHY FULLER-ROWELL

NOAA Goal 3: Weather and Water

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

Milestone 1. Develop the algorithms to provide the ionospheric correctors for GPS dual frequency receivers over the continental United States (CONUS). Provide rapid centimeter or decimeter accuracy positioning from a GPS data file—receiver-independent exchange (RINEX)—requires estimates of the line-of-sight total electron content between the receiver and all GPS satellites in view. These ionospheric correctors will be obtained from the U.S. Total Electron Content (US-TEC) operation product, or a higher accuracy post-processing application, and will be provided to the National Geodetic Survey.

US-TEC is a NOAA operational product designed to predict the total electron content over CONUS. The procedure uses data from a network of ground-based, dual-frequency, Global Navigation Satellite System (GNSS) receivers and combines the information with an empirical ionospheric model using a Gauss-Markov Kalman filter. The product provides an estimate of the line-of-sight electron content from any point over the CONUS to any of the GPS satellite constellation in view.

The algorithms for a new product have been developed to provide GNSS ionospheric positioning correctors (GIPC) for precise positioning, real-time kinematic, and other navigation users. The standard format for a GNSS receiver is a RINEX file. For a given RINEX file from a specific location, GIPC ingests the ambiguous, but precise, estimates of the electron content from the phase information and levels these TEC phase estimates to the accurate information from US-TEC. The algorithms will be transitioned to the National Geodetic Survey for real-time applications.

AMOS-04 Observing Facilities, Campaigns, and Networks

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

GMD-02 Surface Radiation Network

FEDERAL LEAD: JOSEPH MICHALSKY, NOAA RESEARCH
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.

Milestone 1. Using the surface radiation (SURFRAD) irradiance database, look for long-term changes in the total horizontal irradiance (referred to as global dimming or brightening) and relate this, if applicable, to the concomitant aerosol changes from the Multi-Filter Rotating Shadowband Radiometer aerosol optical depth measurements. Publish the results.

It was found that shortwave irradiance has increased over the United States by 8 W/m^2 per decade since 1996. This is three times the corresponding widespread $2\text{-}3 \text{ W/m}^2$ longwave increase reported from Global Energy Balance Archive (GEBA) records spanning 1986-2000. The idea that the observed shortwave brightening over the United States is predominantly caused by direct aerosol effects was found to be false; the primary driver of the observed brightening is changes in cloudiness.

Product: Long et al. 2009.

PSD-10 Cloud and Aerosol Processes

FEDERAL LEAD: TANEIL UTTAL, NOAA RESEARCH
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. Begin analysis of data from Variability of the American Monsoon Systems (VAMOS) Ocean-Cloud-Atmosphere-Land Study (VOCALS) research cruises in October/November 2008, key surface marine boundary layer parameters, low cloud macrophysical, microphysical, and radiative properties.

Data collected from the VOCALS campaign has been processed to produce hourly and sub-hourly covariance, inertial-dissipation, and bulk turbulent estimates of the fluxes of heat and momentum. This is the initial step for the construction of the synthesis dataset wherein all observations from the experiment are compiled into an interpre-

table format. All data have been archived under ftp://ftp.etl.noaa.gov/et6/cruises/VOCALS_2008/RHB/flux/Processed/Post-processed_flux_files_1Jul09/. In addition to the turbulent fluxes, the data include five meteorological radars, a doppler lidar, microwave radiometers, a cloud imaging probe, a ceilometer, and radiosonde profiles.

Milestone 2: Submit paper on flux/cloud comparisons of African Monsoon Multidisciplinary Analysis cruise data and NOAA model.

Not completed due to termination of funding.

Milestone 3. Participate in African Monsoon Multidisciplinary Analysis research cruises in May 2010; deploy cloud radar, radiometer, and flux systems to measure key surface marine boundary layer parameters, low cloud macrophysical, microphysical, and radiative properties.

Not completed due to termination of funding.

Milestone 4. In an international collaboration, continue analyzing and modeling the Arctic Summer Cloud Ocean Study (ASCOS) dataset over the Arctic pack ice, focusing on links between low-level clouds, boundary layer structure/processes, surface energy budget, and cloud aerosols.

Significant collaborative and individual work has been carried out during the past year towards this milestone, with several manuscripts having been submitted or in preparation. The lack of aerosols near the North Pole creates an environment in which the addition of aerosols increases the longwave cloud forcing effect. The aerosol thereby act as warming agents, an effect opposite to that observed at lower latitudes. This behavior is demonstrated by the ASCOS dataset; a manuscript describing this phenomenon has been submitted to *Atmospheric and Chemistry Physics Journal* (Mauritsen et al. 2010).

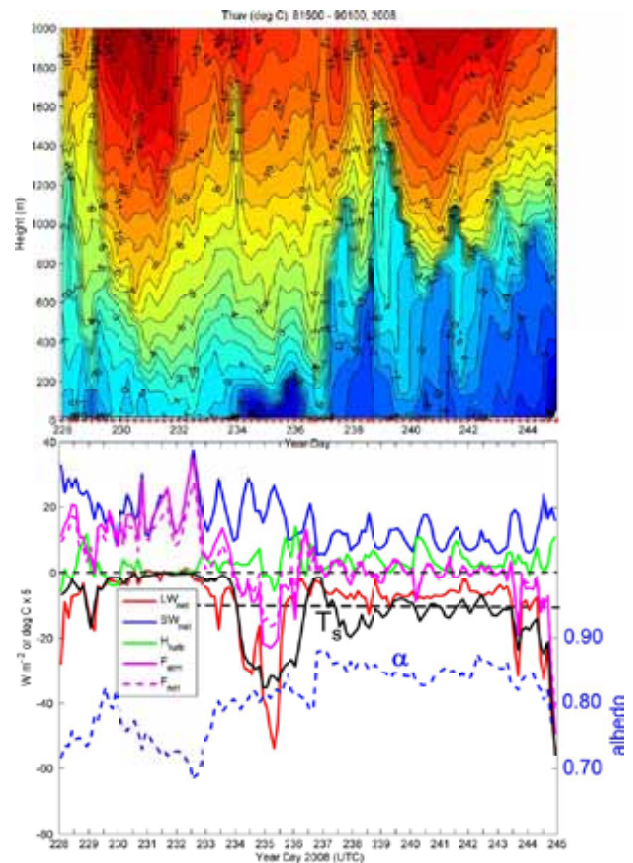
A study of the link between the surface energy budget (SEB) and the cloud characteristics has: shown the evolution of the major SEB terms during ASCOS, quantified the shortwave attenuation increase as a function of increasing cloud liquid water path, and quantified the shortwave forcing decrease as a function of the solar zenith angle increase. These are described in a submitted journal article (Sedlar et al. 2010). Recent work of comparing the ASCOS data with the boundary layer and SEB structure in the United Kingdom Unified Model has produced a manuscript soon ready for submission (Birch et al. 2010).

Additional work has combined data from the wind profiler, sodar, scanning radiometer, cloud radar system, and soundings to obtain high-temporal-resolution time-height series of the Richardson number through the entire three-week field program. Data are being studied to better understand how the stability and mixing near cloud top interacts with the boundary layer to transport heat, momentum, moisture, and possibly aerosols between cloud top and the surface of the ice pack. It appears as if the mixing may occur in short episodes of a few hours and then only between a few levels in the boundary layer. However, over a longer time period, the mixing appears to be able to transport air, moisture, etc., to and from the surface, and from and to the cloud top. This process may be very important for the net cooling of the entire boundary layer during this time of year, as radiative cooling occurs at cloud top, which destabilizes the cloud layer, mixing the cooler air downwards to just below cloud base.

At later times, this cooler air near cloud base gets incorporated into an eddy mixing from the surface, thereby completing the transport.

The high-temporal-resolution temperature profiles show a relatively steady temperature decrease throughout the boundary layer during this time once the diurnal cycle is removed. The figure below shows the well-mixed boundary layer in the lowest 700-1,400 m and its variation during the time after the end of the melt season when the whole lower troposphere is cooling (YD236-245).

Products: Birch et al. 2010, Mauritsen et al. 2010.



Top, time-height section of virtual potential temperature (Θ^v) in the lowest 2 km from 15 August to 1 September 2008, near 8°N. Bottom, time series of key surface energy budget terms measured on the sea ice during the same time period. Albedo is given by the dashed blue line with the scale to the right. The surface temperature is multiplied by 5 and uses the scale to the left. The net surface energy flux (dashed magenta) is near 0 W/m^2 after 23 August (YD236), and T_s is approximately $-2^{\circ}C$ during this time. Stratocumulous clouds are located along the top of the boundary layer near the strong vertical Θ^v gradient (not shown).

Milestone 5. Using data from Arctic Mechanisms of Interaction between Surface and Atmosphere (AMISA), continue the analysis of the spatial thermodynamic, kinematic, and cloud structure over the pack ice in the vicinity of the research vessel Oden deployed during ASCOS.

A NOAA technical memo describing the AMISA intensive observation periods has been published (Persson 2010). Primarily through efforts by a colleague at the University of Leeds, the microphysical data from the NASA DC-8 aircraft is now in much better shape, with better calibration of cloud-liquid water and particle size distributions. Plans have been made to use analyses from Persson (2010) and the improved

microphysical data to augment analyses from the research vessel *Oden* Arctic Summer Cloud Ocean Study (ASCOS) data in case studies, by providing spatial information on the boundary-layer, cloud, and surface characteristics.

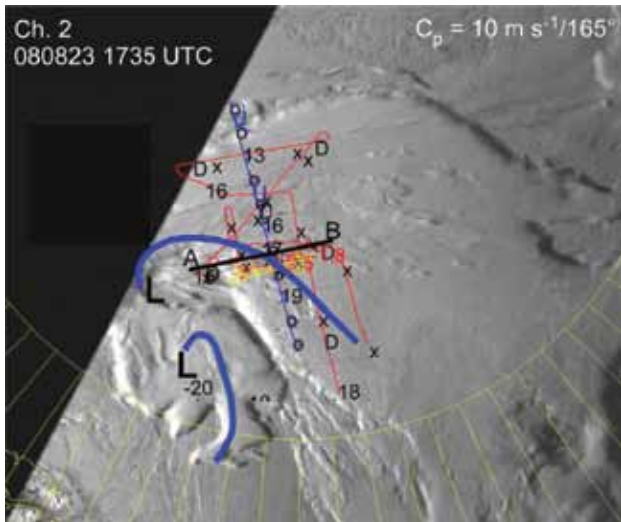


Figure 1: Visible satellite image at 1735 UTC 23 August 2008 with the DC-8 flight track overlaid (red). A time-space adjustment was applied using a phase velocity of 10 m/s from 165°. The time-space adjusted Oden track is shown (thin blue), and preliminary frontal analyses at about 0.7 km altitude are also shown (heavy blue). The heavy black line A-B denotes the location of the vertical cross sections shown in Figure 4.5.5 of Persson (2010).

Two cases have been identified for this purpose and some work has begun. The first case is 23 August 2008, (Figure 1) the day a storm passed over the site and ended the summer melt season, as seen by the analysis of the ASCOS surface energy budgets. Aircraft dropsondes will provide the spatial data necessary to determine the forcing of the clouds and precipitation on that day, and will add valuable validation and boundary-layer and aerosol data to that collected by sensors on the *Oden* (Figure 2, below). Another important case study will be 25 August 2008, which consisted of primarily

stratocumulus clouds with little or no precipitation, but with transitions in the boundary-layer structure and vertical mixing. The aircraft data will again be used to help understand the dynamical forcing of these stratocumulus clouds, the forcing of the changes in the boundary layer, and their links to the microphysical structure.

Product: Persson 2010.

Milestone 6. Produce cloud macrophysical and microphysical datasets for Arctic Atmospheric Observatories.

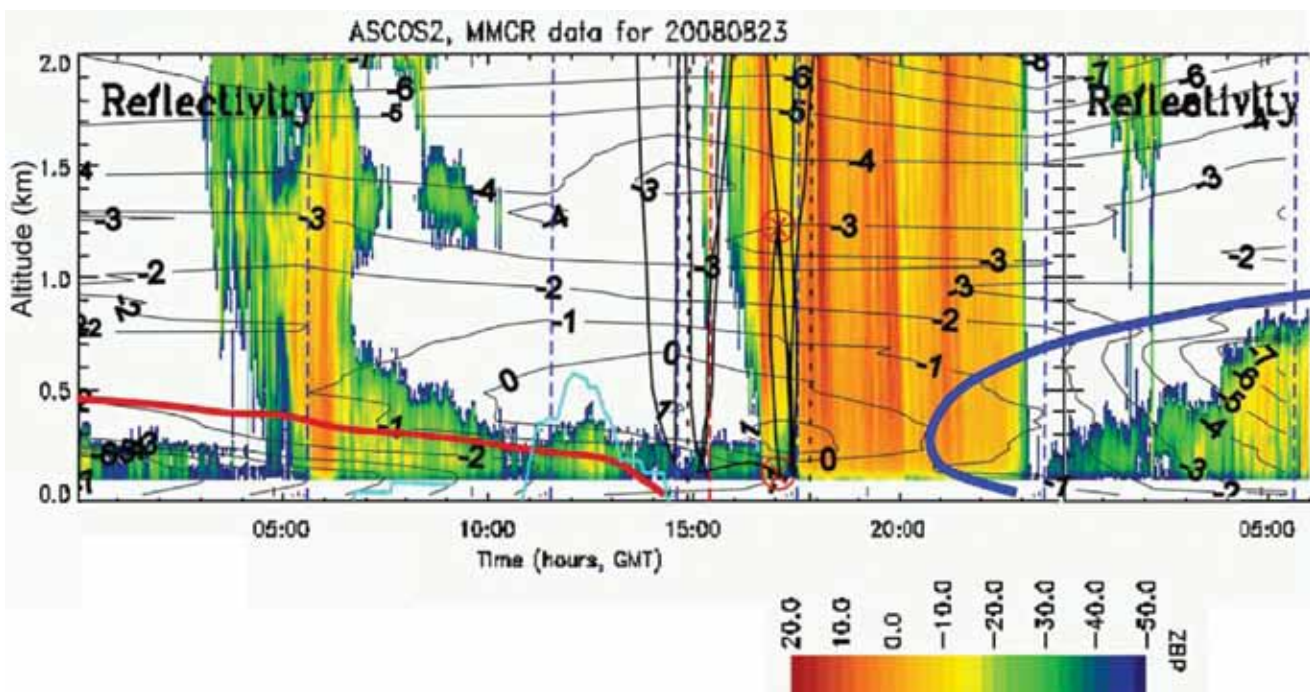
Important datasets summarizing the macrophysical and microphysical properties of clouds have been produced using observations made at a number of Arctic atmospheric observatories located across the Arctic Basin.

These observatories include Barrow and Atkasuk (Alaska), Eureka (Canada), Ny Ålesund (Norway), Summit (Greenland), and the Surface Heat Budget of the Arctic (SHEBA) ice station.

The macrophysical properties include cloud occurrence fraction, occurrence as a function of height, and boundaries. A comparison of the simple cloud occurrence fraction in the vertical column (figure opposite page) shows that clouds occur frequently in the Arctic and that there is generally a trend towards increased cloudiness in the late summer and fall. All sites exhibit a similar annual trend except for Eureka, Canada, which has fewer clouds in the spring and early summer than other Arctic locations.

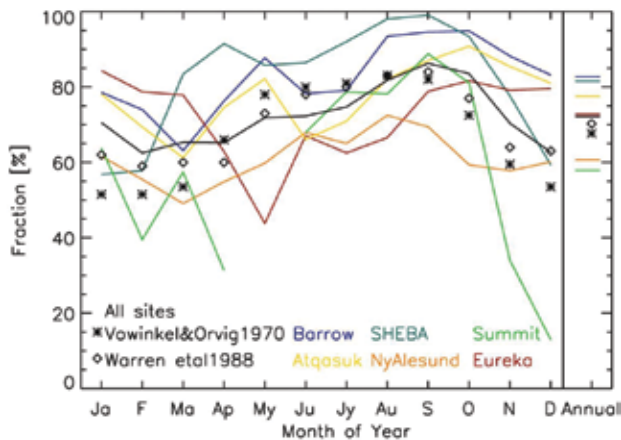
Results on Arctic cloud macrophysical properties have been summarized in a journal article now in review at the *Journal of Applied Meteorology and Climatology*. Microphysical properties datasets have been produced for Barrow,

Figure 2: Time-height section of temperature (thin solid black line) from the soundings and the 60 GHz radiometer and Ka-band reflectivity (color) in the lowest 2 km along the Oden track in Figure 1. The warm front (red) and the low-level cold front (blue) are marked. Locations of the upsondes (blue dashed) and dropsondes (red dashed) are shown. Also shown are the locations of aircraft ascent/descents (thicker black solid) and two horizontal aircraft legs (circled X) performed perpendicular to the cross-section. Tethersonde tracks are shown in cyan.



Eureka, and SHEBA, and include cloud thermodynamic phase, condensed mass content, and hydrometeor size for both solid and liquid phase hydrometeors. A manuscript summarizing Arctic cloud phase is also in review at the *Journal of Applied Meteorology and Climatology*. Most of these datasets have been made available to the scientific public in free archives.

Products: Shupe et al. 2010, Shupe 2010.



Cloud occurrence fraction in the vertical column for sites around the Arctic indicate a trend toward increased cloudiness in late summer and fall (except for in Eureka, Canada, which has fewer clouds in the spring and early summer).

Milestone 7. Submit paper discussing seasonal variation of back trajectories.

A system has been developed to produce atmospheric back trajectories and has been applied to multiple Arctic atmospheric observatories. A paper summarizing the trajectory results has not yet been prepared.

GSD-04 Unmanned Aircraft Systems

FEDERAL LEAD: SARA SUMMERS, NOAA RESEARCH
 CIRES LEAD: ELIZABETH WEATHERHEAD

NOAA Goals 1 and 3: Ecosystems and Weather and Water

Project Goal: Test and evaluate a variety of unmanned aircraft systems to collect scientifically valuable environmental data. The tests will be carried out in a variety of situations in support of multiple scientific goals. Results of funded unmanned aircraft projects will be provided in written reports that can be shared within NOAA and the general scientific community.

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

More than 27,000 images were collected in May of 2009 with the Scan Eagle UAS aboard the NOAA vessel *MacArthur II*. The images have now been examined for ice characteristics including fractional ice cover, largest ice pieces, and edge-to-area characteristics. One program has been developed to automatically identify and characterize the ice; an additional program has been developed to identify potential images of seals. More than 120 images of seals have been identified through these automated methods. The analysis shows that UAS can be used successfully to identify ice characteristics and seals in Arctic conditions. This accomplishment is significant because

NOAA is now able to carry out its mission to monitor seal populations without needing to rely on other agencies for helicopter-capable ships and without putting pilots at unnecessary risk. The capabilities of UAS to collect scientifically useful results will allow more extensive monitoring of the vast Arctic, while not exposing pilots to areas where search and rescue operations are limited or impossible. The development of programs to automatically analyze images will allow for future missions to be more efficient in producing results, while supplying consistent and cost-effective analyses. Initial results were discussed at an UAS meeting in Seattle, WA in September 2009. Scientific results were presented at the American Geophysical Union (AGU) 2009 fall meeting, and discussed at the AGU Arctic UAS Roundtable Annual Meeting. The results were presented to the public at a press conference organized by CIRES. A phone interview with a CIRES researcher was presented on National Public Radio and the work was reported on in *Scientific American*. Continued work focuses on the relationship between seal populations and ice characteristics. Further work could use these results to improve forecasts of sea ice on the hourly to seasonal basis.

Product: Weatherhead and Angliss 2009.



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, NOAA RESEARCH
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 aircraft-based instruments. Assess data for long-term quality. Evaluate stability and interannual variability in the ground-based and aircraft-based datasets. Provide scientific community with information relevant to climate research and evaluate usefulness of data for validation of other independent measurements, including satellite observations.

Milestone 1: Investigate the impact of stray light in Dobson and Brewer instruments on the consistency of ozone retrievals from Umkehr measurements to improve these observations for trend analysis and satellite validation.

Stratospheric ozone depletion and its ongoing recovery are closely related to the 1987 Montreal Protocol and its amendments. The protocol helped governments understand the danger of the anthropogenic chemicals to the Earth's health and to negotiate a plan that would curb the production of ozone-depleting substances and monitor the amount of chemicals remaining in the atmosphere. Predictions of future ozone levels are based on estimates of the chemical's lifetime, the present amount of chemicals in the atmosphere, and future release rates. To monitor the health of the Earth's atmosphere and its ozone layer, various ozone measurement techniques are operated worldwide.

The Dobson ozone spectrophotometer (Dobson) is the primary ground-based instrument making measurements of total column ozone and ozone profiles from the ground. Internal stray light within the Dobson instrument limits the ability of the instrument to make accurate measurements at high total ozone amounts and high solar zenith angles (SZA). A similar problem exists in some Brewer spectrophotometers that have been progressively added to the World Meteorological Organization (WMO) network of ozone measurements. The effect is well-

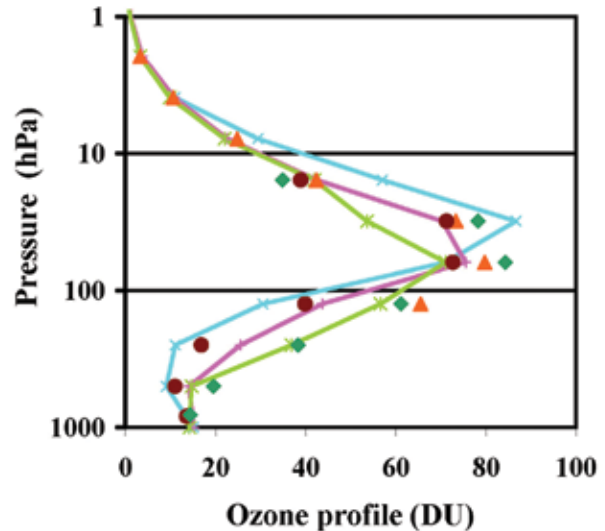
Opposite page: Photo analysis shows that unmanned aircraft systems can be used to identify ice characteristics and seals (circled) in Arctic conditions. NOAA could monitor seal populations without needing to rely on other agencies for helicopter-capable ships and without putting pilots at unnecessary risk.

NOAA

known and can be easily identified when observations are continuously made on the direct solar beam over a half day at a northern high-latitude site. It becomes particularly noticeable in springtime when the total column ozone is high. Total ozone values calculated from the observations show a sharp decrease after the SZA increases beyond a certain point. Additionally, a recent analysis of comparative Dobson observations of the Umkehr effect (zenith-sky radiation is used to derive ozone profiles) has shown that internal stray light produces incompatible results for compared instruments.

A method of measuring this internal stray light was developed by using a small modification to the instrument and an external filter. Stray light contribution to the Umkehr ozone retrievals was then assessed (Evans et al. 2009).

Ozone profiles are thus difficult to compare from station to station. Current investigations into the level and effects of stray light within the instrument suggest that much of the difference can be attributed to out-of-band stray-light characteristics of individual Dobson and Brewer instruments. Resulting changes in retrieved ozone profiles suggest that adjusting measurements for stray-light components removes much of the existing bias between Umkehr profiles and other ozone-measuring datasets. Results of additional research show that Mark IV instruments in the Brewer UV spectrophotometer series have a higher level of stray light than the Mark III instruments, and are similar in value to a stray-light contribution observed in Dobson Umkehr measurements. This new information has implications for both observational methods and completeness of existing datasets. (Petropavlovskikh et al. 2009).



The simulated stray-light effect is based on climatological ozone profiles for low, middle, and high latitudes (blue, magenta, and green lines, respectively) normalized to 360 Dobson Units (DU) total ozone column. Layer-integrated ozone amounts as measured by Aura Microwave Limb Sounder over Boulder station on 4 April 2008 (orange triangles), and by ozone sounding in Boulder on 4 April 2008 (red circles) and 9 April 2008 (green diamonds) are shown for comparison.

Milestone 2: Develop an ozone profile retrieval algorithm for use with automated Dobson and Brewer radiometric measurements. Implement an operational ozone profile processing and retrieval system that will provide expanded capability for detection and tracking of projected

stratospheric ozone recovery, and validation of satellite profile observations.

This work is done in collaboration with partners at NASA, NOAA's National Environmental Satellite, Data, and Information Service (NESDIS) and with the international community responsible for satellite ozone products such as those from the Solar Backscatter UV radiometer (SBUV), the Ozone Monitoring Instrument (OMI), the Microwave Limb Sounder (MLS), and the Ozone Mapping and Profile Suite (OMPS) instruments. Since there are similarities between ozone retrieval techniques from satellite and ground-based ultraviolet measurement systems, strong interaction among these measurement communities is required.

ESRL maintains a network of 15 Dobson ozone spectrophotometer (Dobson) stations, with six stations automated to provide vertical ozone profiles by using the Umkehr technique. There are an additional six Brewer stations under the NOAA-U.S. Environmental Protection Agency ultraviolet Brewer (NEUBrew) network, which make total ozone and Umkehr measurements, and eight ozonesonde stations. Ground-based ozone stations are included in the OMPS ozone profile and column validation plan set for the planned 2011 launch of the National Polar-orbiting Operational Environmental Satellite System (NPOESS) Proprietary Project (NPP) satellite. Their participation ensures timely availability of this data and good understanding of its quality. Additional data from the Network for the Detection of Atmospheric Composition Change and the World Ozone and Ultraviolet Radiation Data Centre will complement these measurements.

Improvements in the capabilities and calibration of these assets and development of programming tools to make comparisons of satellite and ground-based measurements are ongoing. Instrument improvements include rebuilding the Boulder Dobson. This instrument is now fully automated with improved visualization and quality control. A second automation system will be installed for the Mauna Loa Dobson in the summer of 2010. The NEUBrew system has improvements to the processing software and display capabilities (<http://www.esrl.noaa.gov/gmd/grad/neubrew>). In particular, updates allow improved computation of Langley calibration constants. Test comparisons of Umkehr data with Solar Backscatter Ultraviolet Radiometer (SBUV/2) overpass have been performed. The matchup and analysis tools will be re-used for similar comparisons between Umkehr data and the OMPS nadir profile ozone products.

The effects of clouds and tropospheric air quality on surface ultraviolet (UV) spectral irradiance measurements are under investigation. Ozone and UV data are obtained from the re-established U.S. Environmental Protection Agency UV Network (NEUBrew) at six locations across the United States: Bondville, IL; Fort Peck, MT; Raleigh, NC; Boulder, CO; Rocky Mountain Research Station, CO; and Houston, TX. ESRL/CIRES research answers two key questions: How do changes in surface UV levels due to tropospheric ozone compare with changes in surface UV levels due to particulate matter or other tropospheric pollutants? And how do clouds and other meteorological conditions affect surface UV levels and exposures?

Tropospheric ozone values are derived daily from the NEUBrew Umkehr vertical ozone profile dataset and published at <http://www.esrl.noaa.gov/gmd/grad/neubrew/ProductDisplays.jsp>. Morning and afternoon

time series are extracted from the corresponding vertical profiles. The tropospheric ozone values are plotted as a function of time. Validation of the Brewer-measured Umkehr ozone profiles in Boulder, CO is performed regularly against the co-located ozone sounding data.



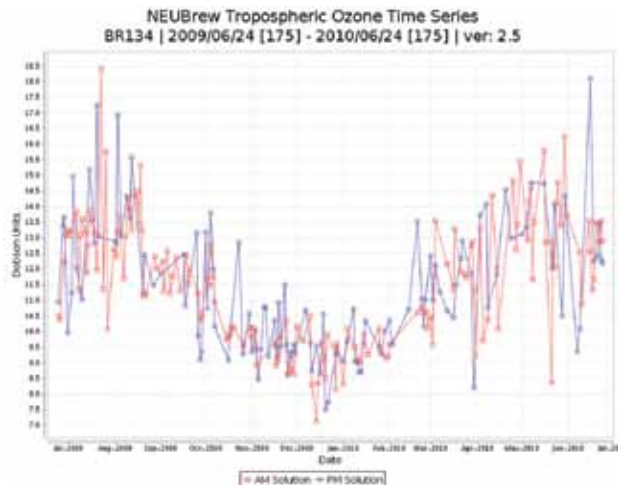
Glen McConville (CIRES) operates Dobson 083 on the roof of the David Skaggs Research Center in Boulder, CO during intercomparisons in 2009.

Milestone 3: Develop new products for Brewer NOAA network, such as tropospheric ozone and NO₂ column. Evaluate and characterize new products against well-established and co-located measurements. Provide data to Ozone Monitoring Instrument (OMI)/Aura satellite validation campaigns.

While ozonesondes provide more detailed information on ozone in the troposphere, they are not available in many places and are expensive to operate. Umkehr measurements are automated and less expensive. Therefore, the Umkehr is used to monitor tropospheric ozone variability in places where there are no balloon observations. Umkehr can retrieve free tropospheric ozone in single layer 1 (surface to about 250 mb). Variability in tropospheric ozone comes from hydrocarbons, vegetation, transport from the stratosphere, pollution, UV-sunlight-initiated chemistry, etc.

Tropospheric ozone is monitored because it is harmful to humans and the environment and because it is a greenhouse gas. It can be challenging to compare ozonesonde measurements and Umkehr ozone because ozone values are in different units and resolutions, and measurements are often done on different days. Therefore, comparisons were made at a maximum of one day apart. Data were also filtered using several factors: meteorological regimes, tropopause heights, troposphere thicknesses, and back trajectories. The same-day ozonesonde and Umkehr data in Boulder between 1978 and 2007 show a correlation of 52 percent, and the slope of the scatter plot is about 0.56. The correlation is as low as 34 percent when data are taken one day apart. The reason is high variability in the tropospheric ozone due to transport and local pollution sources. A CIRES/NOAA goal is to achieve at least the same level of correlation in Umkehr/sounding pairs taken one day apart. Following the method of Follette-Cook et al. (2007) and Hudson et al. (2003 and 2006), it was found that the

correlation can be improved from 17 to 36 percent when measurements are taken on different days, but are in the same meteorological regime (defined by the location of subtropical and polar jets). Results were presented as posters at the International Association of Meteorology and Atmospheric Sciences conference in July 2009 and at the American Meteorological Society meeting in January 2010.



Seasonal and daily variability in tropospheric ozone measured for one year at the Table Mountain NEUBrew facility near Boulder, CO.

Products: Petropavlovskikh et al. (2009), Kirchmier and Petropavlovskikh (2010).

PSD-04 Decadal Climate and Global Change Research

FEDERAL LEAD: RANDALL DOLE, NOAA RESEARCH
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 analyses and GCM experiments. Provide attribution for long-term regional climate changes.

Milestone 1: Investigate the relative contributions of El Niño-Southern Oscillation (ENSO)-related and ENSO-unrelated tropical sea-surface temperature (SST) variations on global climate changes over the last 130 years.

A paper was published addressing an important question in assessing 20th century climate change, namely: To what extent have ENSO-related variations contributed to the observed trends? Isolating such contributions is challenging for several reasons, including ambiguities arising from how ENSO itself is defined. In our study, 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-yr (1871-2006) Hadley Centre Global Sea Ice and Sea-Surface Temperature (HadISST) dataset. The analysis showed that previously identified multi-decadal variations in the Pacific, Indian, and Atlantic oceans all have substantial ENSO components. The long-term warming trends over these oceans were also found to have ap-

preciable 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 internally generated coherent multi-decadal variations. Two surprising aspects of these ENSO-unrelated variations were noted: 1) a strong cooling trend in the eastern equatorial Pacific Ocean, and 2) a nearly zonally symmetric multi-decadal tropical-extratropical seesaw that has amplified in recent decades. The latter has played a major role in modulating SSTs over the Indian Ocean.

Milestone 2: Continue assessing the importance of coupled air-sea interactions, decadal ocean dynamics, land-surface feedbacks, and land-use changes on decadal and longer-term atmospheric variability.

ENSO events are known to force atmospheric teleconnections that impact extratropical sea-surface temperatures and surface winds. In a recently published study, focused model experiments were used to investigate whether this extratropical variability can feedback to, and significantly impact, the tropics through ocean Rossby waves. An atmospheric GCM coupled to a reduced-gravity Pacific Ocean model is used to isolate these potential feedback loops and quantify their impact on ENSO variability. It was found that anomalous winds and heat fluxes located in regions of maximum mean subduction in the subtropical North Pacific trigger ocean Rossby waves that take approximately four years to reach the equator. Most notably, it was demonstrated that this feedback loop causes a primarily two-year ENSO, when only the tropics are coupled, to shift to a more realistic broad two- to five-year range by damping similar to two-year variability and amplifying similar to four-year variability.

Milestone 3: Diagnose impacts of subseasonal tropical and stratospheric variability on longer-term global climate variability and the mean climate.

Tropical weather and climate have major impacts on global weather and climate. Specifically, the quasi-periodic Madden-Julian Oscillation (MJO) with dominant power in the 30- to 70-day period band, and the El Niño-Southern Oscillation (ENSO) with dominant power in the two- to seven-yr period band, have been shown to exert important influences around the globe. Yet these phenomena continue to be poorly represented in state-of-the-art numerical weather and climate models. It is widely thought that the difficulty arises partly from an inadequate treatment of air-sea coupling in MJO dynamics, which not only causes errors in the MJO, but also leads, through a distorted MJO-ENSO connection, to errors in ENSO. To clarify the issue, a coupled linear inverse model (C-LIM) derived from observed fluctuation-dissipation relationships between the tropical atmospheric circulation and SST variables was used. It was first shown that the model successfully captures the time-lag covariance structure and power spectra of these variables. It was then shown that the eigenvectors of the system's dynamical evolution operator are cleanly separated into two distinct but nonorthogonal subspaces: one governing the nearly uncoupled MJO dynamics, and the other governing the strongly coupled ENSO dynamics. An important implication of such a clean separation of the uncoupled and coupled tropical dynamics is that erroneous air-sea coupling in GCMs may cause

substantial errors in ENSO simulations and predictions, but probably not in MJO simulations and predictions. In conclusion, the MJO-ENSO connection, often claimed to be important in ENSO dynamics, is largely illusory, in that the same initial perturbation that sets off an ENSO event also tends to set off an MJO event, but without any direct interaction between them.

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

FEDERAL LEAD: DAVE M. ANDERSON, NOAA NESDIS
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 both data and information from the paleoclimatic record.

Milestone 1: Create the first version of a database of raw data used in paleoclimate reconstructions of the last thousand years.

The first product of the Paleoclimate Network (PCN) was released, integrating 92 high-resolution temperature records derived from paleoclimate proxies, mostly tree rings, over the past two-plus millennia (<http://www.ncdc.noaa.gov/paleo/pubs/pcn/>). These records cover global, hemispheric, regional, and local scales, generally with annual resolution. All of the proxies were recalibrated to the same set of instrumental temperature data, a process that standardizes the way in which these proxies quantitatively extend the instrumental record backward in time and enables more robust descriptions of longer-term climate fluctuations. Metadata for these records include citations to original publications, season reconstructed, latitude/longitude, and links to the original archived data. Records are available in multiple formats, including netCDF, ASCII (text), and Excel spreadsheet. ASCII files provided for each individual record have fixed header and data formats, allowing computer-automated reading of the data for ease of processing. Overall, this collection of paleoclimate reconstructions puts into context the warming trend of the last century, showing that recent decades are the warmest of the last 1,000 years or more.

Product: Wahl et al. 2010.

Milestone 2: Continue to expand and enhance data search at NOAA Paleoclimatology website by harvesting XML records from other data centers and by adding advanced search capabilities.

Paleoclimate data distributed by the NOAA Paleoclimatology website were improved by expanding the data collection and improving the ability to search and retrieve data. Working with international partners in Bern (Past Global Changes Program) and Bremen (World Data Center for Marine Environmental Sciences), protocols were implemented for sharing and harvesting catalog information. Users seeking paleoclimate data from NOAA now access an expanded collection that includes resources from our partners in Bremen. During the second half of the year, the catalog sharing concept was extended to include smaller programs in the United States, including the fossil database developed by the U.S. Geological Survey in Denver (focused on the desert Southwest), and the diatom

database developed by the Academy of Natural Sciences in Philadelphia, PA. Searching and retrieving information from aggregated catalogs can be challenging, and in the second half of the year, the search capabilities were overhauled with the construction of new and powerful indexes and the implementation of Google-type online searches as well as more advanced fielded searches. The significance of these efforts are to bring Bizrate- or Nextag-like capabilities to environmental data, where information about items of interest can be aggregated (harvested) from many different sources, and where powerful search techniques can be used to parse the catalogs, find items of interest, and determine their suitability for scientific research.

CSV-02 Mechanism and Forcings of Climate Variability

- CSD-03 Chemistry, Radiative Forcing, and Climate
- PSD-01 Modeling of Seasonal to Interannual Variability
- PSD-02 Understanding and Predicting Subseasonal Variations and their Implications for Longer-Term Climate Variability
- GMD-04 Climate Forcing

CSD-03 Chemistry, Radiative Forcing, and Climate

FEDERAL LEAD: SUSAN SOLOMON, NOAA RESEARCH
CIRES LEAD: JOOST DE GOUW

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 that influence the radiative balance in the global atmosphere. Quantify the chemical and optical properties that determine the lifetimes, abundances, and trends of greenhouse gases. Use passive cloud observations to develop techniques that can be used to estimate cloud properties.

Milestone 1. Evaluate the evolution of the chemical composition of the lower atmosphere over the past 30-40 years, using both chemistry-transport and chemistry-climate models. Compare the results of the simulations with observations, perform sensitivity studies, and quantify the impact of anthropogenic processes on the evolution of the troposphere over the past few decades.

The evolution of the chemical composition of the lower atmosphere is driven by changes in the surface emissions of chemical species. It is therefore essential to assess how well we are currently able to quantify the surface emissions of key compounds and their distributions.

This study is the start of a systematic evaluation of the distribution of surface emissions of both gaseous and particulate compounds at the global and regional scales over the past three decades (1980-2010). As a first step, work has focused on the emissions of carbon monoxide (CO) and nitrogen oxides (NO_x), which are both primary pollutants and tropospheric ozone precursors; sulfur dioxide (SO₂), a precursor of sulfate aerosols; and black carbon, which plays an important role in air quality and radiative forcing.

In this evaluation of surface emissions, all global and regional publicly available inventories that provide anthropogenic and biomass burning emissions are being taken into account. During the past two years, NOAA CIRES staff have participated in the development of an inventory covering the 1850-2000 period, which is currently under open discussion in *Atmospheric Chemistry and Physics Discussions* (Lamarque et al. 2010). Figure 1 displays two examples of the results obtained. The top figure shows a comparison of anthropogenic CO emissions in the United States, including emissions from several global inventories and the regional emissions provided by the U.S. Environmental Protection Agency. The different inventories show very large differences, which can reach a factor of about two. The trends during the past three decades are also quite different, with some inventories showing a relatively low decrease, while others show a decrease of a factor of about three. The bottom figure shows the changes in SO₂ anthropogenic emissions in China since 1980. While all inventories show a large increase in the emissions, the rate of change depends strongly on the inventory. Depending on the inventory, the rate of increase is between two and four percent per year.

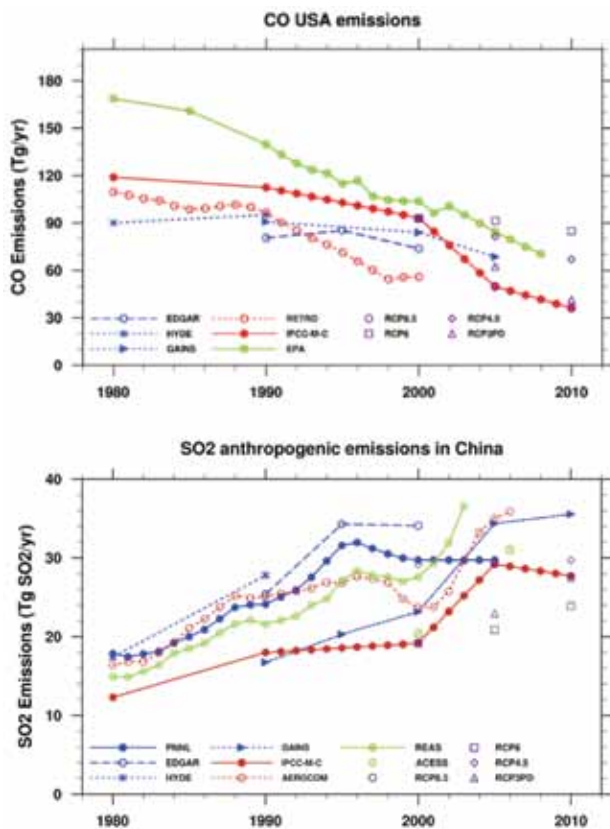


Figure 1: Top, carbon monoxide (CO) emissions in the United States, from emissions inventories noted. Bottom, Sulfur dioxide (SO₂) emissions in China since 1980.

These results show that there is still much work to accomplish to better define the surface emissions of atmospheric compounds and their changes with time. A paper discussing these results will be submitted for publication shortly (Granier et al. 2010).

CIRES researchers and colleagues have also started to use the different distributions of surface emissions considered in this work as boundary conditions in the global chemistry-transport model, Model for Ozone and

Related Chemical Tracers, version 4. The analysis of the results, which is under way, will allow quantification of the impact of the uncertainties of surface emissions on the evolution of the distributions of the gaseous and particulate compounds of the troposphere.

Products: Lamarque et al. (2010), and another paper in preparation.

Milestone 2. Evaluate the effect of aqueous organic chemistry on aerosols in the troposphere.

Organic compounds comprise a large fraction of aerosol mass in the free troposphere. Current organic aerosol models do not include all formation processes and underestimate organic aerosol mass by a large factor (about 10). In addition, models often underestimate the oxidation state of organic aerosol mass, which points to a poor understanding of the exact chemical formation pathways and mechanisms.

It has been shown that in the aqueous phase of particles, highly oxidized organics can be formed that do not have any other known sources in the atmospheric system. Water is ubiquitous in the atmosphere and is associated with cloud droplets but also, in smaller amounts, with atmospheric particles that exist at relative humidities less than 100 percent.

While it has been recognized for a decade that chemical reactions in cloud droplets can efficiently form organic mass, until recently it has been assumed that the aqueous volumes of aerosol particles (about 100 times smaller than cloud droplets) are too small to allow efficient mass formation.

However, many recent laboratory studies point to fundamental differences of chemical pathways in aqueous particles (that usually contain high salt concentrations) and more dilute cloud droplets. Additional chemical reactions favor the formation large molecules, due to the higher probability of recombination reactions of organic molecules in the small particle volume.

Based on laboratory studies, a kinetic framework has been developed that numerically describes such particle reactions. The new reaction parameters allow the implementation of chemical processes in aqueous particles into models to compare their efficiency to other processes (e.g., in cloud droplets) in terms of mass formation and modification of physical and chemical properties.

The first model studies suggest that 1) chemical reactions in aqueous particles might add a considerable amount of additional organic mass to particles, 2) particle phase chemistry can be as efficient as chemical processes in cloud droplets, and 3) the newly developed reaction module is the first model module that can explain the formation of light-absorbing, high-molecular-weight organic molecules that have been identified in atmospheric particles.

This work benefitted from the support of the CIRES Innovative Research Program (Secondary organic aerosol formation from glyoxal: Linking laboratory, field and model studies, 2009).

Product: Ervens and Volkamer 2010.

Milestone 3. Use satellite measurements, radiosondes, and global chemistry climate models to examine changes

in the width of the tropical upper troposphere and the height and temperature of the tropical tropopause in response to sea-surface temperature (SST) changes.

The tropical tropopause layer is an important region for climate and global change. CIRES researchers and colleagues have shown previously that changes in tropical tropopause temperature significantly impact the input of water vapor into the stratosphere (Rosenlof and Reid 2008), and that such changes appeared to be related to tropical SST changes, with increased SSTs correlated with increased upwelling at the tropical tropopause, decreased tropical tropopause temperatures, and decreased input of water vapor into the stratosphere. The changes in stratospheric water vapor as a result of tropical tropopause changes are significant; the observed change in stratospheric water vapor due to tropical tropopause temperature decreases was shown to have a significant impact on surface temperature trends (Solomon et al. 2009), with a decrease in lower stratospheric water vapor slowing the rate of decadal warming after 2000 by 25 percent (Figure 1). Changes in the latitudinal width of the tropics and in upwelling rates through the tropical tropopause due to greenhouse gas increases have been predicted with chemistry-climate models. Using a variety of metrics, CIRES scientists and colleagues have examined evidence for changes in the width of the tropics using observationally based estimates, and have found little change over the period 1979-2009 in the Northern Hemisphere, and a poleward expansion in the Southern Hemisphere. An example of trends from one metric, National Centers for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) tropopause height trends, is shown in Figure 2 (Davis and Rosenlof 2010). An increasing trend in altitude near the mean tropics edge indicates poleward expansion (Southern Hemisphere), and a decreasing trend indicates equatorward compaction (Northern Hemisphere).

Products: Solomon et al. 2010; Davis et al. 2010, An update and intercomparison of trends and variability in tropical edge diagnostics in meteorological reanalyses and satellite observations, in preparation.

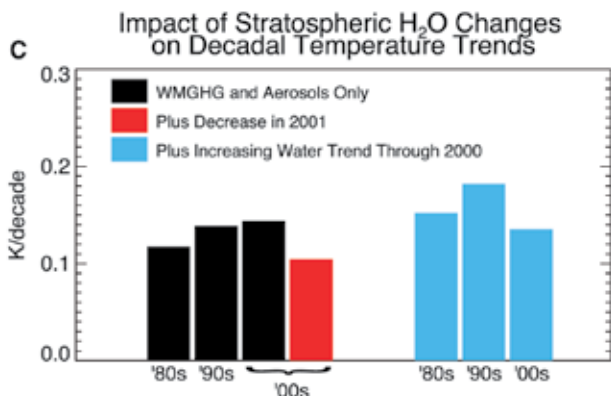


Figure 1: Decadal warming rates arising from the well-mixed greenhouse gases (WMGHG) and aerosols alone (black), and that obtained including the stratospheric water decline in 2001 (red) and including both the stratospheric water vapor decline in 2001 and the increase in the 1980s and 1990s through 2000 (blue).

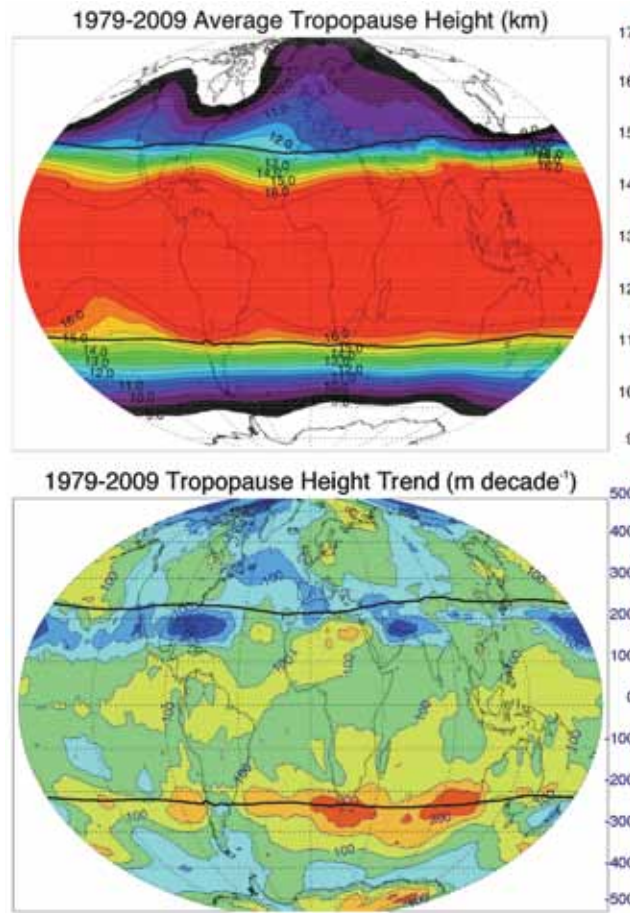


Figure 2: Top, 30-year average tropopause height from the NCEP/NCAR reanalysis. The 30-year average tropical edge in each hemisphere is shown by a heavy black line. Bottom, linear trends in the tropopause height, showing largely positive values in the Southern Hemisphere indicative of a tropical expansion, and near zero or negative values in the Northern Hemisphere, indicate of little change or a possible tropical contraction.

PSD-01 Modeling of Seasonal to Interannual Variability

FEDERAL LEAD: MARTIN HOERLING, NOAA RESEARCH
 CIRES LEAD: PRASHANT SARDESHMUKH

NOAA Goal 2: Climate

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

Milestone 1. Assess the legitimacy of atmospheric GCM simulations with prescribed sea-surface temperature (SST) boundary conditions to estimate atmospheric predictability associated with SST changes, through clean comparisons with corresponding coupled GCM integrations.

The usefulness of atmospheric GCM integrations with prescribed SSTs is frequently questioned in the context of climate diagnosis, climate model error diagnosis, and short-term climate predictions. To what extent do the re-

rors in surface heat fluxes, caused by decoupling air-sea interactions in this manner, affect climate variability and the mean climate? This issue was addressed by generating and comparing multi-century coupled GCM simulations with corresponding atmospheric GCM simulations with prescribed SSTs obtained from the coupled simulations. Overall, the results show that the errors introduced by prescribing SSTs in atmospheric GCMs are not negligible, but are generally much smaller than the atmospheric response to the SSTs themselves. This finding justifies performing and using such uncoupled integrations for diagnostic and prediction purposes. A journal article describing these results is in preparation.

Milestone 2. Continue 20th century reanalysis efforts in collaboration with the National Centers for Environmental Prediction, the National Center for Atmospheric Research, the National Climatic Data Center, the European Centre for Medium-Range Weather Forecasts, the University of East Anglia, Environment Canada, ETH Zurich, and the UK Hadley Centre.

Production of a global atmospheric circulation dataset was completed for 1891-2008, using only daily surface-pressure observations and an ensemble Kalman-filter-based data assimilation system, and making the dataset widely available through a web interface.

Production was started on version 2 of the global atmospheric circulation dataset, extending it back to 1871 using a longer and improved surface-pressure database and an improved model for assimilating those data. The improved model included better specifications of time-varying CO₂ and aerosol radiative forcings during the assimilation period. This effort will extend our ability to quantify climate variability over the historical record, provide uncertainty estimates for climate change detection, and aid attribution efforts to inform climate policy decisions.

Product: http://www.esrl.noaa.gov/psd/data/grided/data.20thC_Rean.html.

Milestone 3. Assess the importance of the global nonlinear impacts of central equatorial Pacific sea-surface temperature (SST) changes.

An ensemble of atmospheric GCM (AGCM) integrations with anomalous SST prescribed only in the Niño-4 area of the central tropical Pacific was found to capture all the major elements of the global response obtained in several multi-decadal AGCM integrations with prescribed observed global SST variations over the second half of the 20th century. This area lies at the western edge of the region of warmest anomalous SST during El Niño events, but accounts for most of the global anomalies associated with El Niño. The global response to SST changes in this area was also found to be significantly nonlinear in large ensembles of GCM integrations with prescribed positive and negative SST anomalies in the region. The response remained similar in pattern, but varied nonlinearly in amplitude as the anomalous SST was varied from a 5°C cooling to a 5°C warming. The precipitation response saturated for strong cooling (as expected), but varied remarkably linearly from the weak cooling to strong warming cases. The global circulation response, on the other hand, saturated for both strong cooling and strong warming, but at different amplitudes. The negative saturation was closely, but not exclusively, linked to the negative saturation

of the precipitation response. The positive saturation could not be so linked; it had a dynamical origin. This asymmetry of the circulation response was clearly evident in the Pacific North Atlantic, North Atlantic Oscillation, and Arctic Oscillation regions of strong regional climate variability.

The asymmetric saturation of the circulation response to warming and cooling of the central tropical Pacific has large implications for the global response to anthropogenic forcing. Because of it, one may expect the global climate to be affected not just by a mean SST change in this area, but also by a change in its variability associated with a change in ENSO dynamics.

Milestone 4. Assess the predictability of Northern American precipitation, associated with the ENSO-related and ENSO-unrelated components of anomalous SST fields, using a number of atmospheric general circulation models.

There is strong evidence that anomalous seasonal precipitation over North America is linked to anomalous tropical SSTs, however the degree to which that link is associated only with ENSO is less clear. The basic issue is whether ENSO-unrelated tropical SST changes, such as those associated with global warming, also have a large impact. To address this, one needs a way to separate tropical SST variations into ENSO-related and ENSO-unrelated contributions. It is challenging to isolate such contributions for several reasons, including ambiguities in the definition of ENSO itself. Defining ENSO with a single index and ENSO-related variations with regressions on that index (as is often done) can lead to inaccurate conclusions. In a recently published study, it was argued that ENSO is best viewed not as a number, but as an evolving dynamical process for this purpose. Specifically, ENSO was identified with the four dynamical eigenvectors of tropical SST evolution that are most important in the observed evolution of ENSO events. This definition was used to isolate the ENSO-related and ENSO-unrelated components of not just the tropical, but global SST variations on a month-by-month basis in the 136-yr (1871-2006) Hadley Centre Global Sea Ice and Sea-Surface Temperature (HadISST) dataset. This SST dataset is planned for use in the next phase of the project to isolate contributions of the ENSO-related and ENSO-unrelated parts of the SST variations to the observed variations of precipitation over North America over the last century.

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

FEDERAL LEAD: JEFFREY WHITAKER, NOAA RESEARCH
CIRES LEAD: PRASHANT SARDESHMUKH

NOAA Goals 2 and 3: Climate and Weather and Water

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

A paper was published investigating the effect of air-sea coupling on tropical climate variability in a coupled linear inverse model (LIM) derived from the simultaneous and one-week lag covariances of observed seven-day running mean departures from the annual cycle. The results showed that air-sea coupling has a very small effect on subseasonal atmospheric variability. It has much larger effects on longer-term variability, in both the atmosphere and ocean, including greatly increasing the amplitude of El Niño-Southern Oscillation (ENSO) and lengthening its dominant period from two to four years. Consistent with these results, the eigenvectors of the system's dynamical evolution operator also separate into two distinct sets: a set governing the nearly uncoupled subseasonal dynamics, and another governing the strongly coupled longer-term dynamics. One implication of this remarkably clean separation of the uncoupled and coupled dynamics is that general circulation model errors in anomalous tropical air-sea coupling may cause substantial errors on interannual and longer time scales, but probably not on the subseasonal scales associated with the Madden-Julian Oscillation.

Milestone 2. Continue investigating the variability and predictability of extratropical subseasonal variations in all seasons of the year using a linear empirical-dynamical model that includes air-sea coupled tropical and stratospheric influences. Assess the predictability from deterministic and probabilistic perspectives, particularly in regard to the case-by-case and regime-dependent variations of predictability.

Following up on previous published studies of subseasonal extratropical variability and predictability, the week-two and week-three forecast skill of two state-of-the-art global atmosphere-ocean coupled models developed at NOAA and NASA was compared with that of a simple linear inverse model (LIM) based on the observed lag-correlations of the Northern Hemispheric circulation and tropical convection fields. It was found that the comprehensive coupled models beat the LIM only slightly, and only if an ensemble-forecasting methodology was adopted. To assess the prospects for further skill improvement, a predictability analysis based on the relative magnitudes of the forecast signal and forecast noise was conducted. This analysis suggested that the coupled model forecast skill of the extratropical circulation may already be close to the potential skill, but that there is still room for improvement in the tropical circulation forecast skill. A manuscript describing these results is being prepared for submission to a refereed journal.

GMD-04 Climate Forcing

FEDERAL LEAD: DON NEFF, NOAA RESEARCH
CIRES LEAD: JOHN MILLER

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. Conduct an intensive field campaign to compare three instruments that measure aerosol hygroscopic growth.

This proposed field campaign received approval for funding from the Science Board of the U.S. Department of Energy Atmospheric Radiation Measurement program. Funds, however, were not received because the funding agency reallocated resources toward a sudden and large commitment to American Recovery and Reinvestment Act (ARRA) projects. The funding for ARRA projects was only for capital expenses and not personnel.

Milestone 2. Complete development of a field-operational temperature/humidity/GPS 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).

The development of the field-operational system has been completed. The equipment has been installed and is in use in the NOAA/ESRL Carbon America aircraft network. Relatively inexpensive off-the-shelf commercial sensors were used with custom, in-house electronics to satisfy the need for a robust, inexpensive system that would meet the accuracy and precision requirements of the network and that would interface efficiently with greenhouse gas sampling equipment already in use.

Milestone 3. Establish one new tall-tower site in the NOAA/ESRL Carbon America tall-tower network to aid in reducing the uncertainty of carbon uptake by the North American continent and to better characterize regional terrestrial carbon flux estimates.

One new tall-tower site was established. A tower was instrumented for continuous measurements of carbon dioxide and carbon monoxide as part of a partnership with the U.S. Department of Energy Office of Science to expand carbon cycle research at the Savannah River Site in South Carolina. The tower site is also instrumented with an automated flask sampling system that provides daily measurements of a suite of greenhouse gases, carbon isotopes, halocarbons, and other compounds. This site takes advantage of a pre-existing comprehensive meteorological network in the region that is operated by the Savannah River National Laboratory. This location samples the southeastern United States within a mixed-use agricultural, residential, and industrial zone.

Milestone 4. Implement assimilation of eddy covariance carbon flux measurements in the NOAA/ESRL ensemble Kalman filter carbon data assimilation system, CarbonTracker.

After careful investigation it was decided that direct assimilation of eddy covariance data within CarbonTracker was not the most effective way to use this type of data. Instead, eddy covariance data were used to help tune a model of the terrestrial biosphere, which was in turn used as a first-guess carbon flux within the CarbonTracker assimilation system. This method allowed for the information in the very local eddy covariance data signal to be extrapolated spatially via the biosphere model. North American and global carbon flux calculations using this approach are currently underway.

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, NOAA RESEARCH
CIRES LEAD: ERIC RAY

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's High-performance Instrumented Airborne Platform for Environmental Research (HIAPER) Gulfstream V aircraft to examine transport and photochemical processes in the upper troposphere and lower stratosphere.

Ozone data have been obtained in a number of HIAPER flights. As a first step in interpreting the dataset, comparisons with ozone profile retrievals from leading satellite instruments have been made in the extratropical upper troposphere and lower stratosphere. The satellite instruments capture ozone spatial gradients very well and show reasonable agreement with ozone variability above 200 ppb ozone. Below that value, the satellite instruments reveal significant positive biases. These results provide important guidance on using global datasets from aircraft and orbital platforms in constraining transport and photochemical processes in global models.

GMD-05 Ozone Depletion

FEDERAL LEAD: JAMES ELKINS, NOAA RESEARCH
CIRES LEAD: FRED MOORE

NOAA Goal 2: Climate

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

Milestone 1. The Ozone-Depleting Gas Index will be updated and refined as needed, with continued measurements of ozone-depleting gases.

Measurements of long-lived substances that cause stratospheric ozone depletion were continued at remote sites

during July 2009 through June 2010. These measurement data are used to update the Ozone-Depleting Gas Index (Figure 1). These measurement data were also included in the 2010 World Meteorological Organization *Scientific Assessment of Ozone Depletion*. 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.

Related to this, the abundance of HFC-23, a trace gas produced inadvertently during HCFC-22 production, was studied (Miller et al. 2010). HCFC-22 is a prominent temporary replacement for the main ozone-depleting substances. Results suggest that global efforts to minimize the emission of this long-lived and potent greenhouse gas have been somewhat successful.

Product: World Meteorological Organization Global Ozone Research and Monitoring Project: *Scientific Assessment of Ozone Depletion* (2010), in press.

Miller et al. 2010.

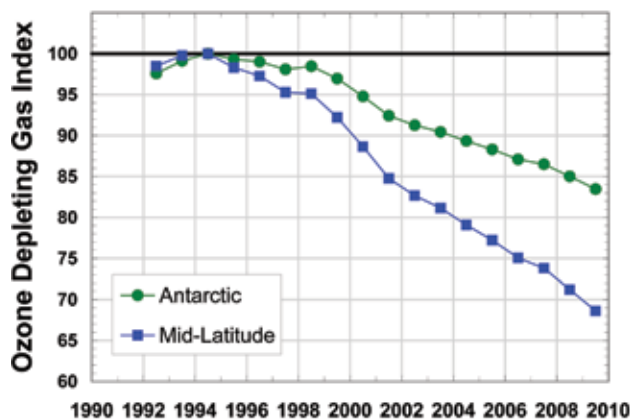


Figure 1: The Ozone Depleting Gas Index (ODGI) represents the tropospheric abundance of ozone-depleting gases. The ODGI index is explained at <http://www.esrl.noaa.gov/gmd/odgi/>.

Milestone 2. Utilize medium- and high-altitude aircraft and stratospheric balloon platforms to validate tropospheric and stratospheric measurements of ozone-depleting gases (N₂O, CFC-11, CFC-12) by spaceborne instrumentation aboard the Aura satellite.

The NASA Global Hawk unmanned aircraft system (UAS) is a new platform for conducting research at stratospheric altitudes up to almost 20 km (65,000 ft). The Global Hawk Pacific Experiment (GloPac) conducted in March-May 2010 was the first Earth science mission of the aircraft. One of the main goals of this experiment was to conduct validation of the Aura satellite sensors. Global Hawk, with 11 atmospheric sensors onboard, flew uninterrupted for up to 28.5 hours, covering 17,965 km (9,700 nautical miles). The aircraft conducted vertical profiles during takeoffs and landings and during dives from 18.2 km to 13 km (60,000 to 43,000 ft). In addition to overpasses for satellite validation, highlights of GloPac included sampling a fragment of highly aged polar vortex air at midlatitudes, a long-duration flight to near the North Pole, and extensive data over the remote Pacific Ocean.

CIRES and NOAA scientists had two ozone instruments on GloPac, and a two-channel gas chromatograph, which monitored atmospheric ozone, nitrous oxide, methane, hydrogen, and sulfur hexafluoride during five flights. A CIRES Fellow was the co-mission scientist for GloPac. CIRES and NOAA scientists also contributed to flight planning. The GloPac flights are the first aircraft flights since 2000 (Stratospheric Aerosol and Gas Experiment-III [SAGE] Ozone Loss and Validation Experiment, on an ER-2 aircraft) to conduct in situ vertical profiling over 13 km (60,000 ft) of ozone-depleting gases. Similar in situ measurements were last made with a balloon platform in 2004. Data from these high-altitude platforms have helped scientists understand transport in the stratosphere during the past three decades (Ray et al. 2010).

Product: Ray et al. 2010.



NASA

NASA Global Hawk over the Edwards Dry Lake in California.

Milestone 3. Utilize the NSF/NCAR High-performance Instrumented Airborne Platform for Environmental Research (HIAPER) aircraft to measure the latitudinal, longitudinal, and vertical distributions of ozone-depleting gases above a large region of the Pacific Ocean during different seasons.

The jointly funded NSF and NOAA HIAPER Pole-to-Pole Observations of Greenhouse Gases (HIPPO) mission was continued with two new series of flights for HIPPO-2 in October-November 2009 and for HIPPO-3 in March-April of 2010. There will be a total of five series of flights conducted in different seasons and each series includes more than 120 vertical profiles of the troposphere. The flights begin at Rocky Mountain Metropolitan Airport in Broomfield, CO, and proceeded as far north as possible towards the North Pole, head south towards Antarctica, and back to Colorado. These flights will improve our understanding of transport, including inter-hemispheric isolation/exchange; boundary-layer trapping; free troposphere mixing; and bulk transport of polluted air, many greenhouse gases, and black carbon aerosols. Data analysis is in full stride and the richness of the dataset is shown in Figure 1, opposite.

CFC-11 cross sections illustrate stratospheric loss; dichloromethane shows large Northern Hemispheric sources and interhemispheric transport south; dimethyl sulfide and methyl nitrate highlight oceanic sources; carbonyl sulfide

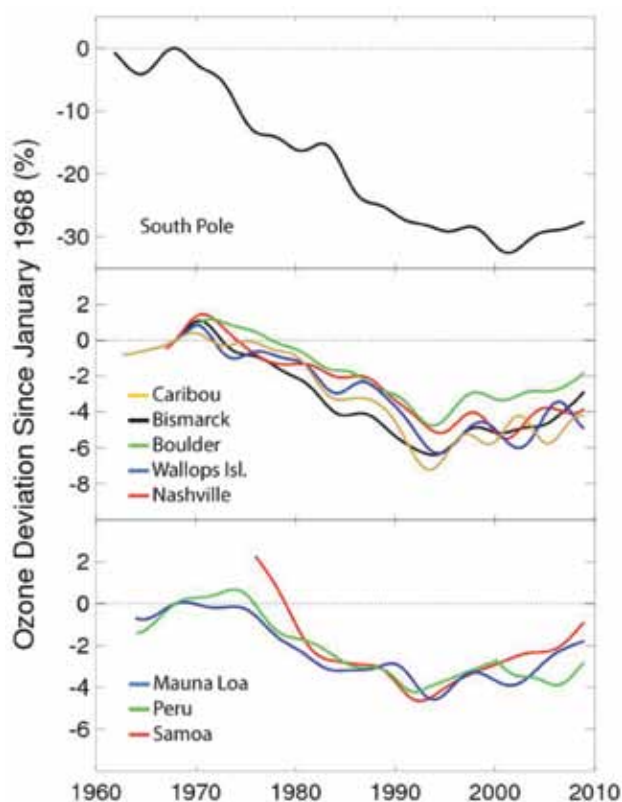
has strong oceanic sources and sinks over land vegetation; and methyl chloride illustrates the importance of convective transport in the tropics.

These HIPPO datasets will provide needed tests of atmospheric transport models and will help to quantify large-scale ozone-depleting gas sources and sinks.

Milestone 4. The longer-term ozonesonde record (more than 20 years) at South Pole will be used to look for signs of springtime stratospheric ozone recovery by testing various indicators of ozone profile changes in regions that are most sensitive to chemical ozone loss.

Column ozone data to 2009 from the U.S. Cooperative Dobson Network have been analyzed using a trend model that uses several variables to account for auto-correlation in the time series (see figure below).

Product: Input to the 2010 *Scientific Assessment of Ozone Depletion*.



Smooth trend curves of monthly ozone values from selected Dobson stations (South Pole, continental United States, and the tropics) to 2009. Changes represented by the growth rate determined from these curves are a measure of the rate of change of stratospheric ozone and thus represent various aspects of ozone layer decline and recovery.

Milestone 5: The longer-term ozonesonde record (more than 20 years) at South Pole will be used to look for signs of springtime stratospheric ozone recovery by testing various indicators of ozone profile changes in regions that are most sensitive to chemical ozone loss.

Owing to variations in meteorology and stability of the polar vortex, year-to-year variations in the severity of the ozone hole are expected. Analysis of the ozone loss rate in September indicates large interannual variability. This dynamic variability influences the presence of polar stratospheric clouds. Prior to the mid-1990s, the ozone-depleting

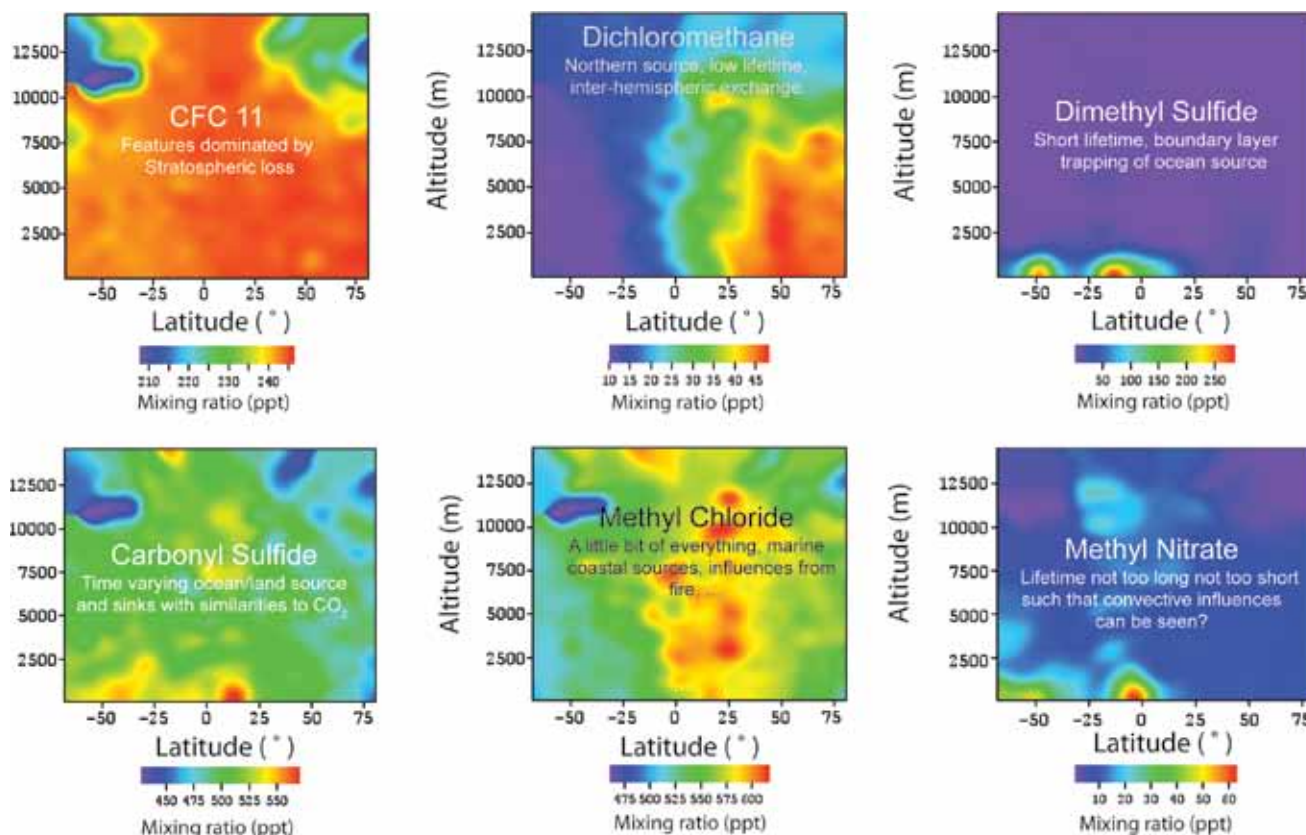
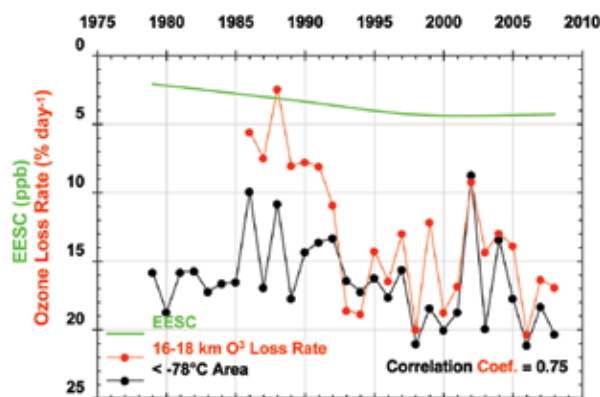


Figure 1: Vertical-latitude cross sections of six atmospheric trace gases measured on the National Center for Atmospheric Research's HIAPER Gulfstream-V aircraft during the HIPPO-1 mission in January 2009, showing the diversity of sources and sinks in the troposphere (flask data from NOAA and E. Atlas, U. Miami).

halogen substances (represented by equivalent effective stratospheric chlorine [EESC]) were still increasing—so the ozone loss rate was also increasing (see figure below).



South Pole September ozone loss rates for 16–18 km (red) and the area encompassed by temperatures colder than -78°C , representing the conditions under which polar stratospheric clouds can form (black). The equivalent effective stratospheric chlorine (EESC) amount for Antarctica is also shown (green).

By the mid 1990s, halogen levels were high enough that all of the ozone in the 16-18-km layer was being destroyed so that the year-to-year changes in the loss rate were dominated by the variations in polar stratospheric clouds.

Product: Hofmann et al. 2009

CSV-04 Climate Dynamics

- PSD-06 Climate Dynamics
- PSD-03 Empirical and Process Studies
- PSD-15 Surface Processes

PSD-06 Climate Dynamics

FEDERAL LEAD: CHRIS FAIRALL, NOAA RESEARCH
CIRES LEAD: LESLIE HARTTEN

NOAA Goal 2: Climate

Project Goal: Conduct research to improve understanding of tropical Pacific Ocean dynamical processes related to the sub-seasonal atmospheric variability, and atmospheric circulation, convection, and moisture and heat budgets associated with the El Niño phenomenon and the North American Monsoon (NAM).

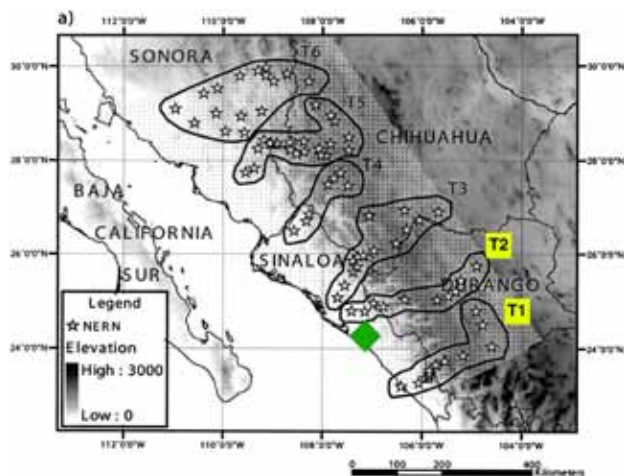
Milestone 1. Evaluate the ability of National Centers for Environmental Prediction (NCEP) regional reanalyses to capture the daily cycles observed during the North American Monsoon (NAM) along the Gulf of California. This will be done by comparing daily cycles of 915-MHz profiler winds and virtual temperatures and precipitation observed during multi-year NAM experiment (NAME) deployments with NCEP regional reanalysis products.

The listed milestone for this year, a comparison of the observed and modeled daily cycle in the lower atmosphere

during the NAM, was not addressed because of logistical issues and because previous results suggested a more intriguing and unique observational exploration. Therefore, FY10 research focused on closer examination of the sea breeze along the Mexican Coast and on the co-variability of lower-tropospheric winds near the coast of Mexico and precipitation over the Sierra Madres Occidental (SMO) during the NAM.

The primary field phase of the NAME occurred during summer 2004. However, some field observations extended beyond this time period, often for multiple years. For example, the first automatic-recording tipping-bucket rain gauges that make up the NAME Event Rain Gauge Network (NERN; Gochis et al. 2003, 2004) along the western slope of the SMO were deployed in 2002. A maximum of 87 gauges were deployed in 2005 and the NERN continues to collect data. Also, a suite of instruments including a 915-MHz lower-tropospheric wind-profiling radar was deployed at Estación Obispo (ETO), Mexico during the summers of 2004, 2005, and 2006 as part of NAME. The profiler measured winds from about 200 m to 3,000 m; these have been processed into hourly wind profiles.

In an initial attempt to correlate the daily cycle of winds along the western Mexico Coast with the strongly diurnal precipitation along the SMO, circular statistics were used to search for a relationship between a simple measure of the sea breeze at ETO and the daily rainfall at “uphill” NERN gauges. In the process of constructing the sea-breeze timeseries, it was discovered that sea breezes are much more frequent (occurring about 90 percent of the time) and from a broader range of directions (160°-290°) than previously thought. (Direct onshore flow at ETO would be from about 225° or southwesterly).



The North American Monsoon Experiment Event Rain Gauge Network, with six transects arrayed along the western slope of the Sierra Madres Occidentales. The green diamond indicates Estación Obispo and T1 and T2 identify two transects of interest in this project. Adapted from Gochis et al. (2004).

The near-ubiquity of sea breezes at ETO and the highly variable nature of rain at the NERN sites meant that no “C-association” was found between the 2-5 p.m. mean wind direction at ETO and daily rainfall at the upwind NERN sites. C-association, based on a rank analysis, is the proper statistic to use when searching for what one would otherwise call correlation between a linear variable (e.g., rainfall) believed to be dependent on a circular variable such as wind direction (Fisher 1993). Future work will test different approaches, such as averaging rainfall along

elevation bands or using the onshore wind component, to shed light on the relationship between these short-scale aspects of the NAM.

Products: Vincente 2009, Vincente 2010, Hartten et al. 2010.

PSD-03 Empirical and Process Studies

FEDERAL LEAD: KLAUS WEICKMANN, NOAA RESEARCH
CIRES LEAD: PRASHANT SARDESHMUKH

NOAA Goals 2 and 3: Climate and Weather and Water

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. Develop empirical models of daily sea-surface temperature (SST) and near-surface air temperature variations at all oceanic grid points from observations and climate model simulations.

Two studies were completed concerning the skewness and kurtosis of daily SST variations, which are strongly linked at most locations around the globe. These quantities were analyzed in terms of a simple stochastically forced, mixed-layer ocean model. The predictions of the analytic theory were found to be in remarkably good agreement with observations, strongly suggesting that a univariate linear model of daily SST variations with a mixture of SST-independent (additive) and SST-dependent (multiplicative) noise forcing is sufficient to account for the skewness-kurtosis link. Such a model of non-Gaussian SST dynamics has important implications for predicting the likelihood of extreme events in climate, as many important weather and climate phenomena, such as hurricanes, ENSO, and the North Atlantic Oscillation (NAO), depend on a detailed knowledge of the underlying local SSTs.

Milestone 2. Continue assessing stochastic influences on climate variability and predictability through 1) linear and nonlinear inverse modeling, and 2) development and implementation of stochastic parameterizations in weather and climate models.

Two recently published studies of observed SST variations have clarified the role of rapid wind fluctuations in enhancing the SST amplitudes, and provided striking evidence that the non-Gaussian aspects of the SST statistics can be understood within a context of linear stochastically forced models in which the amplitude of the noisy wind forcing depends linearly on the SST. One study (Sura and Sardeshmukh 2008) was based on a general one-dimensional Langevin model, whereas the other (Sura and Newman 2008) considered an explicitly coupled two-dimensional model of SST and local surface air temperature, and emphasized the crucial role of thermal air-sea coupling in generating the non-Gaussian statistics. In a new published study (Sura and Sardeshmukh 2009), it was shown that these previous studies were not necessarily mutually inconsistent. In particular, the one-dimensional model can be derived from the two-dimensional model as a special case, in which the air temperature is approximated as comprising a part linearly dependent on SST plus a pure noise part. This version of the one-dimensional model,

SEB Term	Main processes represented	ERA-40 bias	ERA-Interim bias	NCEP/DOE bias	JRA-25 bias	RMS bias
H_s	turbulence transfer coefficient	-2.9	-1.05	-21.71	-8.32	11.7
H_l	turbulence transfer coefficient	3.7	2.95	0.99	3.02	2.9
SW_d	SW cloud properties	-7.9	-5.69	29.47	21.83	19.0
SW_u	SW_d , surface albedo	-13.2	-9.77	34.01	-4.45	19.0
LW_d	LW cloud properties	-1.8	-1.29	-29.89	-27.09	20.2
LW_u	surface temperature	7.5	6.5	-3.61	5.59	6.0
SEB	Sum of all energy flux terms	-7.1	-8.8	-11.0	-9.3	
RMS bias		7.3	5.5	23.8	14.9	

Table 1: Annual biases of the individual surface energy fluxes for the four reanalysis datasets. The bottom row shows the root-mean-square (RMS) biases of the flux terms for each reanalysis, while the right-most column shows the RMS bias of the reanalyses for each flux term.

however, can only predict positive SST skew given the observed thermal damping and coupling constants over the globe. The fact that the more general one-dimensional model can also capture the essence of the local SST dynamics in regions of negative SST skew therefore implies that other physical mechanisms not included in simple local thermally coupled models, such as stochasticity in oceanic heat transports, may also be important in those regions. As emphasized in all our studies of this topic, a proper accounting of such state-dependent noise effects is crucial for understanding and correctly representing air-sea coupling in weather and climate models.

Product: Sura and Sardeshmukh 2009.

PSD-15 Surface Processes

FEDERAL LEAD: JAMES WILCZAK, NOAA RESEARCH
CIRES LEAD: OLA PERRSON

NOAA Goal 3: Weather and Water

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

Milestone 1. Determine accuracy of European Center for Medium-Range Weather Forecasts reanalysis ERA-40 surface turbulent fluxes over the Arctic pack ice, and devise methods of improvement through a combination of satellite measurements and modeling.

CIRES work in this area has been focused on evaluating the surface basic meteorological parameters, radiative and turbulent fluxes, integrated cloud properties, total surface energy fluxes (SEB), and parameter relationships in four reanalysis datasets over the entire annual cycle over sea ice using the only dataset adequate for such an evaluation, the Surface Heat Budget of the Arctic (SHEBA) dataset. Reanalysis datasets evaluated were two from the ECMWF (ERA-40 and ERA-Interim), one from the National Centers for Environmental Prediction/U.S. Department of Energy (NCEP/DOE), and the Japanese 25-year Reanalysis (JRA-25).

The purpose of this evaluation is to better understand our ability to track key environmental parameters for Arctic change, for which these reanalyses are frequently used. More specifically, it was to determine the quality of the surface fluxes and the surface energy budget produced by these reanalyses, which are frequently considered to be the best “data” for describing the surface fluxes over sea ice. Of course, reanalyses are actually

an assimilation of available observations into a model-generated first-guess field. It is the best analysis possible, but it must be remembered that over the data-poor Arctic Ocean, most of the near-surface fluxes result from the model parameterizations rather than from observations.

Clearly, the reanalyses do not produce reliable estimates of the surface energy fluxes nor correct relationships between fluxes, and much of the problems lie with the parameterizations used in the associated models. The assimilation of the satellite and the sparse in situ observations cannot overcome these limitations, likely because fluxes are not directly assimilated. A crude method to rank the evaluations of the datasets is to compute the root-mean-square (RMS) of the biases of the key energy flux terms that represent specific processes (sensible heat flux; latent heat flux; and shortwave downward, shortwave upward, longwave downward, and longwave upward radiative flux). The results show that the two ECMWF reanalyses clearly perform better overall for the surface energy fluxes (Table 1), with RMS biases of 5.5-7.3 W/m². JRA-25 ranked next and NCEP/DOE worst, with a RMS bias of 23.8 W/m².

This same method can be used to assess which processes are contributing most to uncertainties in the surface energy fluxes by computing RMS biases for each of the flux terms across the four reanalyses. The results suggest that efforts spent improving the parameterizations involving the downwelling radiative fluxes, the surface albedo, and the turbulent sensible heat flux will likely provide the greatest improvements in the surface energy flux terms over the pack ice. These results quantify for the reanalyses the problems for regional and global climate models reported by others (Tjernström et al. 2005 and 2008, Prenni et al. 2006, Wyser et al. 2007, Karlsson and Svensson 2009). Walsh et al. (2009) suggested similar radiation problems over land with these reanalysis datasets when validating them with cloud forcing data from Barrow, AK, though they did not look specifically at liquid and ice water paths nor did they examine the role of the turbulent fluxes.

Milestone 2. Determine the turbulent flux characteristics and associated processes at the Study of Environmental Arctic Change (SEARCH) sites at Alert and Eureka. Determine the extent to which Monin-Obukhov Similarity (MOS) applies at these locations. Consider if a non-MOS (non-local) flux scheme is necessary and, if so, suggest a process-based algorithm.

There are no accomplishments to report for FY10.

Milestone 3. Analyze the Arctic Summer Cloud Ocean Study (ASCOS) and Arctic Mechanisms of Interaction between Surface and Atmosphere data to better understand the physical processes producing the end of the summer melt season.

Extensive work has been done on this milestone. Collaborative research with international colleagues have looked at the impacts of clouds on the surface radiative forcing during ASCOS, which occurred in 2008 during the end of the summer melt season near the North Pole. One collaborative study showed various relationships associated with cloud radiative forcing during this time period. For instance, the shortwave forcing increased (became less negative) as the surface albedo increased towards the end of the experiment. This would suggest a negative feedback during cloudy conditions as the albedo changes. However, the shortwave attenuation becomes greater as the cloud liquid water path increases, and the shortwave forcing becomes much more negative as the solar zenith angle increases, which it does at that time of year. A journal article (Sedlar et al. 2010) has been submitted on this research.

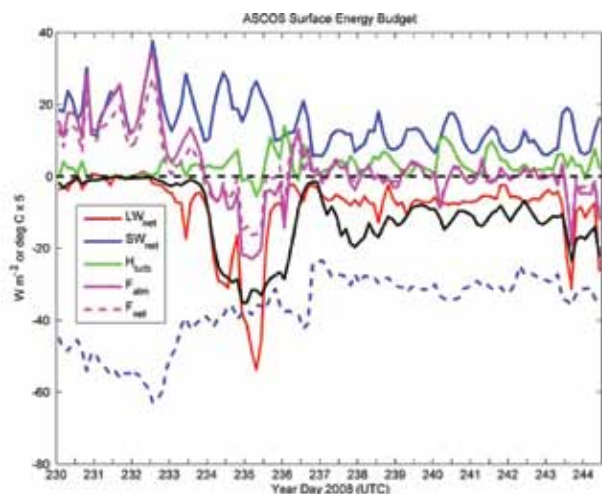


Figure 1: Three-hourly mean surface energy budget terms for ASCOS days YD230-245 (17 August to 1 September 1998). The net energy flux (F_{net}) becomes zero or negative on YD 236 (23 August) and the temperature remains below freezing (black curve). The surface albedo (dashed blue) increases with the snowfall this day, thereby maining low net shortwave radiation (SW_{net}). The net longwave radiation (red, LW_{net}) becomes more negative after this date.

Further analyses suggest that the end of the summer melt occurs with the passage of a storm system on 23 August 2008 (Figure 1). This storm system produced snowfall that increased the surface albedo, thereby reducing the solar radiation absorbed by the surface snow. Furthermore, cold air advection followed this storm system, allowing for positive turbulent heat fluxes that also tended to cool the surface and a reduction in the downwelling longwave radiation. Since the net energy flux was only slightly positive before this storm, these three changes produced the necessary reduction in the net energy flux to end the summer surface melt season. The snowfall on 23 August 2008 also reduced the solar radiation penetrating through the sea ice, so oceanic temperatures just below the sea ice begin to decline on this date.

Current work is incorporating the ASCOS analysis into

a broader analysis of other data of the onset and end of the summer melt season. The other data being used in this comprehensive analysis includes data from the Surface Heat Budget of the Arctic, North Pole Environmental Observatories, Arctic Ocean Expedition, and the Russian Drifting Station. This will show how typical is the ASCOS series of processes.

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

CIRES LEAD: FLORENCE FETTERER

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.

Milestone 1. Add additional glacier photograph collections to the Online Glacier Photograph Data Base, in collaboration with NOAA NGDC, and the NOAA Climate Data Modernization Program.

The Glacier Photograph Collection (http://nsidc.org/data/glacier_photo) added 500 glacier photographs taken between 1994 and 2010 by astronauts stationed on the International Space Station and the Space Shuttle *Endeavor*. The search interface was also improved, allowing searches by spatial coverage and temporal range; searches by glacier name or by photographer; and multiple searches before placing an order. Photo metadata are now delivered via FTP with high-resolution photo orders, instead of having to download the metadata from another location.

NSIDC-03 World Data Center for Glaciology, Boulder—Current Programs

CIRES LEAD: JANE BEITLER

NOAA Goal 2: Climate

Project Goal: Improve our understanding of recent and unexpected changes in polar regions including lower sea-level atmospheric pressure, increased air temperature over most of the Arctic, lower temperatures over eastern North America, reduced sea-ice cover, thawing permafrost, and changes in precipitation patterns.

Milestone 1. Maintain and update existing research datasets (e.g., the Sea Ice Index). Publish new datasets and improve data visualization tools, including Google Earth.

NOAA@NSIDC launched a new website (<http://nsidc.org/noaa/scicex>) for Science Ice Exercise (SCICEX), a program in which U.S. Navy submarines obtained scientific measurements of the Arctic Ocean, such as ice draft profiles; physical, chemical, and biological water proper-



Astronauts on the International Space Station took this photograph of Viedma Glacier in 2000. The NOAA@NSIDC Glacier Photograph Collection offers more than 13,000 online images, taken from the late 1800s through the present. These images help researchers study long-term changes in glaciers, which are very sensitive to changes in climate.

ties; and bathymetry. The website provides information on SCICEX, and about how and where to acquire the data. For many years, these data have been scattered among several institutions and could be hard to discover and access.

NOAA@NSIDC released the Canadian Ice Service Arctic Regional Sea Ice Charts in SIGRID-3 Format dataset (<http://nsidc.org/data/g02171.html>). The Canadian Ice Service produces ice charts for marine navigation, climate research, and input to the Global Digital Sea Ice Data Bank on a daily basis. The charts are created through the manual analysis of in situ, satellite, and aerial reconnaissance data. This dataset begins in 2006 and covers Canadian waters.

Thousands of classified reconnaissance images of interest to scientists from the Medea program are archived by the U.S. Geological Survey's Global Fiducials Library (GFL). Sea-ice images are among the first of the classified, 1-meter resolution, visible-band images to be publicly released. NOAA@NSIDC staff contribute to this project and published two related datasets with NOAA support: Surface Heat Budget of the Arctic Reconnaissance Imagery (<http://nsidc.org/data/g02180.html>) and Arctic Sea Ice Melt Pond Statistics and Maps, 1999, 2000, and 2001 (<http://nsidc.org/data/g02159.html>).



COURTESY OF THE UNIVERSITY OF ALASKA FAIRBANKS INSTITUTE OF MARINE SCIENCE

The bow of the U.S. Navy submarine USS Hawkbill rises out of the Arctic sea ice cover, during the 1999 Science Ice Exercise expedition.

"Short-term Cooling on a Warming Planet," the featured article for 31 December 2009 in NOAA's Climate Watch Magazine, was authored by NSIDC staff, including interviews with NOAA and academic climate scientists and explaining declining temperatures since 1998.

In collaboration with the CU-Boulder School of Education, NSIDC created a new Google Earth movie called *A Climate Change Tour of Cold Places*. This tour explains how snow and ice play critical roles in the changing climate, and is geared towards a K-12 audience.

Milestone 2. Make research information available through the NSIDC Information Center, acquire and catalog cryospheric materials in the NSIDC library, and maintain NSIDC's analog datasets.

The Roger G. Barry Resource Office for Cryospheric Studies (ROCS) released a film documentary on *Drifting Station Alpha in the Arctic Ocean during the International Geophysical Year, 1957 to 1958* (<http://nsidc.org/data/g02184.html>). The film is narrated by project leader Norbert Untersteiner, and chronicles the life of the team as they built their camp and set up experiments.

ROCS received a NOAA Preserve America Initiative Grant to document the World Data Center for Glaciology (WDC) history at NSIDC. All of the WDC historic documents have been scanned, and a website is being created.

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 LEAD: ROGER PULWARTY, NOAA RESEARCH
CIRES LEAD: JOSEPH BARSUGLI

NOAA Goal 2: Climate

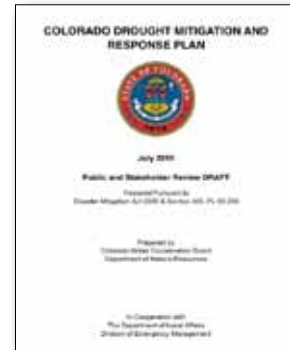
Project Goal: Couple enhanced observations and research in regions of strong climate variability and societal impact with analysis of past data and improved modeling. Determine factors influencing the occurrence of extreme events. Improve the diagnosis, modeling, and prediction of the regional consequences of climate change and variability on time scales of days to decades on hydrological variables of relevance to society.

Milestone 1. Continue monitoring daily, seasonal, and longer-term precipitation variability over the western United States. Continue downscaling National Centers for Environmental Prediction (NCEP) week-two ensemble forecasts for Colorado water-resource managers. Continue developing seasonal forecast guidance tools for the United States based on the predictability of tropical sea-surface temperatures (SSTs) several seasons in advance.

With a 2009 Hollings scholar, week-two predictability of potential evapotranspiration in the Lower Colorado Basin was investigated, using downscaled predictions. Southwestern United States forecast guidance (SWcast) was produced through June 2010; and the production and dissemination of the multivariate El Niño-Southern Oscillation Index has been continued.

Milestone 2. Continue programmatic development and impact assessments of climate, weather, and water services, especially in conjunction with the National Integrated Drought Information Service (NIDIS).

Participation in the Front Range Climate Change Vulnerability Study was continued, as was CIRES/ESRL involvement in educational lectures on climate change, review of documents and draft reports, and participation in monthly meetings. Three CIRES staff members participated in the Climate Change Technical Advisory Group for the Colorado Water Conservation Board, and CIRES/ESRL staff produced a rapid-response climate assessment of the American pika for the U.S. Fish and Wildlife Service. CIRES staff also participated in the Colorado Water Availability Task Force and annual Wildfire Management Workshops.



PSD-07 Experimental Climate Data and Web Services

FEDERAL LEAD: NICK WILDE, NOAA RESEARCH
CIRES LEAD: PRASHANT SARDESHMUKH

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. Continue updating the extensive, publicly-accessible climate data holdings on the Climate Diagnostic Center/Physical Sciences Division website. Continue acquisition of new precipitation and soil moisture datasets.

Web access was developed for a new global atmospheric circulation dataset for 1891-2008, produced by CIRES' Climate Diagnostics Center (CDC) and ESRL scientists using only daily surface pressure observations and an ensemble Kalman-filter-based data assimilation system.

Web access was also developed for a new experimental forecast product for subseasonal tropical forecasts, developed by CDC and ESRL scientists and based on a coupled linear inverse model of weekly tropical sea-surface temperatures and outgoing longwave radiation variations.

Products: http://www.esrl.noaa.gov/psd/data/gridded/data.20thC_Rean.html, and <http://www.cdc.noaa.gov/forecasts/clim/>.

Milestone 2. Continue with acquisition and major updating of South and North American historical daily precipitation datasets.

A full update for Argentina, Colombia, and Santa Fe Province daily precipitation data through 2009 has been acquired and incorporated into recently updated South America gridded data files. The South American dataset is publicly available and contains data from 1940 on (1x1 and 2.5 grids). The CPC "Unified" precipitation has been

updated to version 2 and is up-to-date. From the Climate Data Assimilation System National Centers for Environmental Prediction (NCEP), Reanalysis Models are being continually updated. The NCEP/U.S. Department of Energy Reanalysis 2 has been updated through 2009. The North American Regional Reanalysis has been updated through 2009 and is now available for the general public. The 20th Century Reanalysis from 1871-2008 has been made available and includes daily model precipitation.

Product: Liebmann et al. 2009.

Milestone 3. Continue programmatic development and impact assessments of climate, weather, and water services, especially in conjunction with the newly established National Integrated Drought Information Service (NIDIS).

Staff continued participating in monthly Colorado Water Availability Task Force meetings to assess drought conditions in the state and the prospects of relief. Participation included regular invited presentations on weekly to seasonal precipitation outlooks.

The NIDIS pilot for the Upper Colorado River Basin (UCRB) initiated weekly webinars during spring runoff season. CIRES staff participated in the webinars, as did U.S. Drought Monitor (USDM) author for the week, and CIRES gave input to the USDM on how to depict UCRB.

CIRES staff also participated in the revision of the Colorado Drought Plan, which is now open for public comment.

CIRES staff are collaborating with NIDIS to improve the Surface Water Supply Index (SWSI) and participated in a drought index workshop in 2009. The U.S. Department of Agriculture Natural Resources Conservation Service (NRCS) is working to implement a revised SWSI for Upper Colorado River Basin with input from CIRES, including a plan for historical intercomparison of the original and revised SWSI, to be completed pending receipt of data from NRCS Portland.

CIRES staff are continuing to provide input to the U.S. Drought Monitor along with the U.S. Drought Outlook, which includes experimental seasonal forecast guidance for the interior southwestern United States.

Product: Input to the U.S. Drought Monitor for current conditions: www.drought.gov/portal/server.pt/community/drought_indicators/us_drought_monitor Input to the U.S. Drought Outlook for next season: www.drought.gov/portal/server.pt/community/forecasting.

GEODYNAMICS

GEO-01 Geophysical Data Systems

■ NGDC-05 Improved Integration and Modeling of Geomagnetic Data

NGDC-05 Improved Integration and Modeling of Geomagnetic Data

FEDERAL LEAD: SUSAN McCLEAN, NOAA NESDIS

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 GPS and radio communication.

Milestone 1: Produce and distribute the World Magnetic Model 2010.

The CIRES geomagnetism team at NOAA's NGDC, in collaboration with the British Geological Survey, produced the World Magnetic Model 2010 (WMM2010, released 15 December 2009). This magnetic field reference model, which is updated every five years, provides the basis for converting compass magnetic bearing to true bearing in navigation and heading systems. The WMM is embedded into millions of navigational devices worldwide. Beside traditional uses in aircraft, ships, and hand-held navigation devices, the WMM is also essential in surveying, orienting of antennas and solar panels, modeling of radio wave propagation, and space weather prediction.

The Earth's magnetic field, as measured by a magnetic sensor on or above the Earth's surface, is a composite of contributions from a variety of sources. These fields are superimposed and interact through inductive processes with each other. The most important of these geomagnetic field contributions are: 1) the Earth's main magnetic field generated in the conducting, fluid outer core, accounting for more than 95 percent of the magnetic field at the Earth surface; 2) the magnetic anomaly field generated in Earth's crust and upper mantle; and 3) the combined disturbance field from electrical currents flowing in the upper atmosphere and magnetosphere, which further induce electrical currents in the sea and ground.

The WMM represents only the main field and its linear change in time (secular variation) by a spherical harmonic expansion of the magnetic potential to degree and order 12 (Figure 1 next page). This convenient mathematical representation allows the strength and direction of the ambient geomagnetic field to be estimated at any desired location and time over the five-year life of the model. A major achievement in this revision of the WMM was the complete rewrite of the heritage software library accompanying the model. Due to high interest in using the WMM in mobile devices, a Google programmer assisted CIRES staff in testing the software and ensuring it met industry standards. A detailed technical report, model co-

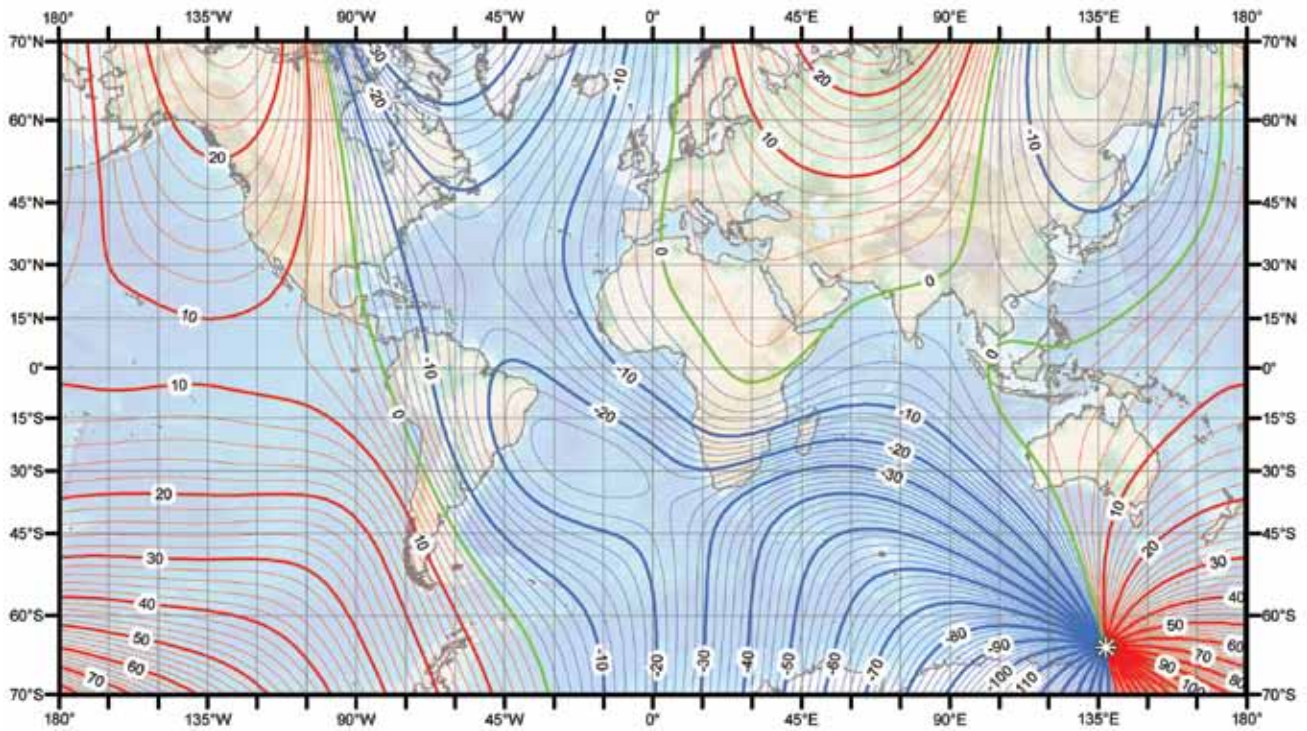


Figure 1: Main magnetic field declination given by WMM2010. Red contours indicate that magnetic is east of true north, while blue indicates a westward deflection of magnetic north. The (agonic) zero line is green; contour interval 2°.

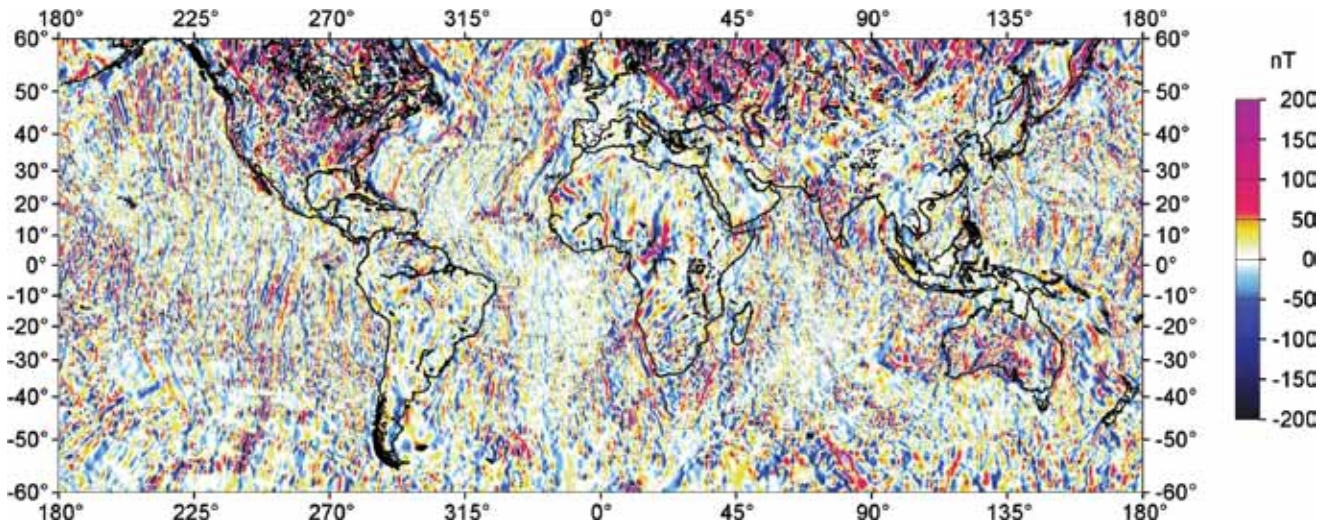


Figure 2. East component of the crustal magnetic field at the Earth surface, as represented in the Enhanced Magnetic Model (EMM2010). Red and blue areas indicate local distortion in the direction of the magnetic field to the east and west, respectively.

efficient, new software library, online calculators, maps, and GIS shape files are available on the WMM website at <http://www.ngdc.noaa.gov/geomag/WMM/DoDWMM.shtml>.

The user base of the WMM has increased dramatically during the past two years with the integration of electronic compasses into high-end cell phones and cameras. These consumer devices determine their location using GPSs, while inferring the orientation of the device by combining an accelerometer with an electronic compass. Examples are Google's Nexus phone, Apple's iPhone and iPad, and Sony's Cyber-shot camera. All of these devices have the

WMM2010 embedded into their firmware.

Product: Maus et al. 2009, and

<http://www.ngdc.noaa.gov/geomag/WMM/DoDWMM.shtml>.

Milestone 2: Produce and distribute beta version of a new advanced geomagnetic model.

While the World Magnetic Model (WMM2010) accounts for the main magnetic field originating in Earth's core, magnetic minerals in the crust and upper mantle give rise to magnetic anomalies that can significantly affect the local

direction of the geomagnetic field. Certain applications, such as directional drilling in the oil and gas industry, require higher accuracy heading information than the WMM2010 provides. To support such specialized users, the CIRES geomagnetism team at NGDC produced an Enhanced Magnetic Model (EMM2010, Figure 2) which was released together with the WMM2010 on 15 December 2010.

The primary challenge in producing this model lay in estimating the 520,000 coefficients of the magnetic potential (for comparison, the WMM has 336 coefficients). Crustal magnetic anomalies are accounted for in the EMM by an ellipsoidal harmonic expansion to degree and order 720, corresponding to 30 arc minutes (56 km) wavelength resolution. Key breakthroughs were achieved with 1) the ellipsoidal harmonic representation of the magnetic potential, 2) reduction of parameter estimation ambiguities, and 3) use of a novel iterative approach to estimate model coefficients. Combined with a highly accurate main field model, the EMM provides the Earth's internal magnetic field vector at any desired location and altitude close to and above the Earth's surface. Apart from implementation in magnetic navigation and heading systems, the EMM will be useful for calibrating ground, marine, and air- and space-borne magnetometers.

Since evaluation of a high-degree magnetic model is computationally expensive, a fast three-dimensional mesh interpolation algorithm was developed specifically for the EMM. A software library, model coefficients, and further materials are available on the EMM website at <http://www.ngdc.noaa.gov/geomag/EMM/emm.shtml>.

Product: Maus 2010, and

<http://www.ngdc.noaa.gov/geomag/EMM/emm.shtml>

PLANETARY METABOLISM

PM-01 Biosphere-Atmosphere Interactions

■ CSD-07 Biosphere-Atmosphere Exchange

CSD-07 Biosphere-Atmosphere Exchange

FEDERAL LEAD: JIM BURKHOLDER, NOAA RESEARCH
CIRES LEAD: JOOST DE GOUW

NOAA Goals 2 and 3: Climate and Weather and Water

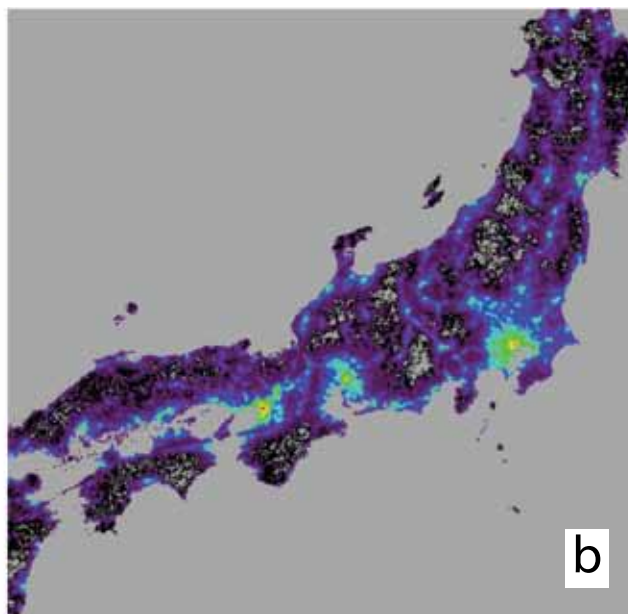
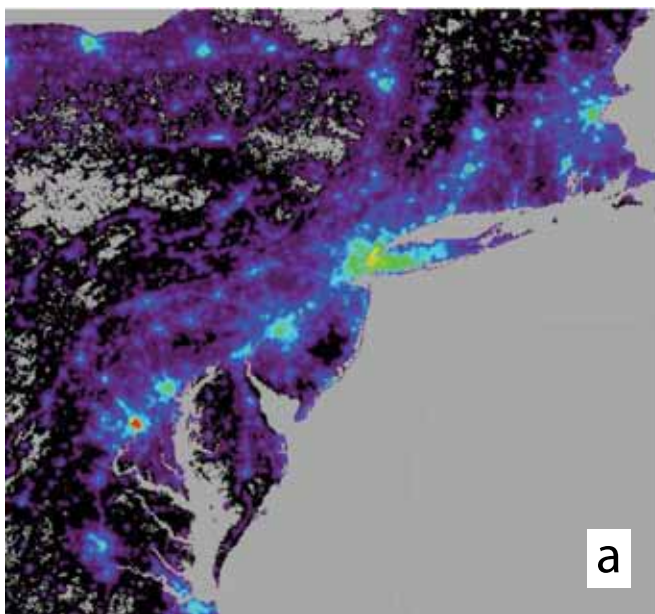
Project Goal: Gain an improved understanding of the role that the exchange of gases between the surface and the atmosphere plays in shaping regional climate and air quality.

Milestone 1: Measure reaction rate coefficients and evaluate the atmospheric degradation mechanisms of key biogenic species.

Organic peroxides are a class of atmospheric trace species that play an important role in tropospheric chemistry. Organic peroxides are primarily formed in the atmosphere and are involved in gas-phase and heterogeneous processing that defines the oxidative capacity of the atmosphere. The chemistry leading to the formation of organic peroxides and their removal from the atmosphere is presently not well characterized. In this study, the gas-phase reactivity of $(\text{CH}_3)_3\text{COOH}$ (t-butyl hydroperoxide) was examined. Rate coefficients for the gas-phase reaction of the OH radical with $(\text{CH}_3)_3\text{COOH}$ (t-butyl hydroperoxide) were measured as a function of temperature (206–375 K) and pressure (25–200 (He, N_2)). Rate coefficients were measured under pseudo-first-order conditions using pulsed laser photolysis (PLP) to produce OH and laser-induced fluorescence (LIF) to measure the OH temporal profile. Absolute pressure and chemical titration methods were used to determine gas-phase infrared cross sections of $(\text{CH}_3)_3\text{COOH}$. The infrared absorption cross sections were used to determine the $(\text{CH}_3)_3\text{COOH}$ concentration in the LIF reactor. The temperature dependence of the rate coefficients is described by the Arrhenius expression $k_{\text{T}} = (7.0 \pm 1.0) \times 10^{-13} \exp[(485 \pm 20)/\text{T}]$ where $k_1(296 \text{ K})$ was measured to be $(3.58 \pm 0.54) \times 10^{-12} \text{ cm}^3 \text{ molecule}^{-1} \text{ s}^{-1}$. The UV photochemistry of $(\text{CH}_3)_3\text{COOH}$ was also studied as part of this work. UV absorption cross sections of $(\text{CH}_3)_3\text{COOH}$ were determined at 185, 214, 228, and 254 nm and over the wavelength range 210–300 nm. The OH quantum yield following the 248 nm pulsed laser photolysis of $(\text{CH}_3)_3\text{COOH}$ was measured relative to the OH quantum yields of H_2O_2 and HNO_3 using PLP-LIF and found to be near unity. The results from this study provide insight into the reactivity and photochemistry of organic peroxides that will aid the understanding of the atmospheric processing of this class of compounds and their impact on the atmosphere and environment.

Product: Baasandorj, M. et al. (2010), $(\text{CH}_3)_3\text{COOH}$ (t-Butyl Hydroperoxide): OH reaction rate coefficients between 206 and 375 K and the OH photolysis quantum yield at 248 nm, *Phys. Chem. Chem. Phys.*, in press.

Milestone 2: Analyze the atmospheric chemistry implications of trace gases emitted from biomass burning.



Grid of total economic activity in millions of dollars per km² pixel, a) of northeastern United States, and b) of Japan.

Biomass burning is a large, but poorly described, source of trace-gas and aerosol emissions to the atmosphere. Biomass burning occurs both naturally in forest fires, but a significant fraction is human-induced; for example, the burning of bio-fuels for heating and cooking, and the burning of agricultural residue and trash. In addition, the frequency and intensity of forest fires may be increasing due to higher temperatures, droughts, and earlier snowmelt in boreal regions as a result of climate change.

The impact of biomass-burning emissions on the atmosphere is poorly described for a variety of reasons. The fuels are only partially combusted, and the highly oxidized nature of the emissions poses a challenge for our present analytical instruments. The variability in fuels and burning conditions give rise to a very large variability in the chemical composition of emissions. The episodic nature of biomass burning makes it difficult to study these sources systematically during field missions.

In this work, the chemical composition of biomass burning emissions has been studied in the laboratory, as well as the long-range transport and transformation of forest-fire emissions in the atmosphere.

To characterize the emissions of trace gases, detailed measurements of biomass-burning emissions were conducted at the Fire Sciences Laboratory of the U.S. Forest Service in Missoula, MT, where controlled burns of biomass can be studied in the laboratory. The instruments used to characterize biomass-burning emissions included a gas chromatography instrument with mass spectrometric detection (GC-MS) and a proton transfer reaction mass spectrometry instrument (PTR-MS). These instruments have been used for field measurements of organic compounds during numerous missions, and comparison with the dataset collected at the Fire Sciences Laboratory is of great interest, as it allows the effects of emissions and chemical conversion to be separated.

Using a newly developed negative-ion proton-transfer chemical ionization mass spectrometer, large emissions of nitrous acid (HONO), isocyanic acid (HNCO), and several carboxylic acids were identified. These observations are of

interest for various reasons. HONO molecules readily produce free radicals in the atmosphere upon photolysis, which affects the chemical transformation of biomass-burning emissions. Isocyanic acid has not been observed previously in the atmosphere and work is in progress to evaluate the atmospheric chemistry of this trace gas. Finally, several of the measured carboxylic acids are efficient precursors of aerosol formation in biomass-burning plumes.

Products: Veres et al. 2010, Burling et al. 2010, Roberts et al. 2010, Veres et al. 2010.

PM-02 Response of Natural Systems to Perturbations

■ NGDC-07 Anthropogenic Remote Sensing

NGDC-07 Anthropogenic Remote Sensing

FEDERAL LEAD: CHRIS ELVIDGE

CIRES LEAD: DANIEL ZISKIN

NOAA Goal: 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: Develop intercomparable radiance-calibrated nighttime lights set for 1996-97, 2000-01, and 2005-06.

The radiance-calibrated products are hybrids between the Stable Lights and Fixed Gain composites made using data from the Operational Linescan System (OLS). The Stable Lights products are composed of OLS data collected with operational gain settings, which allow the gain to vary in response to solar and lunar conditions. The Fixed Gain

products are generated from the relatively sparse OLS data collected with specified reduced gains. Under Fixed Gain conditions bright urban lights tend not to saturate the detector, while the Stable Lights products reveal more of the suburban and rural lighting. The blending of the two collections, by carefully calibrating the radiances of collections made at different gain settings, effectively expands the dynamic range of the OLS, yielding more information than the Stable Lights or the Fixed Gain collection by itself.

Radiance-calibrated nighttime lights products were created for the years: 1996-97, 1999, 2000, 2002, and 2006. A product for 2004 is in progress. When these products are completed, a methodology for creating an intercomparable dataset will be developed. This work is expected to be completed by September 2010.

Product: An oral presentation was made at the Global Monitoring Annual Conference.

Milestone 2: Complete a geospatial depiction of global economic activity based on satellite-observed nighttime lights.

Several activities are in progress: A paper has been written and will be presently submitted for journal publication; a University of Denver Ph.D. dissertation was completed on this topic and accepted in May; and a proposal to continue the research is in preparation. See figure on previous page.

Milestone 3: Develop an Earth observation mission concept for moderate resolution nighttime lights.

Much of the work to achieve this milestone was accomplished in previous years, but never cited as a group goal. The mission concept was developed and follow-on work was also performed, resulting in the research papers listed as products. A Nightsat website was created (<http://www.ngdc.noaa.gov/dmsp/nightsat.html>), featuring links to publications, laboratory spectra, test datasets, and the *Cities at Night* movie from Astronaut Don Pettit.

REGIONAL PROCESSES

RP-01 Regional Hydrological Cycles in Weather and Climate

■ PSD-11 Water Cycle

PSD-11 Water Cycle

FEDERAL LEAD: MARTY RALPH, NOAA RESEARCH

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 2010 Hydrometeorology Testbed-West (HMT-West) field campaign, likely the last in a series of field efforts conducted in the northern California American River Basin (ARB), located in the Sierra Nevada mountains west of Lake Tahoe and east of Sacramento. Also, plan the first HMT-East field campaign, likely to be conducted in the mid to southern Atlantic region of the eastern United States. CIRES investigators will be key participants and contributors to these activities.

Field operations for HMT-West 2010 were conducted for the fifth consecutive season in the ARB from December 2009 through March 2010. The 2010 season was a high water mark for the total number of surface instrument sites to monitor atmospheric and hydrologic conditions in the ARB and throughout California (Figure 1, next page). In addition to the types of surface and remote sensing instrumentation deployed in previous seasons, a new FM-CW S-band precipitation profiling system was deployed at two sites: Colfax in the ARB (CFX in Figure 1) and Shasta Dam (STA in Figure 1). The FM-CW is a low-cost, portable profiling radar with high spatial resolution to monitor the snow level and low-level precipitation vertical structure. There were no gap-filling scanning radars or special balloon soundings during the HMT-West 2010 field deployment and, as a result, there were no declared intensive operating periods. The C-band scanning radar (Skywater) that was planned for deployment was delayed due to logistical issues associated with the site location. This radar is expected to be ready for deployment in late summer or fall of 2010 in preparation for HMT-West 2011 operations. Field project status and activities were discussed on weekly conference calls among HMT participants, including personnel from the Eureka, Monterey, Reno, and Sacramento National Weather Service (NWS) Weather Forecast Offices; the California Nevada River Forecast Center; NWS Western Region headquarters; the Office of Climate Weather and Water Services; the National Severe Storm Laboratory; the Developmental Testbed Center; the University of Washington; and ESRL. In addition, project status, observations, and important links were updated and made available at the ESRL HMT-West 2010 web page: <http://www.esrl.noaa.gov/psd/programs/hmt/2010/>.

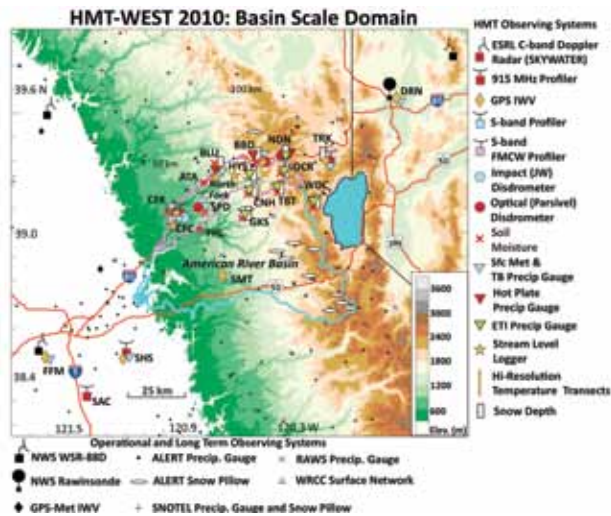


Figure 1: Location of instruments deployed during the Hydrometeorological Testbed-West 2010.

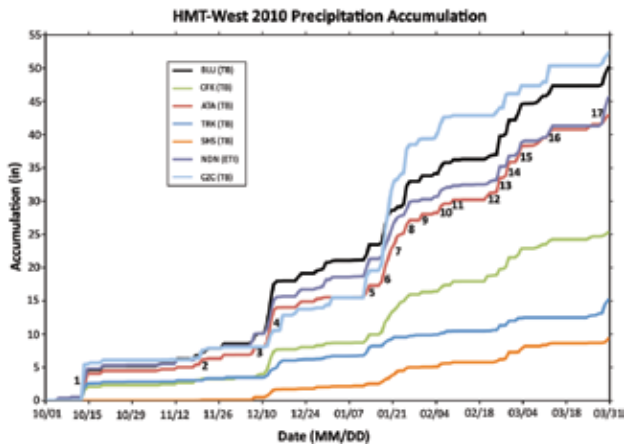


Figure 2: Precipitation accumulation in the American River Basin.

Precipitation events for the 2010 season were determined based on an analysis of accumulated precipitation at the Alta site (ATA) in the ARB. This site was used because of the central location (Figure 1) and elevation (3,559 ft) within the ARB as well as the continuous observation record for the 2010 season. A precipitation event was defined as a period of precipitation accumulation at ATA that lasted at least three hours and produced at least 0.5 inches of liquid accumulation in a 24-hour period (00:00-23:59 UTC). Time periods with no precipitation accumulation for more than six hours were used to separate events.

A snapshot of precipitation events that occurred during the HMT-West 2010 season is provided in Figure 2. Using the above criteria, a total of 17 precipitation events were documented between 1 October 2009 and 31 March 2010. Three events, in particular, were noted for their role in supplying significant moisture across the HMT-West domain: events 1, 4, and 6. Each of these events produced more than four inches of precipitation at ATA and other sites in the ARB. Noteworthy was the fact that one of these events occurred in October (event 1), several months prior to the climatological norm for the wettest precipitation events. The other two large precipitation events occurred in December (event 4) and January (event 6). A series of storms in mid-late January (events 6-8) were significant

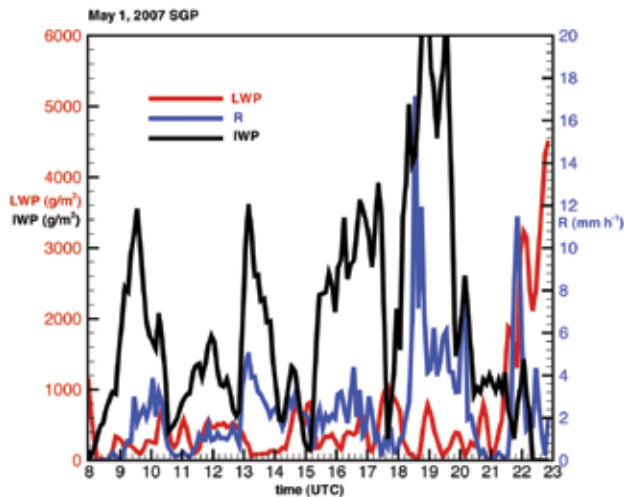
for their relative contribution to seasonal snow pack, effectively increasing the snow depth by a factor of two to three across the ARB. In comparison with previous years, precipitation during HMT-West 2010 was near-normal, as evidenced by an evaluation of snowpack telemetry data from the Natural Resource Conservation Service. The central Sierras, including the ARB, were near normal while mountain ranges north are generally dry and ranges south are generally wet, consistent with the moderate El Niño conditions that occurred throughout the season.

Milestone 2. A real-time, quasi-operational version of the orographic-precipitation support tool will be developed and implemented with web interface access. Evaluation and fine tuning of the product will occur based on continued feedback from weather forecasters and water-resource and emergency managers using the tool to assess real-time flooding risks.

Automated graphical display software was developed and implemented to produce the orographic-precipitation support tool in near real time. Web interface access to the support tool for 12 different NOAA and cooperative agency sites along the U.S. West Coast was provided to scientists, forecasters, and decision makers to help monitor and study extreme orographic precipitation events. Based on evaluation feedback, the tool was expanded to include total water flux at sites where orographic water vapor flux calculations were not feasible. Lastly, component numerical values, which are calculated and used in the tool, were made available in a web- and ftp-based distributable form for end users. These data were used by other operational and research agencies for verification and forecast decision making purposes. For example, ESRL is using these data to verify the newly developed Local Analysis and Prediction System orographic water vapor flux product, and the National Weather Service may ingest these data into the operational Advanced Weather Interactive Processing System, for improved data integration into the forecasting process.

Milestone 3. Develop and test a dual-wavelength mm-wavelength method to simultaneously retrieve cloud and rainfall parameters using ground-based Ka- and W-band radars.

A novel dual-wavelength mm-wavelength method to simultaneously retrieve cloud and rainfall parameters was developed for the use with Atmospheric Radiation Measurement (ARM) program ground-based Ka- and W-band radars. This method is applicable to stratiform precipitation events and allows independent retrievals of mean rain rate, cloud liquid and ice water paths (LWP and IWP, correspondingly) in the atmospheric vertical column. The discrimination between rain and cloud water is based on spectral differences of radio wave attenuation in small droplet suspended liquid (i.e., clouds) and precipitating liquid (i.e., rainfall). Rain rate and LWP retrievals use observed vertical gradients of reflectivity at two cloud radar frequencies. After retrievals in the liquid hydrometer layer, estimates of IWP in the atmospheric layer above the freezing level (which is identifiable from polarimetric and Doppler measurements) are obtained using absolute values of reflectivity corrected for attenuation. The suggested method was tested using observations of precipitating cloud events at the ARM Southern Great Plains site in Oklahoma. The figure (top, opposite page) illustrates results of the retrievals of the water cycle parameters for a 13-hour stratiform precipitation event observed on 1 May 2007.



Retrievals of ice water path, liquid water path, and mean rainfall rate for the 1 May 2007 precipitation event.

Milestone 4. If X-band polarimetric scanning radar observations can be used to identify the precipitation freezing level, NOAA weather forecasters in the field will need a simple display of the freezing level to help support their forecasts. Dependent on the outcome of the 2008-2009 precipitation freezing-level feasibility study, a decision support tool prototype will be developed that estimates the precipitation freezing level height using X-band polarimetric scanning radar observations.

Funding was discontinued prior to the reporting period.

RP-02 Surface/Atmosphere Exchange

■ PSD-12 Air-Sea Interaction

PSD-12 Air-Sea Interaction

FEDERAL LEAD: CHRIS FAIRALL, NOAA RESEARCH
CIRES LEAD: ANDREY GRACHEV

NOAA Goals 2 and 3: Climate and Weather and Water

Project Goal: Perform cutting-edge micrometeorological and climatological research over the open ocean aboard research vessels, sea-based towers, and buoys.

Milestone 1. Begin construction of a synthesis dataset for Variability of the American Monsoon Systems (VAMOS) Ocean-Cloud-Atmosphere-Land Study-Regional Experiment (VOCALS-REX) data.

See PSD-10, Milestone 1 for update on the construction and analysis of VOCALS-REX datasets.

Milestone 2. Continue parameterization of sea spray as part of the NOAA hurricane studies.

A parameterization scheme has been developed to account for the effects of sea spray on the momentum and heat fluxes in numerical weather prediction models. In this scheme, the effects of sea spray can be considered as an additional modification to the stratification of the near

surface profiles of wind, temperature and moisture in the marine surface boundary layer (MSBL). The overall impact of sea-spray droplets on the mean profiles of wind, temperature, and moisture depends on the wind speed at the level of sea-spray generation (or wave state if available). As the wind speed increases, the droplet size increases, rendering an increase in the spray-mediated total enthalpy flux from the sea to the air and leveling off of the surface drag. When the wind is below 35 m/s, the droplets are small in size and tend to evaporate substantially and thus cool the spray-filled layer. When the wind is above 50 m/s, the size of droplets is so big that they do not have enough time to evaporate that much before falling back into the sea. Furthermore, the scheme includes the physics of the suspended sea-spray droplets reducing the buoyancy of the MSBL air, therefore making the surface layer more stable. A journal article that describes the scheme, along with the results from testing the scheme in a numerical weather prediction model, has been submitted to *Monthly Weather Review* for publication.

Milestone 3. Analyze flux and gas transfer observations from NOAA GASEX-III field program in the Southern Ocean. Submit results for publication.

Covariance observations of the air-sea turbulent fluxes of carbon dioxide, ozone, heat, moisture, and momentum have been processed from the 2008 Southern Ocean GasEx cruise. In addition, an ongoing collaboration with researchers from the University of Hawaii continued to process and interpret the fluxes of dimethylsulfide (DMS) from that same cruise. The carbon dioxide flux estimates were coordinated with the collaborators from the Lamont-Doherty Earth Observatory (Columbia University) and the University of Connecticut. The efforts to process, analyze and interpret the ozone fluxes were made in collaboration with CU-Boulder Institute for Arctic and Alpine Research scientists, and this latter effort resulted in two publications. Numerous conference presentations have been developed from the covariance gas flux measurements.

Product: A manuscript is in preparation.

Milestone 4. Parameterization of stable boundary-layers as part of the NOAA/NSF Polar Programs.

Data collected during the Surface Heat Budget of the Arctic Ocean and Cooperative Atmosphere-Surface Exchange Study-99 field programs are employed to examine the flux-gradient relationship for wind speed and temperature in the stably stratified boundary layer. The gradient-based and flux-based similarity functions are assessed in terms of the Richardson number and the stability parameter z/L . The resulting functions are expressed in an analytical form, which is unaffected by self-correlation. Turbulence within the stably stratified boundary layer is classified into four regimes: nearly-neutral ($0 < z/L < 0.02$), weakly stable ($0.02 < z/L < 0.6$), very stable ($0.6 < z/L < 50$), and extremely stable ($z/L > 50$). The flux-based similarity functions for gradients are constant in nearly-neutral conditions. In the very-stable regime, the dimensionless gradients are exponential. The existence of scaling laws in extremely-stable conditions is doubtful.

Product: Sorbjan and Grachev 2010.



MORGAN HEIM/CIRES

CIRES Fellow Rainer Volkamer discusses the flight plan for the California Nexus project (CalNex) with Ron Moyers, lieutenant (junior grade) pilot for NOAA.

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, NOAA RESEARCH
CIRES LEAD: ANNE JEFFERSON

NOAA Goal 3: Weather and Water

Project Goal: Study intercontinental transport events to improve the understanding of their importance in affecting overall air quality and impacts on public health.

Milestone 1. As part of the Department of Energy's Atmospheric Radiation Measurement Program, aerosol optical and cloud forming properties from the Azores Island in the Atlantic will be measured.

In support of the Clouds, Aerosol, and Precipitation in the Marine Boundary Layer (CAP-MBL) field campaign, the aerosol system of in situ measurements was deployed to Graciosa Island, Azores in May 2009. Marine stratus moderate the flux of solar radiation as well as sea-surface temperature and so are critical to understanding climate change. Aerosols are precursors to cloud droplets and have secondary effects on cloud albedo and lifetime. The role of aerosols in cloud formation is the single largest uncertainty in radiative forcing of climate, so characterization of aerosols in cloud microphysics is essential to predicting climate change.

Variability in the aerosol absorption at Graciosa suggests that the area is influenced by long-range transport of pollution to the remote marine site. A method for estimating the cloud condensation nuclei (CCN) as a function of percent supersaturation from the aerosol properties of single scatter albedo and backscatter fraction was developed using the aerosol data from Graciosa and three other sites. The results were published in *Atmospheric Chemistry and Physics Discussions*. The method provides a simple means to estimate the cloud condensation nuclei formation from aerosol optical properties instead of more intensive methods which employ size-dependent composition measurements.

Product: Jefferson 2010.

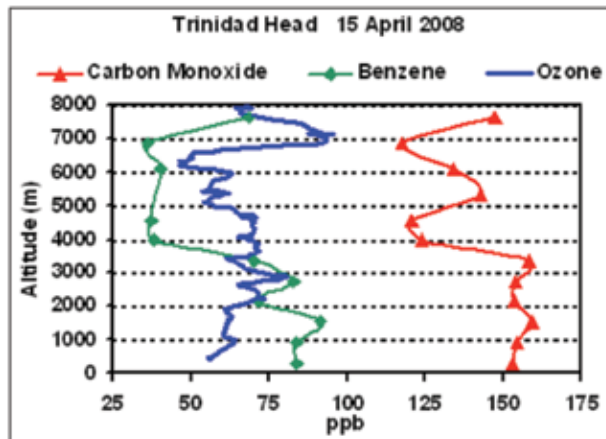
Milestone 2. Analyze ozone profile measurements along with other constituent measurements obtained from small aircraft to identify ozone sources that are associated with long-range transport.

The focus of this project was changed slightly to analyze the surface ozone and ozone vertical profile measurements at Trinidad Head, CA and at Mauna Loa, HI for longer-term changes that could be related to changing Asian emissions.

An analysis of a comprehensive set of ozone-profile data from western North America indicates that ozone in the free troposphere has increased (Cooper et al. 2010). It has also been found that tropospheric background ozone amounts entering the U.S. West Coast, as measured at

Trinidad Head, play a significant role in the ability of inland California locations to meet air-quality standards (Parrish et al. 2010).

Products: Cooper et al. 2010 and Parrish et al. 2010.



Aircraft profile from Trinidad Head in April 2008 showing an enhanced layer of ozone, carbon monoxide, and benzene from the surface to 4 km that was associated with biomass burning in Eurasia.

PSD-13 Air Quality

FEDERAL LEAD: ALLEN WHITE, NOAA RESEARCH
CIRES LEAD: SARA MICHELSON

NOAA Goal 3: Weather and Water

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. Analyze data from the International Polar Year (IPY)/International Chemistry Experiment in the Arctic Lower Troposphere (ICEALOT) cruise on research vessel Knorr for planetary boundary layer flux aspects of winter pollution off the U.S. East Coast (contrast with the New England Air Quality Study).

CIRES and ESRL deployed a comprehensive suite of instruments on the research vessel *Knorr* for the 2008 ICEALOT cruise (<http://saga.pmel.noaa.gov/Field/icealot/>), including a bow-mounted turbulent flux measurement package, ceilometer, cloud radar, radiosondes, and a microwave radiometer. The data from this expedition have been processed, and analysis is ongoing to investigate the marine boundary layer characteristics in the context of aerosol and chemistry outflows from the North American continent into the sub-Arctic Atlantic area. Subsequent analysis and comparison with the results from previous endeavors (e.g., the New England Air Quality Study) will be undertaken in the near future.

Product: A technical memorandum is under development, and the data have been posted to <http://www.esrl.noaa.gov/psd/psd3/cruises/>.

Milestone 2. Participate in the 2010 California Study by deploying a network of wind profilers and related meteorological equipment to provide the meteorological context for air pollution events in California. Monitor the

data collection and provide real-time access to the data, as well as derived products, including mixing depth and wind-profiler-based trajectories.

CIRES staff participated in the mission California Nexus (CalNex) with deployment of wind profilers and other meteorological observing equipment. Meteorological data from these sensors were provided in real-time <http://www.esrl.noaa.gov/psd/data/obs/> and were incorporated into a wind profiler-based trajectory tool (<http://www.esrl.noaa.gov/psd/programs/2010/calnex/traj/>). The data and trajectory tool were interpreted quickly to support CalNex mission goals, which were focused on the intersection of air quality and climate change in California.

CSD-08 Regional Air Quality

FEDERAL LEAD: DAVID PARRISH, NOAA RESEARCH
CIRES LEAD: FRED FEHSENFELD

NOAA Goals 2 and 3: Climate and Weather and Water

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 contributes to the enhancement of air quality prediction and forecasting capabilities.

Milestone 1. Prepare for the 2010 California Nexus Air Quality Study in California and continue to study processes that affect air quality in the Colorado Front Range area.

In preparation for the 2010 California Nexus mission (CalNex, for the nexus of climate change and air quality in California, www.esrl.noaa.gov/csd/calnex/), a small pilot study was conducted, with NOAA's Tunable Optical Profiler for Aerosol and oZone (TOPAZ) lidar flown a Twin Otter aircraft in the Los Angeles (LA) and Fresno, CA study areas in mid-July 2009. The primary objective of this pilot study was to investigate transport patterns associated with mountain slope flows and their impact on ozone distribution within the Central Valley and ozone export out of the LA Basin.

In response to daytime heating of the mountain slopes along the east side of the Sierra Nevada and the edges of the LA Basin, upslope flows occur that push ground-level pollutants that have accumulated in the San Joaquin Valley and the LA Basin into, and sometimes over, the adjacent mountains. During four research flights, upslope transport of high levels of ozone was observed in shallow layers along the flanks of the Sierra Nevada and the mountains surrounding the LA Basin. No evidence was found of transport of ozone across the Sierra Nevada; however, high concentrations of ozone were frequently lifted over the shallower ridges of the San Gabriel and San Bernardino Mountains and transported into the Mojave Desert. Significant transport of ozone through several major mountain gaps was also observed. In one case, high concentrations of ozone (greater than 100 ppbv) were found lofted by the mountain chimney effect into the free troposphere to heights of at least 4 km mean sea level, well above the peaks of the San Gabriel Mountains (Figure 1). Trajectory calculations suggest that this elevated ozone plume from the LA Basin was transported to Utah and Colorado, where some of the ozone was likely mixed down to the surface, causing an increase in ground-level ozone. The results of this case study have been published

in Langford et al. 2010.

Following the CalNex pilot study, two test flights were conducted over northeastern Colorado, during which the University of Leeds Heterodyne Atmospheric Laser Optics (HALO) Doppler wind lidar was mounted alongside the TOPAZ ozone lidar in the NOAA Twin Otter. The objective of these test flights was to demonstrate co-located wind and ozone profile measurements from an airborne platform. This measurement capability allows the determination of ozone fluxes and thus the quantification of ozone transport. The HALO lidar was mounted pointing sideways at a 20-degree-off-nadir angle, providing measurements of the wind component perpendicular to the flight direction. An example of vertically resolved ozone flux transverse to the aircraft heading is shown in Figure 2.

Product: Langford, et al. 2010.

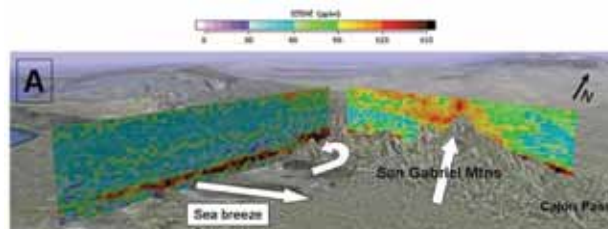


Figure 1: Upslope transport of high ozone concentrations to more than 4 km MSL above the San Gabriel Mountains measured with the TOPAZ lidar on 17 July 2009.

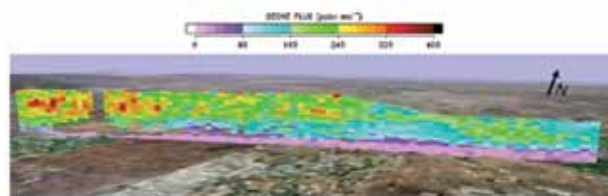


Figure 2: Ozone flux perpendicular to the flight direction measured with co-located TOPAZ and HALO lidars over northeastern Colorado on 31 July 2009.

Milestone 2. Apply new techniques to analyze observations from lidar studies of jet plume characteristics to improve estimates of emission rates.

Previously, CIRES and NOAA researchers successfully developed, demonstrated, and applied lidar measurement and analysis tools for measuring dispersion of exhaust plumes from aircraft jet engines during normal airport operations. Backscatter from the particles formed in the exhaust was commonly adequate as a tracer to quantify plume (particle) dispersion. A method was also invented to infer particulate mass emission factors of those particles from the same data. A spinoff of the latter during the last year was a paper (pertinent to a wider variety of applications) describing the proper method to calculate light scattering from a mixture of gases and correcting some erroneous concepts that sometimes had appeared in previous literature (Eberhard 2010).

Major funding support for this research was from agencies outside of NOAA and CIRES. This milestone was based on the Federal Aviation Administration's (FAA) provision of the first installment of funding to prepare for future campaigns, including a major improvement of the lidar to tailor it for this application. However, a reorganization and shift in research emphasis at FAA resulted in termination of funding, requiring the tabling of this

project midstream. Recent investigations have considered the possibility of transferring these methods to measuring particulate emissions and exhaust plume dispersion from train locomotive engines.

Product: Eberhard 2010.

Milestone 3. Carry out detailed planning for the 2010 CalNex combined air-quality and climate field study.

The California Nexus (CalNex) mission in the spring of 2010 was focused on atmospheric research at the nexus of air quality and climate change. Although separate programs are in place to research and manage both air quality and climate change effects, these problems are not separate and in fact are intimately connected. These connections arise because in many cases the agents of concern are the same, and in many cases the sources of the causative agents are the same or strongly related. Often, efforts to address one of these issues can be beneficial to the other, but in other cases policies addressing one issue can have unintended detrimental impacts on the other.

To provide a scientific basis to inform decisions that involve both air quality and climate change, the CalNex mission was organized in spring of 2010 in collaboration with the California Air Resources Board (CARB). Measurements of trace gases, aerosol, and their effects on radiative forcing of climate were made from a NOAA WP-3D research aircraft, from the Woods Hole research vessel *Atlantis*, and from a surface site on the campus of the California Institute of Technology (Caltech). In addition, collaborations were established with 1) a group from Caltech and others making measurements from a Center for Interdisciplinary Remotely-Piloted Aircraft Studies Twin Otter aircraft and two lidar aircraft (NASA King Air and NOAA Twin Otter); 2) a group supported by the National Science Foundation and CARB making measurements in the Central Valley; 3) U.S. Department of Energy (DOE) scientists making airborne and ground-based measurements in the Sacramento area; and 4) others. Measurements were conducted from mid April until mid-July 2010.

For the planning of CalNex, the efforts of CIRES scientists at ESRL were focused on establishing the contacts and collaboration with CARB, NSF, many academic colleagues, and with DOE; on helping to secure the funding for all the necessary components of the study; and in providing the framework for collaboration in terms of coordination between platforms, data sharing and, in the future, joint data analyses and publication.

Milestone 4. Measure the UV absorption spectrum of the ClO dimer (Cl₂O₂) in laboratory experiments over the range of wavelengths and temperatures most relevant to polar stratospheric photochemistry.

The ultraviolet (UV) photolysis of Cl₂O₂ (dichlorine peroxide) is a key step in the catalytic destruction of polar stratospheric ozone. Although the UV absorption spectrum of Cl₂O₂ has been reported in a number of laboratory studies, a recent study reported results in direct conflict with all earlier work. This recent work, if correct, would significantly alter the current understanding of polar stratospheric chemistry and ozone depletion in this region of the atmosphere. In the present laboratory study, the gas-phase UV absorption spectrum of Cl₂O₂ was measured using diode array spectroscopy and absolute cross sections reported for the wavelength range most critical to atmospheric photo-

chemistry. The study confirmed earlier (1990) work from this laboratory, which was performed using a different experimental approach. An explanation for the discrepancy between our work and the recently published controversial study was identified as part of the new study.

Product: Papanastasiou et al. 2009.

Milestone 5. Continue laboratory measurements to evaluate radical and molecular production formation in the UV/visible photolysis of key atmospheric oxygenated compounds, such as acetone (CH₃C(O)CH₃) and formaldehyde (H₂CO).

Resources were diverted from this research theme to focus on chlorine photochemistry and kinetics related to ozone depletion in the polar stratosphere. Studies of the photochemistry of atmospheric oxygenated compounds will be resumed at a later date. The project undertaken involved the direct measurement of rate coefficients for the ClO + ClO + M reaction, which is a key reaction in the most important ozone-depletion reaction mechanism, over a range of temperatures and pressures relevant to polar stratospheric chemistry. This work identified systematic differences in the efficiency of the reaction under these conditions from values currently recommended for atmospheric modeling. An explanation for the discrepancies and the implications to the understanding of polar stratospheric chemistry and ozone recovery will be pursued in future studies. A manuscript describing this work is in preparation.

Product: A manuscript is in preparation.

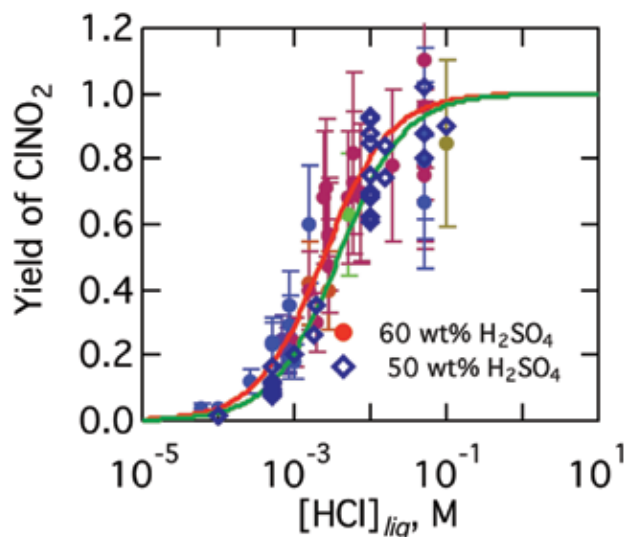
Milestone 6. Measure chlorine activation in laboratory experiments of the heterogeneous reaction of dinitrogen pentoxide (N₂O₅) with hydrogen chloride (HCl)-doped sulfate aerosol and bulk surfaces.

Heterogeneous reactions occurring on sulfate aerosol in the polar stratosphere play an important role in the conversion of chlorine reservoir compounds (e.g. HCl and ClONO₂) into photo-labile active forms such as Cl₂. One of the major loss processes for N₂O₅ in the stratosphere is its heterogeneous removal on sulfate aerosol. Previous studies have only looked at the change in N₂O₅ uptake on sulfuric acid as chloride ions are added to sulfuric acid and not the production of the reaction products. The importance of this chlorine activation chemistry on HCl containing H₂SO₄ aerosol in the stratosphere and its impact on ozone abundance are currently not well known. To evaluate the possible significance of the reaction of N₂O₅ on HCl-doped H₂SO₄ in the stratosphere, knowledge of the reactive uptake coefficients, γ , and product yields, Φ , under stratospheric conditions are needed.

A laboratory study was conducted of the uptake of N₂O₅ on HCl-doped 50-60 percent H₂SO₄ solutions under conditions relevant to stratospheric aerosols, to examine the yields of ClONO₂ and Cl₂. Experiments were performed in the temperature range of about 200-220 K using a rotating wall flow tube reactor coupled to a chemical ionization mass spectrometer for the detection of reactants (N₂O₅ and HCl) and products (ClONO₂, Cl₂), using I⁻ as the reagent ion. The uptake coefficients, γ , of N₂O₅ on pure H₂SO₄/H₂O (different weight percent of H₂SO₄) and HCl-doped H₂SO₄ (range of HCl concentrations in liquid H₂SO₄: 10⁻⁴ M-0.1 M) were found to be independent of temperature and composition (weight percent of H₂SO₄

and HCl concentration) consistent with previous studies from this laboratory and by other investigators. ClNO_2 was observed as a major gas-phase product and its yield was found to be a strong function of the liquid-phase HCl concentration. The Cl_2 yield was very small, less than 1 percent under all conditions studied.

The atmospheric implications of these findings were examined using a two-dimensional atmospheric model. The chemical mechanism of the heterogeneous chemistry will be discussed in a manuscript under preparation, and will be presented in the Gas Kinetics Symposium in Belgium on 18-23 July 2010.



Chlorine nitrite, ClNO_2 , was found to be a major gas-phase product of the reaction of dinitrogen pentoxide with hydrogen chloride-doped solutions of sulfuric acid (laboratory conditions relevant to stratospheric aerosols). The yield of chlorine nitrite, ClNO_2 , is shown in this figure to be a strong function of the concentration of hydrogen chloride in the solution.

GSD-02 Regional Air Quality Prediction

FEDERAL LEAD: JOHN BROWN, NOAA RESEARCH
CIRES LEAD: GEORG GRELL

NOAA Goal 3: Weather and Water

Project Goal: Design and evaluate new approaches for improving air quality prediction.

Milestone 1. Introduce aerosol prediction capability into the Flow-following, finite-volume Icosahedral global weather prediction model (FIM), using the Goddard Chemistry Aerosol Radiation and Transport (GOCART) module together with global wildfire definition and global aerosol emissions data. Make aerosol predictions on test cases.

The GOCART aerosol modules have been successfully included into the FIM. An emissions processor from the Weather Research and Forecast-Chemistry model (WRF-Chem) was modified for use with the FIM to provide global wild fire 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" has been running in real time twice a day since the major volcanic eruption in Iceland in April. Results are being displayed on <http://fim.noaa.gov>.

Milestone 2. Continue to coordinate worldwide development of Weather Research and Forecasting Model-Chem (WRF-Chem) as an air-quality prediction tool.

CIRES' leadership role in the development of this modeling system continues. WRF-Chem version 3.2 was released in April of 2010 with many new additions, including effects of shallow convection (provided by ESRL's Global Systems Division [GSD]), lightning NO_x parameterizations (provided by the National Center for Atmospheric Research [NCAR]), new additions to chemical mechanisms (provided by NCAR, the Pacific Northwest National Laboratory, and ESRL's Chemical Sciences Division [CSD]), coupling of GOCART aerosols with atmospheric radiation (CSD and GSD), and new and improved scalar transport (NCAR and GSD). Volcanic ash transport and ash-fall predictions have been added in collaboration with University of Alaska Fairbanks and the Centro de Previsão de Tempo e Estudos Climáticos in Brazil in the fall of 2009.

RP-04 Intercontinental Transport and Chemical Transformation

■ CSD-05 Tropospheric and Stratospheric Transport and Chemical Transformation

CSD-05 Tropospheric and Stratospheric Transport and Chemical Transformation

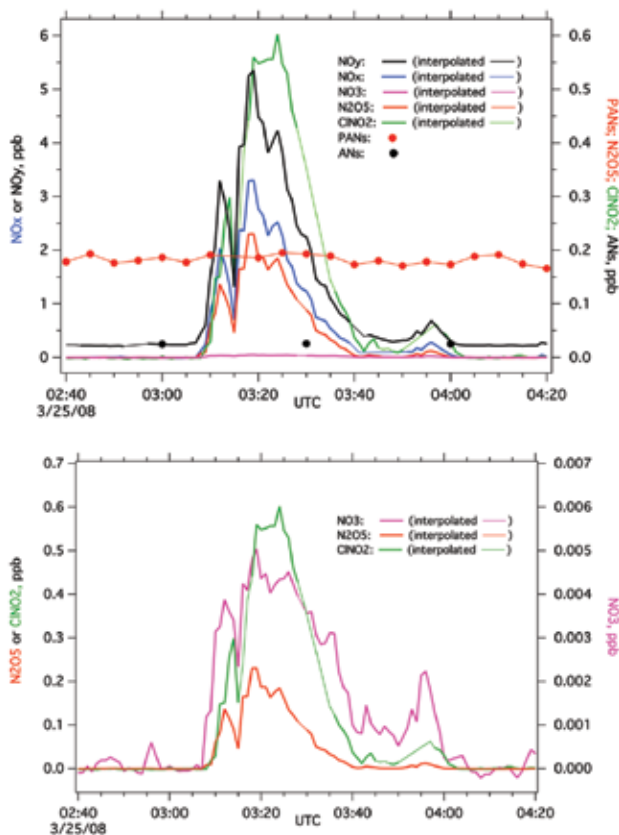
FEDERAL LEAD: TOM RYERSON, NOAA RESEARCH
CIRES LEAD: ERIC WILLIAMS

NOAA Goals 2 and 3: Climate and Weather and Water

Project Goal: Carry out modeling studies and airborne and surface measurements of chemical species in order to elucidate the processes involved in the intercontinental transport of photochemical pollution.

Milestone 1. Analyze, interpret, and publish the climate-related results from the International Chemistry Experiment in the Arctic Lower Troposphere (ICEALOT) field mission.

ICEALOT was a ship-based measurements program focused on data collection at the surface of the ice-free region of the Arctic. This region is highly susceptible to climate perturbations (e.g., rapid sea-ice decline), but little is known of the effects at the surface of pollutant emissions within it, or long-range transport of pollution into it, because most research has been conducted at ground sites (e.g., Barrow, AK) or high-elevation sites (e.g., Mt. Zeppelin, Svalbard). ICEALOT was designed to gather information about background levels of pollutants, emission sources, transport, and transformation of aerosol and gaseous species, and the dynamics of the atmosphere over ice-free water.



The top panel shows the time series of the individual reactive nitrogen species measured in a plume of ship exhaust emitted about three hours earlier. The bottom panel shows three of the measured species on an expanded scale. The very high degree of correlation, as well as the high quality of the data, allows us to examine in detail the nighttime chemistry of reactive nitrogen, especially the production of nitryl chloride (ClNO₂) which converts non-reactive aerosol chloride into highly reactive chlorine atoms. From Williams et al. 2010.

Measurements from the research vessel *Knorr* of gas and aerosol species revealed a number of interesting aspects of chemistry and transport into, away from, and within the ice-free Arctic in springtime. In general, the marine surface layer in this region was found to have very low levels of gas-phase species, such as oxides of nitrogen, oxides of sulfur, and volatile organic compounds (VOCs), normally associated with pollution. However, long-lived pollutants, such as carbon monoxide, were present at elevated levels. A few key highlights are:

- 1) The transit across the North Atlantic demonstrated that Arctic air parcels with depleted ozone are transported over considerable distances (Gilman et al. 2010).
- 2) Ship exhaust released into the cold marine boundary layer at night is capable of producing substantial quantities of nitryl chloride, a chemical species that releases highly reactive halogen atoms after sunrise (figure above and Williams et al. 2010).
- 3) Even though the northernmost regions of Europe are sparsely populated, significant levels of pollutants are released, especially from industrial areas such as the Kola Peninsula.
- 4) The chemistry that destroys ozone was examined in some detail and possible links to two biogenic species—dimethyl sulfide and bromoform—were observed (Lerner

et al. 2010).

5) Levels of black carbon and other aerosol species were generally quite low. The aerosol was typically highly acidic and high in sulfate, consistent with the well-aged air parcels characterized by the gas-phase species.

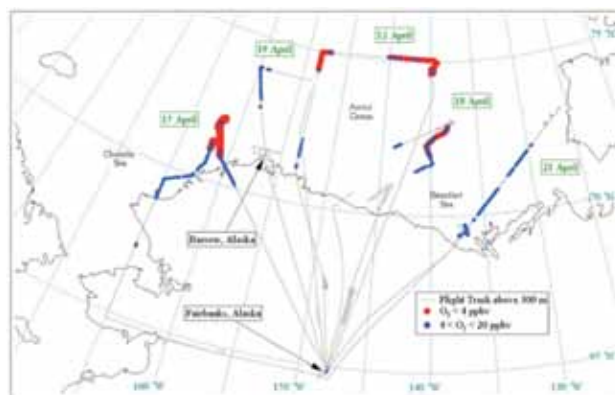
6) Data from remote sensing instruments generally indicated a strong capping inversion that prevented mixing of upper air parcels with surface air. This is consistent with the aerosol and gaseous species data

Product: A manuscript has been submitted and two others are in preparation.

Milestone 2. Analyze, interpret and publish the climate-related results from the Aerosol, Radiation, and Cloud Processes affecting Arctic Climate (ARCPAC) field mission.

Ozone is a greenhouse gas and understanding global ozone abundance is important to predicting climate. Ozone reductions caused by reactive halogens from the ocean have been modeled to occur throughout the troposphere, but experimental verification of these model results regarding halogen chemistry and its impact on ozone is challenging. During the ARCPAC field mission in the spring of 2008, new measurements of inorganic reactive halogen compounds were performed. These aircraft-based measurements showed that severe ozone depletion was confined to the Arctic marine boundary layer that was capped by a temperature inversion at 200- to 500-m altitude. In the marine boundary layer over the Arctic Ocean, soluble bromide and photochemically active bromine compounds were consistently elevated and ozone was depleted. Also, HOBr was shown to rapidly convert to Br₂ on Teflon inlet lines, explaining previous observations of Br₂ that were difficult to interpret. Lastly, BrO observations were compared with those from satellites, demonstrating that interpretations of satellite observations may have overstated the tropospheric burden of arctic BrO. These findings will be useful in assessing the importance of oceanic sources of photochemically active halogens on tropospheric ozone

Products: One manuscript has been submitted, another is in preparation, and Neuman, J.A. et al. (2010), Bromine measurements in ozone depleted air over the Arctic Ocean, *Atmos. Chem. Phys.*, is in press.



1-sec measurements of ozone on five WP-3D flights originating from Fairbanks, AK. Red circles are major ozone depletions, blue are partial ozone depletions, and no symbol represents ozone greater than 20 ppbv. Gray lines indicate flight tracks over 300 m altitude. Gaps in the flight tracks (on 18 April, for example) indicate flight altitudes less than 300 m and ozone greater than 20 ppbv.

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 LEAD: DAN MURPHY, NOAA RESEARCH
CIRES LEAD: JOSHUA SCHWARZ

NOAA Goal 2: Climate

Project Goal: Carry out airborne, shipborne, and ground-based experiments that characterize the chemical composition of radiatively important aerosols in the upper troposphere and at Earth's surface.

Milestone 1. Analyze ship-based Doppler lidar measurements of clear-air vertical velocities and vertical wind shear over the ocean to understand aerosol-cloud-precipitation dynamical interactions and perform satellite validation.

Data collected during the 2008 Variability of the American Monsoon System (VAMOS) Ocean-Cloud-Atmosphere-Land Study regional Experiment (VOCALS) are being used to study stratocumulus topped boundary layer decoupling using clear-air velocity variance and skewness profiles, turbulence kinetic energy profiles, surface-based mixing heights, and cloud-radar-derived cloud-top heights and in-cloud vertical velocity variance.

In the region off the coast of Chile where these measurements were made, the nocturnal boundary layer is typically fully coupled. Nighttime radiative cooling of the stratocumulus cloud deck drives strong top-down convection to the ocean surface. During the day the sunlight warms the cloud deck, convection weakens, and the boundary layer becomes decoupled. This diurnal pattern can be seen in the compilation of vertical velocity variance profiles shown in Figure 1, and the associated decoupling parameter calculated using estimates of the mixed layer height, Figure 2.

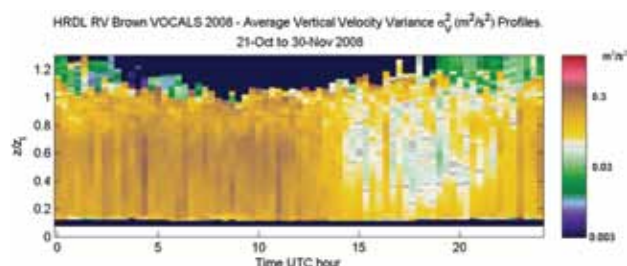


Figure 1: Averaged σ_w^2 profiles for each 20-minute period of the day, created using data acquired when the ship was west of 73° longitude between 21 October and 30 November 2008.

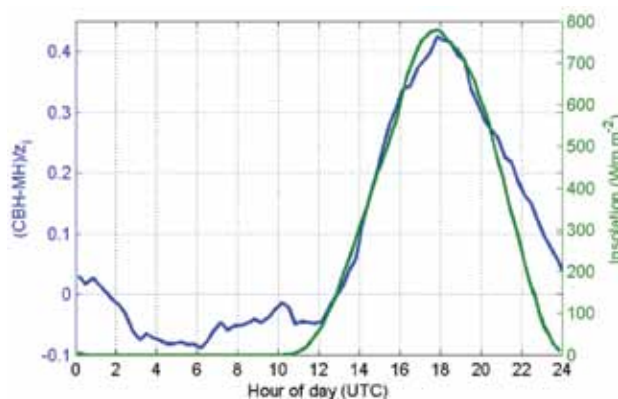


Figure 2: Average diurnal cycle in the Doppler lidar decoupling parameter plotted versus UTC time. Average insolation is overplotted in green.

Milestone 2. Analyze field data from the research vessel Knorr during the International Chemistry Experiment in the Arctic Lower Troposphere (ICEALOT) experiment for the impact of European pollution.

Aerosol properties were measured onboard the research vessel *Knorr* in the European Arctic Ocean during the International Polar Year's ICEALOT campaign (March-April 2008). This experiment was designed to give insights into the characteristics and sources of aerosols emitted within the Arctic or transported from mid-latitudes. One of the goals was the characterization of Arctic haze, a phenomenon that originates from the confinement of pollutants in the stable Arctic springtime boundary layer. The multi-wavelength cavity ring-down spectrometer (CRD) provided measurement of both aerosol light extinction and its dependence on relative humidity, here expressed as gamma. The CRD was coupled with the photo acoustic spectrometer to determine aerosol absorption and the single scattering albedo of the sampled aerosols. All the listed parameters are reported at 532 nm. In general, aerosol levels were rather low (less than 10 M/m), and particles were highly hygroscopic (gamma greater than 0.9) and non-absorbing (albedo about 0.95). Unusually high gamma values (up to 2.5) characterized the air masses sampled off the Kola Peninsula (71°N-19°E): such highly hygroscopic aerosols coincided generally with SO₂ plumes, and at times were highly correlated with bursts of ultra-fine particles. Arctic haze was less absorbing and less hygroscopic than emissions from the Kola Peninsula. Emissions were also observed from fishing boats sampled in the vicinity of the Norwegian coast and a pollution event from North Europe. These results are important for further understanding the characteristics of Arctic springtime aerosols and assessing their direct radiative effect for the overall forcing of a warming Arctic system.

Product: Presentations at the fall 2009 American Geophysical Union meeting.

Milestone 3. Publish and present field data from the NOAA WP-3D research aircraft during the Aerosol Radiation, and Cloud Processes affecting Arctic Climate (ARCPAC) experiment.

In April 2008, the NOAA WP-3D aircraft conducted research flights in northern Alaska and over the Arctic Circle as part of the ARCPAC field study. The goal of the study was to characterize the springtime background air and

pollution transported to the region, to investigate effects of human activity on chemistry and climate of the Arctic.

Dense aerosol layers were frequently encountered above 400 m over the Arctic. Organic and nitrate aerosol mass and black carbon (BC) were well correlated with carbon monoxide (CO) and showed greater enhancements with respect to CO in biomass-burning plumes originating in Siberia and in southern Russia, near the Kazakhstan border. Analysis of the organic mass spectra and relative humidity dependence of extinction measurements in biomass-burning plumes, which were generally 5-10 days old, indicate the presence of strongly oxidized organic species, and thus significant processing of these organic-rich absorbing layers—a factor that can affect water uptake and indirect climate effect of organic aerosols. The dependence of sulfate upon CO varied within different plumes. Greater enhancements in sulfate with respect to CO were observed in plumes with less influence from biomass-burning events, indicating industrial and other anthropogenic sources as the dominant source of sulfur dioxide. Combination of in situ measurements and transport modeling of CO show that in the spring of 2008 it was transported biomass-burning plumes, as opposed to commonly believed anthropogenic and industrial plumes, that were responsible for at least doubling the burden of aerosol mass, aerosol organics, and BC compared with the background in the layers aloft. However, in the surface layer over the Arctic sea ice, lower concentrations of non-refractory submicron aerosol mass, dominated by non-neutralized sulfate aerosol, were observed along with sea salt. Low mixing ratios of acetonitrile and low number fraction of biomass-burning aerosols in the Arctic surface layer suggest that the biomass-burning plumes did not substantially influence the aerosol composition in this surface layer during the sampling time.

Besides meeting presentations and the publication below, two other papers are in preparation by Brock et al. and McNaughton et al., using the microphysical, chemical, and optical aerosol data obtained during ARCPAC.

Product: Presentations at the fall 2009 American Geophysical Union meeting and Warneke et al. 2010.

Milestone 4. Model case studies of the interaction of aerosols with clouds and compare with Arctic field data.

Arctic clouds play a pivotal role in the Arctic climate system. For example, their absence during the summer of 2007 has been linked to the unprecedented ice melt that year. Although progress has been made, our ability to predict Arctic clouds is limited because many of the fundamental physical processes remain poorly understood. A particularly challenging problem in Arctic cloud research is our inability to simulate the long-lived, self-sustaining mixed-phase (ice plus water) clouds that frequently occur from autumn through spring. The spatial and temporal coverage of these clouds depends critically on the nucleation and growth of the ice phase. To this end, a detailed microphysical model has been built to explore the nucleation of ice on aerosol particles (heterogeneous ice nuclei) and the complex growth of these myriad particle habits through vapor diffusion. The model was adapted from one of our existing water cloud models and includes an innovative method of dealing with the variety of ice particle sizes and habits. It has been applied to two case studies from recent field experiments and is being used to identify the environmental conditions under which clouds are most (or

least) likely to be self-sustaining. These results will be used to develop parameterizations of key processes that can be used in larger-scale models.

Milestone 5. Use data from the 2008 ARCPAC study to examine the mass, mixing state, and optical size of individual black-carbon (BC) particles in remote high-latitude regions.

Understanding the processes controlling BC in the Arctic is crucial for evaluating the impact of anthropogenic and natural sources of BC on Arctic climate. Measurements of BC in the Arctic troposphere above the surface are limited but they are needed to constrain transport and microphysics in global aerosol models to better evaluate climate impacts.

Vertical profiles of BC mass were observed from the surface to near 7-km altitude in April 2008, using a Single-Particle Soot Photometer (SP2) during flights on the NOAA WP-3D research aircraft from Fairbanks, AK. In the free troposphere, the Arctic air mass was influenced by long-range transport from biomass-burning and anthropogenic source regions at lower latitudes, especially during the latter part of the campaign. Maximum average BC mass loadings of 150 ng/kg were observed near 5.5-km altitude in the aged Arctic air mass. In biomass-burning plumes, BC was enhanced from near the top of the Arctic boundary layer (ABL) to 5.5 km compared with the aged Arctic air mass. The optical sizes of individual BC-containing particles sampled from the aged Arctic air mass were consistent with substantially higher fractions of non-BC internally mixed material than previously observed with the NOAA SP2 in the tropics and at midlatitudes. At the bottom of some of the profiles, positive vertical gradients in BC were observed in the vicinity of open leads in the sea-ice. BC mass loadings increased by about a factor of two across the boundary layer transition in the ABL in these cases while carbon monoxide (CO) remained constant, evidence for depletion of BC in the ABL. Size distributions of BC mass did not indicate size-dependent removal. BC mass loadings were positively correlated with ozone (O₃) in ozone depletion events (ODEs) for all the observations in the ABL suggesting that BC was removed by dry deposition of BC on the snow or ice because molecular bromine (Br₂), which photolyzes and catalytically destroys O₃, is thought to be released near the open leads in regions of ice formation. The deposition flux of BC mass to the snow was estimated using a box model constrained by the vertical profiles of BC in the ABL. The open leads may increase vertical mixing in the ABL and entrainment of pollution from the free troposphere possibly enhancing the deposition of BC to the snow.

Product: These results were presented orally at the spring and fall American Geophysical Union meetings in 2009, in poster format at the NOAA Physical Sciences Division Laboratory Review in March 2010 and the CIRES External Review in April 2010; and in Spackman et al. 2010.

INTEGRATING ACTIVITIES

IA-01 Science and Society

- CSD-10 Scientific Assessments for Decision Makers
- Policy-01 Science Policy Lecture Series

CSD-10 Scientific Assessments for Decision Makers

FEDERAL LEAD: A.R. RAVISHANKARA, NOAA RESEARCH
CIRES LEAD: CHRIS ENNIS

NOAA Goal: Climate

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: Carry out the early planning, organizational, and drafting stages of the United Nations Environmental Programme (UNEP)/World Meteorological Organization (WMO) 2010 scientific state-of-understanding assessment of the ozone layer for the U.N. Montreal Protocol.

In the *Scientific Assessment of Ozone Depletion: 2010* (the *Assessment*), the world's leading scientists define the current scientific understanding of the ozone layer and the phenomenon of stratospheric ozone depletion, updating the 2006 *Assessment* as required by Article 6 of the United Nations Montreal Protocol on Substances that Deplete the Ozone Layer. This is a highly coordinated multi-agency effort involving NOAA, UNEP, WMO, NASA, the European Commission, and numerous universities and agencies worldwide. The report is truly global in its importance, serving as the centerpiece of all national and international discussions related to ozone depletion. It is relied upon by scientists in the international community in its assessment of the current state of scientific understanding on the topic. By summarizing scientific findings in policy-relevant terms, the *Assessment* plays a unique role as a bridge between the scientific community and decision makers. Specifically, the science in the *Assessment* will underpin future international decisions regarding ozone-depleting substances and the protection of the ozone layer.

The 2010 *Assessment* includes an update on atmospheric processes underlying ozone abundance at the poles and globally, observations of both short-lived and long-lived ozone-depleting substances in the atmosphere, expectations for recovery of the ozone layer, and discussion of the current state of understanding regarding the interactions between climate and the ozone layer.

CIRES scientists have made many contributions to the 2010 *Assessment*, including serving as coauthors, reviewers, and coordinating editor of the entire report. In FY10, the major milestones in the drafting and review of the document were completed, and all major international meetings associated with the review of the report were successfully held. The executive summary of the *Assessment* will be released in August 2010, and the final printed copies of the report will be available in April 2011.

Policy-01 Science Policy Lecture Series

FEDERAL LEAD: RANDALL DOLE, NOAA RESEARCH
CIRES LEAD: ROBERTA KLEIN

NOAA Goal 2: Climate

Project Goal: Provide useful information that will help improve the relationship between societal needs and science and technology policies.

Milestone 1. Continue the highly successful noontime seminar series held at the Center for Science and Technology Policy Research (CSTPR) that brings in students, faculty, and researchers to discuss their science policy research; and conduct additional outreach to departments that have not previously been involved to broaden the audience.

The CSTPR partnered with the Institute of Behavioral Science (IBS) Environment and Society Program to produce fall and spring noontime seminar series. A partnership with the CU-Boulder Renewable and Sustainable Energy Institute (RASEI) during the spring semester resulted in eight seminars focused on energy policy. These partnerships helped attract a broader audience for the noontime talks, since IBS and RASEI helped to advertise the talks to their members. Noontime talks were held at various locations around campus including the CIRES auditorium and the Atlas Building as an additional attempt to broaden the audience, which ranged from 20 to 50 people per talk.

In fall of 2009, CSTPR staff organized a panel discussion titled "The first 300 days: An assessment of President Obama's energy and climate policy," featuring two CSTPR faculty. A Center staff member gave the keynote address at RASEI's fall symposium: "Finding the right trousers: Radically rethinking climate policy and low carbon energy."

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, NOAA RESEARCH
CIRES LEAD: KRISTEN AVERYT

NOAA Goals 2 and 3: Climate and Weather and Water

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

Milestone 1: Colorado River Climate Change Analysis. Utilize U.S. Bureau of Reclamation (USBR)'s Colorado River Seasonal Forecasting (CRSS) model to investigate the vulnerability of the Upper Colorado River basin to changes in inflows based on stochastically-generated streamflows that preserve spectral characteristics identified in historic and paleo records. The CRSS operations model will be used

to analyze how current operating policies perform under differing streamflow regimes. In addition, the operations model will be run in optimization mode to identify how different operating policies would perform under modified streamflows.

CIRES researchers and colleagues have developed a method that directly simulates daily data at multiple locations from a single annual flow value. The procedure is simple, data-driven, and captures observed statistics quite well. The method is compatible with any streamflow generation technique and is not limited to a specific time scale (results were very good for monthly and seasonal in addition to daily). A manuscript, "A non-parametric stochastic approach for multisite disaggregation of annual to daily streamflow," has been resubmitted to *Water Resources Research* after responding to reviewer comments.

WWA-02 Climate Products

FEDERAL LEAD: ROBIN WEBB, NOAA RESEARCH
CIRES LEAD: KRISTEN AVERYT

NOAA Goals 2 and 3: Climate and Weather and Water

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

Milestone 1. Monthly Intermountain West Climate Summary (IWCS): Climate information is widely scattered on the Web and other locations. Water managers and other climate-sensitive sectors have requested a single-monthly summary of climate information including precipitation, temperature, snow water equivalent, long-lead temperature and precipitation outlooks, reservoir levels, and streamflow forecasts.

The new web-based HTML format of the IWCS was unveiled with the March 2009 issue, with a streamlined and more-user friendly content and organization as outlined above. Subsequent issues in 2009 (April, May, July, October) and 2010 (January, March, April, May) continued this format, and user feedback regarding the change has been uniformly positive. Production of the IWCS now takes far less WWA staff time per issue, with little, if any, loss of overall effectiveness in conveying timely and salient climate information. The feature articles and focus pages continue to accompany each issue, and remain in pdf format for ease of printing and sharing. Nearly all of these articles are written expressly for the IWCS.

Milestone 2. Web-based seasonal guidance for water managers, Climate Prediction Center (CPC): Improve ability of federal, state, and local water managers to plan water operations during drought. Provide input to CPC seasonal outlooks.

On the national scale, these climate forecasts continue to be used by wildfire managers in the western United States (11th annual Fire Assessment Workshop in April 2010), and by the CPC, both for seasonal climate forecasts and in particular for the U.S. Drought Monitor Outlook. This input is critical given the role of both the seasonal forecasts and the Drought Monitor Outlook in decision making by water-resource managers.

Milestone 3. National Integrated Drought Information System (NIDIS): As necessary, the Western Water Assessment

(WWA) will provide support activities for NIDIS implementation efforts. This may include providing support for conferences, performing research, and providing input to NIDIS pilot projects, including the anticipated Colorado River pilot.

The partnership between WWA and NIDIS continues to grow, as demonstrated by multiple collaborative efforts over the past year. This includes efforts to build a drought impact and vulnerability indicator suite, research focused on ecological vulnerabilities to climate variability and change in southwestern Colorado, the Colorado Climate Roadshows held throughout the state in late 2009, and the Four Corners Tribal Climate Adaptation Meeting. All these efforts represent new research directions for WWA that have evolved from discussions and collaborations with NIDIS.

Milestone 4. WWA website: Provide a portal into all Western Water activities for researchers, water providers and the public. Website provides extensive documentation on Colorado River climate, various forecasts, and results of past research.

In addition to routine updating and maintenance, several key enhancements were made to the WWA website, including the development of databases of WWA publications (http://wwa.colorado.edu/about_us/DBPubs.html) and presentations (http://wwa.colorado.edu/about_us/present.html) since 1999. Providing access to this information is important to stakeholders sifting through climate-relevant information. WWA will continue to update these databases and it is hoped the interface will be further improved in the coming year.

WWA-03 Climate and Water Affairs

FEDERAL LEAD: ROBIN WEBB, NOAA RESEARCH
CIRES LEAD: KRISTEN AVERYT

NOAA Goals 2 and 3: Climate and Weather and Water

Project Goal: Increase decision makers' knowledge about climate science so they can become better consumers and demanders of climate products and assessments, which will assist WWA in setting its research agenda.

Milestone 1. Dendrohydrological workshops: Increasing interest by water managers in tree-ring reconstructions of streamflow has led to a demand for a hands-on workshop on how the reconstructions are generated and assessed. The goal is to provide water managers with the necessary tools to better interpret the reconstructions and apply them to water planning.

The popularity of the dendrohydrological workshops illustrated the need for paleostreamflow data to inform water managers. To meet the growing demand by resource managers for a clearinghouse of such information, WWA, in collaboration with researchers from the Climate Assessment for the Southwest (CLIMAS), developed a web portal to access paleo records. The new, expanded TreeFlow web resource (<http://treeflow.info>) went live for review in late June 2009 and was publicly announced to stakeholders in September 2009.

Milestone 2. Water Availability Task Force (WATF): Provide technical support for the Governor's drought task force, as needed, including issuing experimental regional seasonal forecasts.



ISTOCK

Depending on drought conditions, WWA team members give monthly-to-seasonal briefings to the Colorado Water Availability Task Force (WATF) and other stakeholders on experimental climate outlooks and other climate forecast products. These briefings are based on the monthly updated website (<http://www.cdc.noaa.gov/people/klaus.wolter/SWcasts/>) that covers the recent and projected evolution of the El Niño-Southern Oscillation phenomenon, discusses the most recent Climate Prediction Center climate forecasts, and examines experimental forecast guidance for the full interior U.S. Southwest, with special emphasis on Colorado. These briefings are critical to informing the WATF about relevant climate phenomena that may affect their decision making.

Milestone 3. Speakers for interested organizations and public events: WWA is often invited to speak on the interaction of climate and water at public events and to various organizations, and will continue to perform this service.

Collectively, WWA researchers gave more than 100 public talks and seminars since 1 July 2009; these were cited, quoted, or interviewed by the media more than 50 times. 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. There are also several projects within the purview of core management activities that focus on enhancing outreach, communication, and education—which are core objectives of WWA.

Milestone 4. Provide Technical Analysis and Education for Front Range Water Providers. A consortium of Front Range Water providers has been awarded an American Water Works Association Research Foundation grant to investigate the changes in runoff that may occur in response to climate change. WWA will provide technical support and educational services for this effort.

The Joint Front Range Climate Change Vulnerability study is nearly complete. The final draft has completed review, and revisions are being made. WWA staff participated in most of the Front Range group's monthly meetings, provided additional technical guidance through informal contact with Denver Water staff, extensively reviewed an early draft, and submitted comments on the final draft. In addition, interaction with Denver Water on the *Water Utility Climate Analysis* white paper on climate models helped to inform the use of climate model information for this project. This interaction is representative of the successful stakeholder-scientist collaborations in which WWA researchers engage.

WWA-04 Management

FEDERAL LEAD: ROBIN WEBB, NOAA RESEARCH
CIRES LEAD: KRISTEN AVERYT

NOAA Goals 2 and 3: Climate and Weather and Water

Project Goal: Provide overall guidance to project as well as day-to-day management.

Milestone 1. General management activities: Hold bi-weekly team meetings. Prepare annual budget. Interact with Regional Integrated Sciences and Assessments (RISA) Program managers. Interact with CIRES and NOAA administrative staff. Establish strategic activities.

WWA's Core Management Team is responsible for maintaining and fulfilling obligations relating to outreach and education, and promoting communication among NOAA's RISA and with other federal partners. The WWA successfully rebid to remain the regional RISA program for at least the next five years, and the Core Team was fundamental in conceiving, drafting, and delivering the proposal. The WWA has been busy implementing many of the novel strategies outlined in the proposal in advance of the initiation of the new funding term. The Core Team is critical to the successful operation of WWA and to enabling the interactions of our researchers with our stakeholders.

IA-03 Resource Development for Educators and Decision Makers

■ Policy-02 Outreach to Decision Makers through the Internet

■ Policy-03 Outreach to Decision Makers through Newsletters

Policy-02 Agricultural Adjustments to Drought

FEDERAL LEAD: ROGER PULWARTY, NOAA RESEARCH
CIRES LEAD: ROBERTA KLEIN

NOAA Goals 2 and 3: Climate and Weather and Water

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.

This is a new project at the CIRES Center for Science and Technology Policy Research that is starting this summer so there are no accomplishments yet to report.

Policy-03 Impact of Earlier Snowmelt on Water Rights Holders in the Intermountain West

THIS PROJECT IS INACTIVE

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Measures of Achievement

CIRES scientists and faculty published 579 peer-reviewed papers in 2009, commanding attention from the scientific community and the news media. International awards and a strong record of service reflect institutional excellence.

Peer-reviewed publications	144
Non-Peer-reviewed publications	161
Journals in which CIRES published	168
Honors and Awards	170
Selected Service and Outreach	172
News	178



Mary Huisenga and Ariann Blankenship take water samples from a frozen Lake Dillon in Colorado.

MORGAN HEIM/CIRES

Publications by the Numbers

CIRES scientists and faculty published 579 peer-reviewed papers during calendar year 2009. The table below tabulates publications by affiliation of first author. CIRES scientists and faculty published an additional 232 non-refereed publications in 2009. 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
CIRES Lead Author	112	177	165	188	141	130	110	158
NOAA Lead Author	60	31	56	20	81	73	99	79
Other Lead Author	110	183	134	145	289	264	385	342
Total	282	391	355	353	511	467	594	579

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<i>Acta Acustica united with Acustica</i>	<i>Cryosphere</i>	<i>Innovation</i>
<i>Advanced Space Research</i>	<i>Current Problems in Atmospheric Radiation</i>	<i>Integrative and Comparative Biology</i>
<i>Advanced Water Resources</i>	<i>Current Science</i>	<i>International Journal of Chemical Kinetics</i>
<i>Advances in Earth Science</i>	<i>Earth and Planetary Science Letters</i>	<i>International Journal of Climatology</i>
<i>Aerosol Science and Technology</i>	<i>Earth Surface Processes and Landforms</i>	<i>International Journal of Ecological Economics and Statistics</i>
<i>Agricultural and Forest Meteorology</i>	<i>Earth, Moon, and Planets</i>	<i>International Journal of Informatics Society</i>
<i>American Journal of Respiratory Cell and Molecular Biology</i>	<i>Earth, Planets, and Space</i>	<i>International Journal of Oceanography</i>
<i>American Midland Naturalist</i>	<i>Ecohydrology</i>	<i>International Journal of Remote Sensing</i>
<i>American Scientist</i>	<i>Ecological Monographs</i>	<i>International Journal of Sustainability Communication</i>
<i>American Society of Limnology and Oceanography Bulletin</i>	<i>Ecology</i>	<i>ISPRS Journal of Photogrammetry and Remote Sensing</i>
<i>Annals of Geophysics</i>	<i>Ecology Letters</i>	<i>Issues in Science and Technology</i>
<i>Annals of Glaciology</i>	<i>Energies</i>	<i>Journal of Acoustical Society of America</i>
<i>Annual Review of Environment and Resources</i>	<i>Energy Forum, Journal of Japan Environment Research Letters</i>	<i>Journal of Advances in Modeling Earth Systems</i>
<i>Annual Review of Marine Science</i>	<i>Environment Science and Policy</i>	<i>Journal of American Water Resources Association</i>
<i>Antarctic Climate Change and the Environment</i>	<i>Environmental Chemistry</i>	<i>Journal of Applied Mathematics and Computation</i>
<i>Antarctic Science</i>	<i>Environmental Engineering and Science</i>	<i>Journal of Applied Meteorology and Climatology</i>
<i>Applied Environmental Microbiology</i>	<i>Environmental Hazards</i>	<i>Journal of Astrophysics</i>
<i>Applied Optics</i>	<i>Environmental Science and Technology</i>	<i>Journal of Atmospheric and Oceanic Technology</i>
<i>Arctic, Antarctic, and Alpine Research</i>	<i>Environmental Values</i>	<i>Journal of Atmospheric and Solar-Terrestrial Physics</i>
<i>Astrobiology</i>	<i>Enzyme and Microbial Technology</i>	<i>Journal of Atmospheric Science</i>
<i>Atmosfera</i>	<i>EOS Transactions of AGU</i>	<i>Journal of Chemical Physics</i>
<i>Atmospheric Chemistry and Physics</i>	<i>Faculty of 1000 Biology Reports</i>	<i>Journal of Climate</i>
<i>Atmospheric Chemistry and Physics Discussions</i>	<i>FEMS Microbiology Letters</i>	<i>Journal of Geodesy</i>
<i>Atmospheric Environment</i>	<i>Field Techniques for Sea Ice Research</i>	<i>Journal of Geophysical Research</i>
<i>Atmospheric Measurement Techniques</i>	<i>Forest Policy Economics</i>	<i>Journal of Geophysical Research- Oceans</i>
<i>Atmospheric Measurement Techniques Discussions</i>	<i>Freshwater Biology</i>	<i>Journal of Geophysical Research- Atmospheres</i>
<i>Atmospheric Ocean</i>	<i>Functional Ecol</i>	<i>Journal of Geophysical Research- Biogeosciences</i>
<i>Atmospheric Research</i>	<i>Geochemistry, Geophysics, Geosystems</i>	<i>Journal of Geophysical Research-Earth Surface</i>
<i>Behavioral Ecology and Sociobiology</i>	<i>Geochimica Cosmochimica Acta</i>	<i>Journal of Geophysical Research-Solid Earth</i>
<i>Biogeochemistry</i>	<i>Geoderma</i>	<i>Journal of Geophysical Research-Space Physics</i>
<i>Biogeosciences</i>	<i>Geoforum</i>	<i>Journal of Glaciology</i>
<i>Biogeosciences Discussions</i>	<i>Geological Society of America (GSA) Today</i>	<i>Journal of Hydrologic Engineering</i>
<i>Biotechnology and Bioengineering</i>	<i>Geological Society of American Bulletin</i>	<i>Journal of Hydrology</i>
<i>Boundary Layer Meteorology</i>	<i>Geology</i>	<i>Journal of Hydrology New Zealand</i>
<i>Bridges</i>	<i>Geophysical Research Letters</i>	<i>Journal of Hydrometeorology</i>
<i>Bulletin American Meteorological Society</i>	<i>Geophysics, Journal of International Geoscientific Model Development</i>	<i>Journal of Intelligent Robotics Systems</i>
<i>Bulletin Earthquake Engineering</i>	<i>Global and Planetary Change</i>	<i>Journal of Medicine and Pulmonary Drug Delivery</i>
<i>Canadian Geographer, The</i>	<i>Global Biogeochemical Cycles</i>	<i>Journal of Pharmacy and Pharmacology A</i>
<i>Chemical Physics Letters</i>	<i>Global Change Biology</i>	<i>Journal of Pharmacy and Pharmacology Supplement</i>
<i>Chinese Journal of Geophysics</i>	<i>Global Environmental Change, Human Policy Dimensions</i>	<i>Journal of Physical Chemistry A</i>
<i>Climate Change Science and Policy</i>	<i>Global Environmental Politics</i>	
<i>Climate Dynamics</i>	<i>Global Mapping of Human Settlement Experiences Datasets and Prospects</i>	
<i>Climate Research</i>	<i>Holocene</i>	
<i>Cold Regions Science and Technology</i>	<i>Hydrologic Process</i>	
<i>Computational Statistics and Data Analysis</i>	<i>Icarus</i>	
<i>Computers and Geosciences</i>	<i>ICES Journal of Marine Science</i>	
<i>Conservation Letters</i>	<i>IEEE Transactions on Geosciences and Remote Sensing</i>	



MORGAN HEIM/CIRES

The NOAA WP-3D airplane getting outfitted for a major mission in California, to study air quality and climate change.

Journal of Physical Chemistry C
Journal of Physical Oceanography
Journal of Solid State Chemistry
Journal of Sustainable Forestry
Journal of the International Society for Microbial Ecology
Journal of the Meteorological Society
Mathematical Geosciences
Meteorologische Zeitschrift
Microbial Ecology
Minerva
Monthly Weather Review
Nanomedicine and Nanobiotechnology
Natural Hazards and Earth System Science
Natural Hazards Review
Nature
Nature Chemical Biology
Nature Geosciences
Nature Reports Climate Change
Oceanography
Optical Engineering
Optics Letters
Paleoceanography
Pharmaceutical Research
Philosophical Transactions of the Royal Society A

Physical Review E
Physical Review Letters
Phytochemistry
Phytopathology
Policy Science
Probabilistic Engineering and Mechanics
Proceedings of the Institution of Civil Engineers and Water Managers
Proceedings of the National Academy of Sciences
Professional Geographer
Progress in Natural Sciences
Progress in Physical Geography
Public Affairs Quarterly
Quarterly Journal of the Royal Meteorological Society
Quarterly Journal of the Royal Meteorological Society Part B
Radiocarbon
Rapid Communications in Mass Spectrometry
Reaction Kinetics and Catalysis Letters
Remote Sensing
Remote Sensing
Remote Sensing of the Environment
Respiratory Drug Delivery Europe
Reviews of Geophysics
Reviews of Palaeobotany and Palynology

Reviews of Policy Research Science
Scientific American
Social Epistemology
Social Studies of Science
Social Theory and Health
Soil Biology and Biochemistry
Solar Energy
Solar Physics
Solar Wind
Southwest Hydrology
Space Weather
Sustainable Forestry
Sustainable Science
Technology
Tectonophysics
Tellus B
Terrestrial and Atmospheric Oceanic Science
Theoretical and Computational Acoustics
Vaccine
Verhandlungen des Internationalen Verein Limnologie
Water Resources Research
Waves in Random and Complex Media
Weather

Honors and Awards, 2009

BarAndrews, Elisabeth

- Haagen-Smit Prize, from the editors and publisher of Atmospheric Environment, for an outstanding paper

Araujo-Pradere, Eduardo

- Multicultural science award from the Boulder County Community Action Program

Barry, Roger

- Norbert Gerbier-MUMM International Award from the World Meteorological Organization

Burgdorf, Catherine

- NASA Group Achievement Award for outstanding accomplishments in the 2008 Arctic Research of the Composition of the Troposphere from Aircraft and Satellites mission in Alaska and Canada

Cota, David

- Cash Award for extraordinary work that enabled the delivery of two radars to the State of California to meet a critical deadline

Davis, Sean

- Scholarship to attend the Cargèse International School on Water Vapor in the Climate System, in Cargèse, France

Dutton, Geoffrey

- First place, natural phenomena photography contest, NOAA Office of Oceanic and Atmospheric Research

Eakins, Barry

- CIRES Silver Medal for creating new digital elevation models, reconnaissance maps, assessments, and databases that provide information for tsunami forecasts and warnings

Ennis, Christine

- CIRES Director's Award for outstanding leadership and dedication to U.S. Climate Change Science Program Synthesis and Assessment Products

Fierer, Noah

- Elected member of the Faculty of 1000 (<http://f1000.com/>), in ecosystem ecology

Grothe, Pamela

- CIRES Silver Medal for creating new digital elevation models, reconnaissance maps, assessments, and databases that provide information for tsunami forecasts and warnings

Heller, Molly

- CIRES Service Award for initiating the recycling and composting program at the David Skaggs Research Center

Higgins, Matthew

- American Meteorological Society award for the best student oral presentation at the 10th Conference on Polar Meteorology and Oceanography

Holloway, John

- CIRES Outstanding Performance Award in Science and Engineering for development and operation of a vacuum ultraviolet fluorimeter for the detection of atmospheric carbon monoxide

Hubler, Gerhard

- NASA Group Achievement Award for outstanding accomplishments in the 2008 Arctic Research of the Composition of the Troposphere from Aircraft and Satellites (ARCTAS) mission in Alaska and Canada

Knuth, Shelley

- Antarctic Service Medal, U.S. Department of Defense, for service of more than 30 days in Antarctica

Lack, Daniel

- Recognition by Rear Admiral Jonathon Bailey, NOAA Office of Marine and Aviations Operations, for the development of the NOAA Research Fleet Air Emissions Study

Lim, Elliot

- CIRES Silver Medal for creating new digital elevation models, reconnaissance maps, assessments, and databases that provide information for tsunami forecasts and warnings

Matrosova, Ludmila

- CIRES Silver Medal Award for contributions to the Coral Reef Outlook, which improved global monitoring and managing of coral reef ecosystems relative to climate change

Miller, Benjamin

- Frohlich Fellowship from the Commonwealth Scientific and Industrial Research Organisation (CSIRO) for a three-month visit to Aspendale, Victoria, Australia, to help develop a program for tracking greenhouse gas levels and evaluating the effect of policies

Molnar, Peter

- Jack E. Oliver honorary visiting professor, Cornell University

Mondeel, Debra

- CIRES Silver Award for contributions to the NOAA Annual Greenhouse Gas Index, which assesses human-produced greenhouse gases and allows the public to track its net influence on climate

Murphy, Sylvia

- National Center for Atmospheric Research Computational and Information Systems Laboratory special recognition award for work on the U.S. Department of Energy-funded Earth System Grid project

Nerem, Steven

- Associate Fellow, American Institute of Aeronautics and Astronautics

Oehmke, Robert

- National Center for Atmospheric Research Computational and Information Systems Laboratory special recognition award for improving an aspect of the Earth System Modeling Framework

Parsons, Mark

- Charles S. Falkenberg Award from the American Geophysical Union, for a scientist under 45 years of age who has contributed to the quality of life, economic opportunities, and stewardship of the planet

Patrick, Laura

- Shared CIRES cash award for work building two weatherproof ozone instruments for a tall tower in Moody, TX

Persson, Ola

- Editors' Citation for Excellence in Refereeing for Journal of Geophysical Research-Atmospheres, American Geophysical Union

Pielke Jr., Roger

- Distinguished Visiting Scholar, Aston University, Birmingham, UK

Rajagopalan, Balaji

- Partners in Conservation Award from the U.S. Department of Interior for work developing innovative, new operational guidelines for managing the Colorado River in drought years

Schwarz, Joshua

- NASA Group Achievement Award for participation in the 2008 Newly-Operating and Validated Instruments Comparison Experiment (NOVICE)

Serreze, Mark

- Outstanding Reviewer for Geophysical Research Letters, American Geophysical Union

Sheehan, Anne

- Erasmus Haworth Distinguished Alumni Award, University of Kansas Department of Geology

Sievers, Robert

- Governor's Award for Research Impact
- Humanitarian Award from the Boulder Rotary Club
- New Pioneers Award from the Boulder Historical Museum

Steffen, Konrad

- Honorary Consul of Switzerland in Denver, certified by U.S. Department of State

Tolbert, Margaret

- American Chemical Society National Award for Creative Advances in Environmental Science
- Carnegie Capital Science Evening Lecturer

Udall, Bradley

- Partners in Conservation Award from the U.S. Department of Interior for work developing innovative, new operational guidelines for managing the Colorado River in drought years

Wahr, John

- Designated a "Professor of Distinction" by the CU-Boulder College of Arts and Sciences

Wallace, Allaina

- Selected as one of 26 archivists across the country to attend the Second Archives Leadership Institute in Madison, WI, on a full scholarship

Washenfelder, Rebecca

- Best Presentation in the "NOAA & CIRES Chemical Sciences" Category of the 2009 Boulder Postdoctoral Poster Symposium; Organized by the Boulder Labs Diversity Council

Watts, Laurel

- NASA Group Achievement Award for participation in the 2008 Newly-Operating and Validated Instruments Comparison Experiment (NOVICE)



BRIAN CLARK/CIRES

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■ Science Advisory Boards and Editorial Service

Acoustical Society of America, Technical Committee on Acoustical Oceanography
Advances in Atmospheric Sciences
 American Chemical Society
 American Forestry Foundation Research Partners
 American Geophysical Union Student Poster Judge
 American Geophysical Union, EOS, Transactions of the American Geophysical Union
 American Meteorological Society Scientific and Technological Activities Commission
 American Meteorological Society, Board on Women and Minorities
 American Meteorological Society, Haurwitz Memorial Lecture Selection Committee
 American Meteorological Society
 American Quaternary Association
 American Water Works Association Research Foundation
 Arctic Council, Cryosphere Project
 Arctic Council; Snow, Water, Ice, and Permafrost in the Arctic Assessment
Atmospheric Chemistry and Physics
Atmospheric Environment
Atmospheric Measurement Techniques
 Bipartisan Policy Center, Committee on Science for Policy
Bioorganic Chemistry
Boundary Layer Meteorology (Journal), Netherlands
 The Breakthrough Institute
 Bureau Central de Magnétisme Terrestre, France
 CALFED Science Program, state (CAL) and federal (FED) agencies participating in Bay-Delta Accord
 Carbon Cycle Interagency Science Working Group
 Chinese Academy of Sciences
Climate Research
 Climate Variability and Predictability (CLIVAR), World Climate Research Programme
 CLIVAR Decadal Prediction Working Group Working
 CLIVAR Reanalysis and Integrated Earth System Analysis Workshop
Cold Regions Science and Technology
 Colorado Earthquake Hazards Mitigation Council
 Colorado Regional National Ocean Sciences Bowl (Mountain Mariner Challenge)
 Colorado State Science and Engineering Fair
 Colorado Water Availability Study, State of Colorado
 Community Initiative for Emissions Research and Applications
 Consortium of Resonance and Rayleigh Lidars

Consortium of Universities for the Advancement of Hydrologic Sciences
 Coyote's Guide to IDL Programming
Cryosphere, The
Current Opinion in Microbiology on Ecology and Industrial Microbiology
Darwin
Earth Planets, and Space
 Earth Science Informatics, Springer Editorial Board
Encyclopedia of Inland Waters
 Energy and Environment Research Associates
Environmental Science and Policy
Environmental Hazards
 Foundation for Calabrian Archaeology
 Friends of Cooper Island Science Advisory Council
 Front Range Aerosol Program
 Front Range Community College Computer Information Services
 Geochemical Society Goldschmidt Award Committee
Geophysical Research Letters
Geosphere
 Global Earth Observation System of Systems
 Global Environmental Change
 IEEE, Data Archiving and Distribution Technical Committee
 Integrated Climate System Analysis and Prediction, University of Hamburg, Germany
 International Coordination Group on Laser Atmospheric Studies
International Journal of Photoenergy
 International Society for Limnology, Publication Advisory Committee
 Japan Aerospace Exploration Agency Global Change Observation Mission
Journal of the Acoustical Society of America
Journal of Atmospheric Chemistry and Physics
Journal of Climate
Journal of Earth System Science
Journal of Earthquake Engineering
Journal of Hydrologic Engineering
Journal of Geophysical Research-Atmospheres
Journal of Geophysical Research-Earth Surface
Journal of Geophysical Research-Oceans
Journal of Geophysical Research-Solid Earth
Journal of Oceanic and Atmospheric Technology
Limnology and Oceanography Methods
Minerva
Mountain Research and Development
 NASA
 NASA Earth Observatory
 NASA Earth Science Data Systems Technology Infusion
 NASA Gravity Recovery and Climate Experiment
 NASA ICESat Science Team
 NASA's Geomagnetism Science Working Group
 Greenbelt

National Research Council
 America's Climate Choices
 America's Climate Choices: Advancing the
 Science of Climate Change
 America's Climate Choices: Stabilization
 Targets for Atmospheric Greenhouse Gas
 Concentrations
 Board on Environmental Sciences and
 Technology
 Committee on the National Requirements for
 Precision Geodetic Infrastructure
 Polar Research Board
 Tropospheric Airborne Measurement
 Evaluation Panel
 National Center for Ecological Analysis and
 Synthesis
 National Polar-orbiting Operational
 Environmental Satellite System Integrated
 Program Office (IPO) Ozone Operational
 Algorithm Team
 National Science Foundation (NSF)
 NSF, Arctic Observing Network Design
 Implementation Team
 NSF, Arctic System Science Program
 NSF, CEDAR Workshop Lidar Tutorial
 NSF, Climate Education
 NSF, Earth Sciences Instrumentation and
 Facilities Program
 NSF, EarthScope Continental Deformation
 Thematic Working Group
 NSF, High Precision Isotope Ratio Mass
 Spectrometry Consortium
 NSF, Office of Polar Programs
 National Solar Observatory User's Committee
 National Weather Service, Inter-Regional
 Integrated Services
Natural Hazards Review
Nature and Culture
 NOAA Calibration and Validation
 NOAA Science Data Stewardship program
 North American Carbon Program
 National Snow and Ice Data Center User Working
 Group
 Oak Ridge Environmental Science Advisory
 Committee
Ocean Modeling
Open Atmospheric Science Journal
 Ozone Mapping and Profiler Suite, National
 Polar-Orbiting Operational Environmental
 Satellite System
 Pacific El Niño-Southern Oscillation Applications
 Center
 Paleoclimate Modeling Intercomparison Project
Polar Geography

Proceedings of the National Academy of Sciences
 Quantifying and Understanding the Earth System
 Renewable And Sustainable Energy Institute
 Rocky Mountain Hydrologic Research Center
Soil Biology and Biochemistry
 Soil Ecology Society
Spectroscopy Letters
 Study of Environmental Arctic Change
 Sustainable Maritime Solutions United Kingdom
 Swarm Magnetic and Atmospheric Research Team
 Consortium
 Swarm Mission Advisory Group
 Texas Air Research Center
 U.S. Climate Variability and Predictability
 Research (CLIVAR) Applications Panel
 U.S. Department of Energy, Atmospheric System
 Research Program
 U.S. Department of Energy, Cloud Modeling
 Working Group
 U.S. Department of Energy, Ion Source
 Technology Project, Idaho National
 Laboratory
 U.S. Environmental Protection Agency
 Atmospheric Exposure Regulatory Model
 Improvement Committee
 U.S. Geological Survey Isotope Ratio Review
 Committee
Water Resources Research
 WCRP Climate and Cryosphere (CliC) Panel
 WCRP Member of Observation Products Panel
 WCRP/Global Climate Observing System
Weather, Climate, and Society
 Western North America Interferometric Synthetic
 Aperture Radar Consortium
 WIRES Reports Climate Change, John Wiley and
 Sons
 WMO World Climate Research Programme -
 Climate and Cryosphere Project
 World Climate Research Programme, Joint
 Working Group on Coupled Models
 World Climate Research Programme,
 Stratospheric Processes And their Role in
 Climate
 World Meteorological Organization,
 Solar Radiation subcommittee on UV
 instrumentation
 Zeitschrift fuer Gletscherkunde und
 Glazialgeologie

■ **Conference Convener/Session Organizer**

American Astronomical Society, Solar Physics
 Division conference
 American Geophysical Union (AGU) Fall Meeting
 Challenges in Understanding and Modeling
 Global-Regional Climate Connections
 Climate Literacy

Education and Human Resources General
Contributions
Indian Monsoon
Organics in the Atmosphere: Chemical and
Physical Transformations
Town Hall on Renewable Energy
AGU Spring and Fall meeting planning committees
American Meteorological Society (AMS) Renewable
Energy Meeting
AMS 10th Aerodyne Aerosol Mass Spectrometer
Users' Meeting
AMS Meetings Oversight Committee
Antarctic Meteorological Observation, Modeling,
and Forecasting Workshop
Clinic Meeting for users of the high-resolution time-
of-flight aerosol mass spectrometer
Coordinated U.S. Initiative on Emissions Research
Workshop
Global Emissions Inventory Activity–Atmospheric
Composition Change, European Network of
Excellence Open Conference
International Commission of Polar Meteorology
International Workshop on Air Quality Forecasting
Research
National Science Foundation EarthScope
Past Global Changes Open Science Meeting
U.S. Department of Energy Atmospheric Radiation
Measurement Program

■ Paper and Proposal Review

Acoustical Physics
Acta Geophysica
Advances in Atmospheric Sciences
Advances in Geosciences
Advances in Space Research
Advances in Water Resources
Aerosol Science and Technology
American Journal of Physics
American University of Beirut
Analytical Chemistry
Annales Geophysicae
Annals of Glaciology
Antarctic Climate Change and the Environment
Annual Review of Biochemistry
Applied and Environmental Microbiology
Applied Optics
Aquatic Sciences
Arctic, Antarctic, and Alpine Research
Association of American Geographers
Atmospheric Chemistry and Physics
Atmospheric Environment
Atmospheric Measurement Techniques
Atmospheric Research
Biochemistry
Biogeochemistry
Biogeosciences
BioScience

Boreal Environment Research
Boundary-Layer Meteorology
Bulletin of the American Meteorological Society
Centre National de la Recherche Scientifique
Chemical Geology
Chemical Physics
Chemical Physics Letters
Climate Dynamics
Climatic Change
Computers and Geosciences
Cryosphere, The
Dynamics of Atmospheres and Oceans
Earth and Planetary Science Letters
Earth Interactions
Earth Science Informatics
Earth Surface Processes and Landforms
Ecological Applications
Ecology
Ecology Letters
Ecosystems
Environmental Chemistry
Environmental Science and Technology
Environmental Science and Policy
European Geosciences Union
French National Research Agency
Freshwater Biology
Geochemistry, Geophysics, Geosystems
Geosphere
Geological Society America Bulletin
Geology
Geophysical Journal International
Geophysical Model Development
Geophysical Research Letters
Geophysical Research Letters-Atmospheres
Georgian National Science Foundation
Geoscience and Remote Sensing Letters
Geoscientific Model Development
German Research Foundation
Global and Planetary Change
Global Biogeochemical Cycles
Global Change Biology
Holocene, The
Hydrologic Information System review
Hydrological Processes
IEEE Geoscience and Remote Sensing
International Journal of Chemical Kinetics
International Journal of Climatology
International Journal of Digital Earth
*International Journal of Environmental Research and
Public Health*
International Journal of Mass Spectrometry
International Journal of Geophysics
International Society for Microbial Ecology Journal
Irish Research Council for Science, Engineering and
Technology
Israel Science Foundation
Journal of the Acoustical Society of America
Journal of the Air and Waste Management Association

Journal of the American Society for Mass Spectrometry
Journal of the American Water Resources Association
Journal of Applied Mathematics and Computing
Journal of Applied Meteorology and Climatology
Journal of Atmospheric and Oceanic Technology
Journal of the Atmospheric Sciences
Journal of Atmospheric and Solar-Terrestrial Physics
Journal of Climate
Journal of Computational Acoustics
Journal of Environmental Analytical Chemistry
Journal of Geology
Journal of Geological Society of India
Journal of Geophysical Research
Journal of Geophysical Research-Atmospheres
Journal of Geophysical Research-Earth Surface
Journal of Geophysical Research-Oceans
Journal of Glaciology
Journal of Hydrologic Engineering
Journal of Hydrology
Journal of Hydrometeorology
Journal of Physical Chemistry
Journal of Physical Chemistry A
Journal of Physical Oceanography
Journal of Plankton Research
Journal of Volcanology
Journal of Wildlife Management
 Kearney Foundation
Landscape Ecology
Limnology and Oceanography
 Marsden Foundation (New Zealand)
Mathematical Geosciences
Meteorologische Zeitschrift
Meteorology and Atmospheric Physics
Monthly Weather Review
 NASA
 NASA Applied Science Program
 NASA Earth Sciences Directorate
 NASA Global Climate Change Education Program
 NASA Planetary Instrument Definition and
 Development program
 NASA Venture
 National Institutes of Health (NIH)
 NIH Special Emphasis Panel
 NIH MSFE Study Section
 National Water Resources Institute
 Natural Environment Research Council
 Natural Sciences and Engineering Research Council
 of Canada
Nature
Nature Geoscience
 Nauka / Interperiodica
 Netherland's Joint Scientific Thematic Research
 Programme
 Netherlands Organisation for Scientific Research
 NOAA Atmospheric Composition and Climate
 Program
 NOAA Climate Program's Global Climate Change

Program
 NOAA Climate Variability and Predictability Program
 NOAA Global Carbon Cycle
 NOAA Small Business Innovation Research
 NOAA Climate Prediction Program for the Americas
 National Academies of Sciences
 National Science Foundation (NSF)
 NSF Arctic Sciences
 NSF Atmospheric Sciences
 NSF CAREER grant
 NSF Climate Dynamics
 NSF Geomorphology and Land-Use
 Dynamics
 NSF Geophysics
 NSF Geospace Environment Modeling
 NSF Hydrological Sciences Program
 NSF Major Research Instrumentation
 NSF Marine Geology and Geophysics
 NSF Mathematics
 NSF Physical Oceanography
 NSF Sedimentary Geology and Paleobiology
 NSF Tectonics
Ocean Modelling
Oecologia
Optical Engineering
Paleoceanography
Philippine Journal of Science
Physical Review E
Physical Review Letters
Plant Journal
Polar Research
Proceedings of the National Academy of Sciences
Quarterly Journal of the Royal Meteorological Society
Quaternary Science Reviews
Radio Science
Remote Sensing
Remote Sensing of Environment
 Research Corporation for Science Advancement
 Russian Fulbright Scholar Program
Risk Analysis
 Royal Meteorological Society
Science
 Science Foundation Ireland
Science of the Total Environment
Sensors and Actuators B
Soil Biology and Biochemistry
Stochastic Environmental Research and Risk Assessment
Tectonics
Tellus
Terra Nova
 UK Natural Environment Research Council
 U.S. Bureau of Reclamation
 U.S. Department of Agriculture
 U.S. Department of Energy (DOE)
 DOE Atmospheric Radiation Measurement
 Climate Research Facility

DOE Early Career Research Program
DOE Pacific Northwest National Laboratory
Small Business Innovation Research
DOE Small Business Innovation Research
DOE Small Business Technology Transfer
U.S. Environmental Protection Agency
Washington State Climate Change Impacts
Assessment
Water Resources Research
Weather and Forecasting
Weather Climate and Society
World Meteorological Organization, Geneva,
Switzerland

■ Professional Membership

Acoustical Society of America
American Geophysical Union (AGU)
AGU, Atmospheric Sciences Fellows Committee
AGU, Education and Human Resources
AGU, Education Awards
AGU, Geomagnetism and Paleomagnetism
AGU, Geodesy Section
AGU, Nonlinear Geophysics Focus Group
Alexander von Humboldt Association of America
American Association for Aerosol Research,
Publications Committee
American Association for the Advancement of
Science
American Association of Pharmaceutical Scientists
American Association of State Climatologists
American Indian Science and Engineering Society
American Libraries Association
American Meteorological Society (AMS)
AMS Coastal Environment Committee
AMS Middle Atmosphere Committee
AMS Polar Meteorology and Oceanography
Committee
AMS Policy Curriculum Advisory
Committee
American Quaternary Association
American Society for Limnology and Oceanography
American Society for Mass Spectrometry
American Society for Photogrammetry and Remote
Sensing Member
Archaeological Institute of America, Boulder Society
Arctic Research Consortium of the U.S.
Arctic-CHAMP (Community-wide Hydrologic
Analysis and Monitoring Program)
Association of American Geographers
Association of Early Polar Career Scientists
Chinese Society of Glaciology and Geocryology
Colorado Alliance for Environmental Education
Colorado Renewable Energy Society

Deutsche Gesellschaft für Polarforschung
Earth Science Information Partners Federation
Ecological Society of America
European Geophysical Society
European Geophysical Union
European Space Agency
Faculty of 1000 Biology
Geological Society of America
Human Factors and Ergonomic Society
IEEE, Data Archiving and Distribution Technical
Committee
IEEE, GeoScience and Remote Sensing Society
International Association for Mathematical Geology,
Student Chapter
International Association for Mathematical
Geosciences
International Association for Mathematical Physics
International Association of Geomagnetism and
Aeronomy (IAGA)
IAGA task force for the World Digital Magnetic
Anomaly Map
IAGA task force for the International Geomagnetic
Reference Field
International Association of Hydrological Sciences
International Facilities Management Association
International Glaciological Society
International Permafrost Association, Standing
Committee for Data, Information and
Communication
International Society on General Relativity and
Gravitation
National Carbon Cycle Working Group
National Center for Science Education
National Science Teachers Association
NOAA Professional Women's Group
Ocean Sciences Education Committee
Polar Libraries Colloquy
Royal Society of Chemistry London
Sigma Xi Scientific Research Society
Society for Industrial and Applied Mathematics
Society of American Archivists
Society of Rocky Mountain Archivists
Solar Physics Division of the American Astronomical
Society
Special Libraries Association
Swarm Level-2 Algorithm Peer Advisory Group
U.S. Climate Change Science Program
U.S. Permafrost Association
University Corporation for Atmospheric Research,
Presidents' Advisory Committee on
University Relations
World Meteorological Organization Global
Atmosphere Watch

Preparing to plant hybrid poplar trees, for a study of plant emissions.
MORGAN HEIM/CIRES



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 FY10, 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, Wired, The New York Times, Scientific American CBS, Discovery, National Geographic, BBC, Business Week, MSNBC, Fox News, and the Los Angeles Times.



Press releases

- Land management decisions and the potential for carbon sequestration in Colorado (06/10)
- CIRES Fellows Noone, Fierer earn prestigious NSF awards (06/10)
- New paper argues for reframing the approach to climate policy (04/10)
- Inuit knowledge helps science learn something new about Arctic weather (03/10)
- Dr. Jose Luis Jimenez to receive 2010 Rosenstiel Award from University of Miami (03/10)
- Greenland Ice Sheet losing ice mass on northwest coasts says new international study (03/10)
- A new kind of fingerprint (03/10)
- Adaptation to climate change in public lands management (03/10)
- Chlorine, air quality culprit, unexpectedly found far from coast (03/10)
- Exaggerating denialism: Media representations of outlier views on climate change (02/10)
- Lessons from the Haiti earthquake (02/10)
- Discursive stability meets climate instability: A critical exploration of the concept of "climate stabilization" in contemporary climate policy (01/10)
- A warmer climate could stifle carbon uptake by trees (01/10)
- Tsunamis may telegraph their presence (01/10)
- NOAA scientist finds clue to predicting solar flares (01/10)
- Study links springtime ozone increases above western North America to emissions abroad (01/10)
- Stratospheric water vapor is a global warming wild card (01/10)
- Incorporating hydrology improves land use climate models (01/10)
- Holistic approach to emissions boosts prediction power for climate and air quality models (12/09)
- New report synthesizes scientific observations of

Greenland Ice Sheet (12/09)

- Flying to the ends of the Earth to measure greenhouse gases (11/09)
- Clearer picture of how land-use changes affect U.S. climate (11/09)
- CU-Boulder map of human bacterial diversity shows wide interpersonal differences (11/09)
- Climate change accelerating beyond expectations, urgent emissions reductions required, leading scientists say (11/09)
- Arctic sea ice extent remains low; 2009 sees third-lowest mark (10/09)
- CIRES, international experts gather in Copenhagen to close gaps in climate education (10/09)
- Unmanned aircraft buzz over gigantic holes in Antarctic sea ice (09/09)
- Scientists, volunteers to assess water quality throughout Rocky Mountain National Park (08/09)
- Power plants help scientists track urban pollution—from space (08/09)
- Future of Western water supply threatened by climate change (07/09)
- New study finds tsunami "shadow" visible from space (07/09)

Spheres magazines

These periodic publications highlight the diversity of CIRES research in particular topics.

- Ecology (24 pp, 05/10)
- Education and Outreach (16 pp, 02/10)
- Water (16 pp, 05/09)



Selected web features

- Arctic sea ice approaching new lows? NSIDC reports. (06/10)
- In Search of Clouds over Greenland. Blog author Matthew Shupe writes from the middle of Greenland as he and colleagues install instruments to measure how clouds affect climate change. (05/10)
- Clinical trials set for inhalable measles vaccine. If tests in India are successful, technique could lead to vaccines for tuberculosis, cervical cancer. (05/10)
- America's Climate Choices: Advancing the Science of Climate Change. New report examines climate specifically in context of US interests. (05/10)
- Music in the air. CIRES' Max Boykoff and others help assess the UK music businesses' effort to curb the industry's GHG emissions. (03/10)
- On Thin Ice. NSIDC researchers Ted Scambos, Rob Bauer, and Terry Haran are blogging about their expedition to the Larsen Ice Shelf region. (03/10)
- NSIDC awarded IceBridge, chosen by NASA to manage crucial data collection in the gap between two important satellites. (03/10)
- Quake Cruise. Anne Sheehan reports from New Zealand, where she travels to recover ocean bottom seismometers left by her team last year. (02/10)
- Tsunami exhibit makes waves. New Science on a Sphere visualization highlights lessons learned after the 2004 Indian Ocean tsunami. (02/10)
- New Arctic Council Report: The Greenland Ice Sheet in a changing climate. (12/09)
- Calm before the storm. Water battles loom as changing snowmelt patterns strain decades-old "gentlemen's agreements." (11/09)
- Draining Asia. (11/09)
- Floating a theory: Small watersheds as a microcosm for a larger region's flood risk. (11/09)



Multimedia

- In situ: Fish History (11/09 video). CIRES doctoral candidate Tommy Detmer treks Rocky Mountain National Park to investigate the effects of fish introductions on lake ecosystems.
- Noah Fierer: Forensic use of hand bacteria (03/10 video). Forensic scientists may soon have a valuable new item in their toolkits—a way to identify individuals using unique, telltale types of hand bacteria left behind on objects like keyboards and computer mice.
- Inuit knowledge helps science learn something new about Arctic weather. (04/10 podcast)
- Ambient marine noise as an eco-friendly way to monitor ocean physics. (07/10 podcast)
- Equipping the CalNex mission. (05/10 slideshow) CIRES science in action: Testing the waters (interactive panorama)
- Fierer lab: Where scientists figure out what's up with microbes (interactive panorama).

Wintertime water sampling on Lake Dillon, Colorado.

MORGAN HEIM/CIRES



Appendices

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Personnel Demographics

CIRES Personnel Breakdown 2009-2010

Category	Total CIRES Personnel	NOAA-supported CIRES Personnel	Highest Degree Earned by NOAA-supported Personnel		
			B.S.	M.S.	Ph.D.
Faculty	21				
Research Scientist	183	106			106
Visiting Scientist	35	0			
Postdoctorate Researcher	20	4			4
Associate Scientist	226	126	54	69	3
Administrative	30	25	20	4	1
Total > 50% NOAA support		261	74	73	114
Undergraduate Students	65	37			
Graduate Students	105	20	20		
Received < 50% NOAA Support		47	14	13	20
Total < 50% NOAA Support		104	34	13	20
Total CIRES personnel	664				
CIRES Personnel in NOAA Boulder Laboratories					
OAR		221			
Chemical Sciences Division		69			
Global Monitoring Division		49			
Global Systems Division		35			
Physical Sciences Division		68			
NESDIS/NGDC		39			
NWS/SWPC		26			
Obtained NOAA Employment in Last Year		1			
Total NOAA		287			



Director Konrad Steffen speaks to more than 300 researchers and employees at CIRES' 2010 Rendezvous! science symposium on the banks of Boulder Creek in Boulder, Colorado.

MORGAN HEIM/CIRES

Acronyms

AGCM	Atmospheric general circulation model (GCM)
AGU	American Geophysical Union
AMISA	Arctic Mechanisms of Interaction between the Surface and the Atmosphere
AMOS	Advanced modeling and observing systems
AOML	Atlantic Oceanographic Meteorological Laboratory
AR4	Fourth assessment report
AR5	Fifth assessment report
ARB	American River Basin (California)
ARCPAC	Aerosol, Radiation, and Cloud Processes affecting Arctic Climate
ARRA	American Recovery and Reinvestment Act
ASCOS	Arctic Summer Cloud Ocean Study
ASFG	Atmospheric Surface Flux Group
ASTER	Aerosol Scattering To Extinction Ratio
BAO	Boulder Atmospheric Observatory
CalNex	California Nexus field campaign
CAP-MBL	Clouds, Aerosol, and Precipitation in the Marine Boundary Layer
CARB	California Air Resources Board
CCN	Cloud condensation nuclei
CDC	Climate Diagnostics Center
CET	Center for Environmental Technology, CU-Boulder
CIRES	Cooperative Institute for Research in Environmental Sciences
C-LIM	Coupled linear inverse model
CLIMAS	Climate Assessment of the Southwest
CME	Coronal mass ejection
CONUS	Continental United States
CoSPA	Consolidated storm prediction for aviation
CRD	Cavity ring-down spectrometer
CRSS	Colorado River seasonal forecasting
CSD	Chemical Sciences Division (NOAA ESRL)
CSTPR	Center for Science and Technology Policy (CIRES center)
CSV	Climate system variability
CU	University of Colorado
DAAC	Distributed Active Archive Center
DEM	Digital elevation models
DFI	Digital filter initialization
DOE	U.S. Department of Energy
DTC	Developmental Testbed Center

ECMWF	European Centre for Medium-Range Weather Forecasts
ECS	Extended continental shelf
EESC	Equivalent effective stratospheric chlorine
ENSO	El Niño-Southern Oscillation
EO	Education and Outreach (CIRES)
ESOC	Earth Science Observation Center (CIRES center)
ESMF	Earth System Modeling Framework
ESRL	Earth System Research Laboratory (NOAA)
FAA	Federal Aviation Administration
FGDC	Federal Geographic Data Committee
FIM	Flow-Following Finite-Volume Icosahedral Model
GASEX	Southern Ocean Gas Exchange Experiment
GCM	General circulation model
GC-MS	Gas chromatography-mass spectrometry
GDS	Ground data system
GEBA	Global Energy Balance Archive
GEFS	Global Ensemble Forecast System
GEO	Geodynamics
GIPC	GNSS ionospheric positioning correctors
GIS	Geographic Information System
GLOPAC	Global Hawk Pacific field campaign
GMD	Global Monitoring Division (NOAA ESRL)
GNSS	Global Navigation Satellite System
GOCART	Goddard Chemistry Aerosol Radiation and Transport
GOES	Geostationary Operational Environmental Satellite
GPS	Global Positioning System
GPU	Graphics processor unit
RUC	Rapid Update Cycle
GRACE	Gravity Recovery and Climate Experiment
GSD	Global Systems Division (NOAA ESRL)
GSI	Gridpoint Statistical Interpolation
HadISST	Hadley Centre Global Sea Ice and Sea-Surface Temperature
HALO	Heterodyne atmospheric laser optics
HIPPO	HIAPER Pole-to-Pole Observations
HNCO	Isocyanic acid
HONO	Nitrous acid
HPCS	High-performance computing systems
HRRR	High-Resolution Rapid Refresh
HWRF	Hurricane Weather Research and Forecasting model

IA	Integrating activities
IBS	Institute of Behavioral Science
ICEALOT	International Chemistry Experiment in the Arctic Lower Troposphere
ICESat-2	Ice Cloud and Land Elevation Satellite-2
IPPC	Intergovernmental Panel on Climate Change (United Nations)
ISO	International Standards Organization
IWCS	Intermountain West Climate Summary
IWP	Ice water path
LIF	Laser-induced fluorescence
LIM	Linear inverse model
LWu	Longwave upward radiative flux
AMAX-DOAS	Airborne Multi-Axis Differential Optical Absorption Spectrometer
MBL	Marine boundary layer
MJO	Madden-Julian Oscillation
MLS	Microwave limb sounder
MSBL	Marine Surface Boundary Layer
NAM	North American monsoon
NAME	North American monsoon experiment
NAO	North Atlantic Oscillation
NASA	National Aeronautics and Space Administration
NAVD 88	North American vertical datum of 1988
NCAR	National Center for Atmospheric Research
NCEP	National Centers for Environmental Prediction
NESDIS	National Environmental Satellite, Data, and Information Service
NEAQS	New England Air Quality Study
NEUBrew	NOAA-EPA Brewer Spectrophotometer UV and Ozone Network
NEVS	Network-Enabled Verification Service
NGDC	National Geophysical Data Center
NIDIS	National Integrated Drought Information System
NOAA	National Oceanic and Atmospheric Administration
NPOESS	National Polar-Orbiting Operational Environmental Satellite System
NPP	NPOESS Proprietary Project
NRCS	Natural Resources Conservation Service
NSF	National Science Foundation
NSIDC	National Snow and Ice Data Center
NWS	U.S. National Weather Service
OA	Organic aerosol
OLS	Operational linescan system
OMI	Ozone Monitoring Instrument

OMPS	Ozone Mapping and Profiler Suite
PCN	Paleoclimate network
PLP	Pulsed laser photolysis
PM	Planetary Metabolism
POES	Polar Operational Environmental Satellite
POM	Princeton Ocean Model
PSD	Physical Sciences Division (NOAA ESRL)
PTR-MS	Proton transfer reaction mass spectrometry
RASEI	Renewable and Sustainable Energy Initiative (CU)
RINEX	Receiver-independent exchange
RMS	Root mean square
RP	Regional processes
SAPHIR	Simulation of Atmospheric Photochemistry in a Large Reaction Chamber
SBUV	Solar backscatter UV radiometer
SCIAMACHY	Scanning Imaging Absorption Spectrometer for Atmospheric Chartography
SCICEX	Science for Ice Experiment
SEAESRT	Space Environmental Anomalies Expert System, Real-Time
SEARCH	Study of Environmental Arctic Change
SEB	Surface energy budget
SEISS	Space Environment In Situ Suite
SHEBA	Surface Heat Budget of the Arctic
SIMM	Simulation of the Inner Magnetosphere
SMO	Sierra Madres Occidental
SOA	Secondary Organic Aerosol
SPIDR	Space Physics Interactive Data Resource
SPO	SHEBA Project Office
SST	Sea-Surface Temperature
STEREO	Solar Terrestrial Relations Observatory
SUFRAD	Surface radiation
SUVI	Solar Ultraviolet Imager
SWd	Shortwave downward radiative flux
SWPC	Space Weather Prediction Center
SXI	Solar X-Ray Imager
SZA	Solar zenith angle
TEC	Total electron content
TexAQS	Texas Air Quality Study
TOPAZ	Tunable Optical Profiler for Aerosol and Ozone
UAS	Unmanned Aircraft Systems
UCRB	Upper Colorado River Basin

UNEP	United Nations Environmental Programme
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
UV	Ultraviolet
VAMOS	Variability of the American Monsoon Systems
VOCALS	VAMOS Ocean-Cloud-Atmosphere-Land Study
VOCs	Volatile Organic Compounds
WATF	Water Availability Task Force
WMM	World Magnetic Model
WMO	World Meteorological Organization
WRF	Weather Research and Forecasting model
WSA	Wang-Sheeley age
WWA	Western Water Assessment (CIRES/NOAA)