CIRES

2013 annual report

COOPERATIVE INSTITUTE FOR RESEARCH IN ENVIRONMENTAL SCIENCES

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Waleed Abdalati

CIRES Interim Director (July 1, 2012–June 30, 2013)
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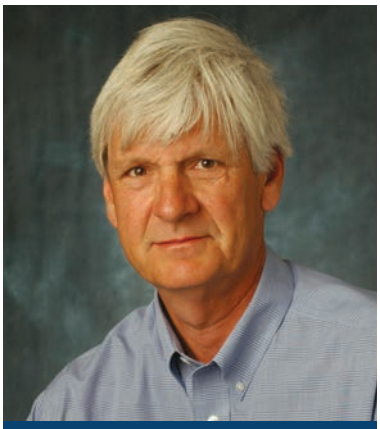
From the Interim Director



William M. Lewis Jr.

Dear Colleagues,

CIRES is as steady as a battleship most of the time, but occasionally she pitches and rolls in rough water. This was the case during the University of Colorado Boulder's 2013 fiscal year (July 2012 to June 2013, FY13), which began calmly enough. As we were preparing ourselves to meet the challenge of a request for proposals (RFP) from NOAA to submit a recompetition proposal for the CIRES-NOAA Cooperative Agreement, however, we experienced the loss of Suzanne Van Drunick, Associate Director for Science, and then Konrad Steffen, Director. The lead time for preparation of the proposal was short, and the administrative staff was anxious, to say the least. CIRES hired Kristen Averyt, to become the new Associate Director for Science. As a veteran of proposal preparation for NOAA, she proved a great asset for our response to the RFP. The administrative staff put forth considerable effort, and we relied on the expertise of senior CIRES scientists working with the federal laboratories to identify research areas to meet the nine new themes identified for us by NOAA for future research. The outcome was success: CIRES received a five-year award for up to $160 million and will have the opportunity to submit a renewal proposal for a second five years.

Also in FY13, we experienced an undefined budget threat, as did all federal and federally supported programs. Sequestration or other budget measures could have affected CIRES severely. There was some shortfall of projected income in the NOAA-CU collaboration, but it was absorbed by programmatic changes that did not result in layoffs or other personnel actions.

Yet another challenge for FY13 was the search for a new CIRES Director. After a process much longer than anticipated, and well into 2013, CIRES successfully made an offer to Waleed Abdalati, a CU-Boulder faculty member and most recently Chief Scientist for NASA, who became Director on July 1, 2013. It seems that FY13 will be a good year for recuperation, enjoyment of the new Cooperative Agreement, and new leadership.

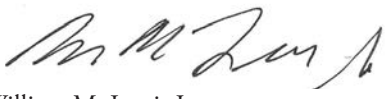
Despite administrative turbulence, the CIRES-NOAA science machine worked smoothly and productively during FY13. As the text of this report will show, CIRES scientists turned out some fundamentally important and, in some cases, surprising observations and analyses during FY13. For example, CIRES and NOAA scientists collaborated on the first comprehensive quantitative analysis of black carbon (soot), which is released in quantity through fossil fuel combustion as well as fires. The importance of black carbon to the heat balance of Earth has been greatly underestimated; the NOAA-CIRES analysis has produced more accurate estimates of its effects and will allow projections into the future, including evaluation of potential benefits to come from control of black carbon in the atmosphere.

In a study of regional significance, CIRES scientists showed through field sampling of the atmosphere in the vicinity of Colorado oil and gas wells that emission of ozone precursors from gas wells is much higher than previously estimated, and several times as high as in comparable extraction fields at a number of other locations in the United States.

As part of a long series of studies on mass balance of ice, CIRES scientists showed in FY13 that an important mechanism for melting of the Greenland Ice Sheet stems from the distribution of thin, low-lying clouds over the ice sheet. In addition, the CIRES National Snow and Ice Data Center, which provides international access to data on global ice cover, reported Arctic sea ice in September 2012 at its lowest extent since the initiation of satellite records.

CIRES accomplishments in science for FY13 were diverse, abundant, and significant. We anticipate the same for FY14.

Sincerely yours,



William M. Lewis Jr.

CIRES: science in service to society

Photo credit: David Oonk/CIRES

Since its inception more than 45 years ago as NOAA's first cooperative institute, the Cooperative Institute for Research in Environmental Sciences (CIRES) at the University of Colorado Boulder has emerged as an international leader in research that addresses the pressing challenges facing our planet.

CIRES researchers use time-honored and cutting-edge approaches to study diverse aspects of Earth system science, with a focus on research that NOAA's Research Council terms "use-inspired." That is, CIRES science seeks to improve fundamental understanding of the changing world and to produce applications that are useful and used by decision makers, educators, the private sector, and others.

William M. Lewis Jr., served as CIRES' Interim Director during the 12 months of this reporting period (July 1, 2012, to June 30, 2013). Under his leadership, CIRES continued its tradition of excellence in research and training, helping to ensure NOAA advanced its mission and met strategic goals.

This summary highlights a few of the past year's activities and research successes. In the Project Reports section of this report, accomplishments are reported in full, organized by CIRES' nine themes (page 72). Here, highlights are presented in alignment with NOAA's priorities: the overarching goals outlined in NOAA's Next Generation Strategic Plan (NGSP) and two enterprise objectives.

Climate Adaptation and Mitigation (NGSP)

- With NOAA partners, CIRES researchers continue to track global abundances of all major long-lived greenhouse gases. This year, CO_2 levels exceeded 400 parts per million (daily average) at Mauna Loa Observatory in Hawaii for the first time.
- CIRES scientists worked closely with colleagues around the world on parts of the Intergovernmental Panel on Climate Change reports expected in late 2013 and 2014.
- CIRES researchers provided enhanced forecasts for wind energy production, and continue to conduct research on the impact of those forecasts on grid integration of renewable energy.

Weather-Ready Nation (NGSP)

- CIRES researchers and colleagues published papers evaluating the roles of climate change and variability on extreme weather events such as the Texas heat wave of 2011 and the warm spring of 2012 in the Central United States.
- CIRES solar physicists worked with NOAA colleagues in the Space Weather Prediction Center to improve understanding and prediction of solar disturbances in the geospace environment. Such disturbances can affect Earth's atmosphere and technological systems.
- CIRES scientists played critical roles in several intensive field studies of air quality–climate connections, in Utah and California, and in planning for a third field study, in the southeastern United States.

Executive Summary and Research Highlights

Engagement Enterprise

- CIRES researchers and collaborators improved the weather prediction systems (the Advanced Weather Interactive Processing System II) used at all NOAA National Weather Service Weather Forecast Offices, adding functions to help forecasters visualize and annotate maps and other data.
- During the 12 months of this reporting period, 11 new Science On a Sphere® exhibits were installed in five countries, bringing NOAA, CIRES, and other science to global audiences.
- CIRES researchers at the National Snow and Ice Data Center (NSIDC) added daily sea-ice data to archives, to meet user needs and interest, and published "All About Arctic Climatology and Meteorology," a website for educators and high school students.

Science and Technology Enterprise

- CIRES researchers at the National Geophysical Data Center developed new digital elevation models in support of NOAA's tsunami programs.
- CIRES staff continue to work closely with colleagues on tools to improve the reliability, resilience, and usability of NOAA's high-performance computing systems.
- CIRES staff working on satellite imagery of Earth at night began working with much higher-resolution data from a new instrument on a new satellite. The work, collaborative with NOAA, NASA, and others, is revealing more-detailed information about power use, biomass burning, fishing, gas flaring, and other human activities around the world.

In Institute news, CIRES continued to grow during the University's FY13 (July 2012 through June 2013), with expenditures of about $64 million. The Institute's financial health is supported by a diversity of funding sources beyond NOAA and the University of Colorado Boulder: These include NASA, the National Science Foundation, the Department of Defense, Department of Energy, the U.S. Agency for International Development, and more.

In FY13, CIRES included 47 Fellows, nearly 200 research scientists, 250 associate scientists, 38 visiting scientists, 29 postdoctoral researchers, and 131 graduate students—many of them supported by NOAA (page 143). Those researchers and graduate students published more than 500 peer-reviewed papers, earned numerous honors and awards, and were profiled in local, national, and international news outlets. All three measures of success speak to the eminence of CIRES researchers in their fields.

In March 2013, the CIRES Council of Fellows nominated Waleed Abdalati,—CIRES Fellow and former NASA Chief Scientist—to be the new CIRES Director. His appointment was approved by CU-Boulder after the current reporting period and will be reported on in the next Annual Report.

This Is CIRES

The Cooperative Institute for Research in Environmental Sciences (CIRES) was established in 1967 to facilitate collaboration between the University of Colorado Boulder and the National Oceanic and Atmospheric Administration (NOAA). CIRES' original and continuing purpose is to support NOAA goals by facilitating interdisciplinary studies that crosscut traditional scientific fields. CIRES fosters interdisciplinary science through four centers and two key programs: the National Snow and Ice Data Center, the Center for Limnology, the Center for Science and Technology Policy Research, the Earth Science and Observation Center, the Western Water Assessment, and the Education and Outreach program. Such interdisciplinary combinations provide unique opportunities for discovery and for application of knowledge to meet societal needs. The work of the CIRES enterprise strengthens the scientific foundation upon which NOAA's many services depend, and allows coordinated studies on a scale that could not be addressed by university research units or NOAA alone.

University of Colorado Boulder

CIRES

NOAA

University of Colorado Boulder 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 Program

CIRES Divisions

Cryospheric and Polar Processes

Ecosystem Science

Environmental Chemistry

Environmental Observations, Modeling, and Forecasting

Solid Earth Sciences

Weather and Climate Dynamics

Interdisciplinary Research Centers

Center for Limnology

Center for Science and Technology Policy Research

Earth Science and Observation Center

National Snow and Ice Data Center

Programs

Education and Outreach

Western Water Assessment

NOAA Earth System Research Laboratory (ESRL)

Chemical Sciences Division

Global Interoperability Program

Global Monitoring Division

Global Systems Division

Physical Sciences Division

NOAA Centers

National Geophysical Data Center

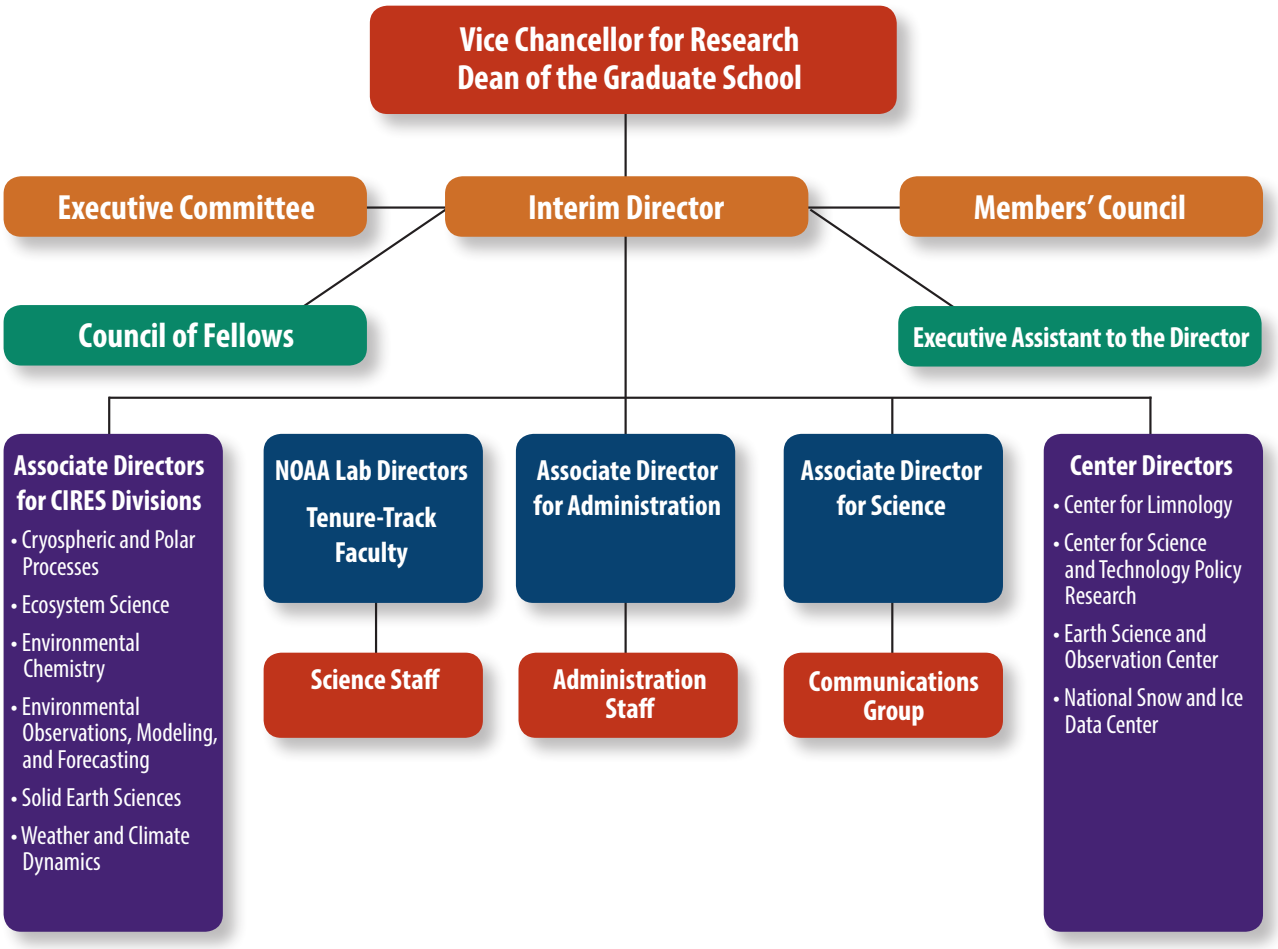
Space Weather Prediction Center

An ice bridge near Anvers Island, on the Antarctic Peninsula. For scale, a person is sitting under the arch. Photo credit: Grant Glenn/CIRES

Governance, Management, and Organization

CIRES is governed and managed through its Council of Fellows, an advisory Executive Committee, and the CIRES Members' Council. The CIRES Centers (Center for Limnology, Center for Science and Technology Policy Research, National Snow and Ice Data Center, and the Earth Science and Observation Center) link NOAA to 11 different university departments. Coordination among all these entities is facilitated through the Communications Group. In FY13, William M. Lewis Jr. led CIRES as Interim Director.

CIRES Organizational Structure



Council of Fellows

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, and government scientists who form the core leadership of the Institute. Members of the Council of Fellows 1) provide leadership at all levels in environmental science, 2) maintain an active scientific research and 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. Fellows personify the spirit 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 nine times during this reporting period: September 20, October 18, November 15, and December 13 of 2012; and January 24, February 28, March 21, April 18, and May 16 of 2013.

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 for CIRES' six divisions, two Fellows elected at large for two-year terms (renewable for one term), and two Members' Council representatives. The Associate Director for Administration, Associate Director for Science, and the Director's Executive Assistant are ex-officio members.

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.

Fellows Appointment Committee

Fellows of CIRES are selected by two-thirds vote of the Council of Fellows and are appointed or reappointed by the Director of CIRES with the concurrence of the Vice Chancellor for Research and the Dean of the Graduate School. New Fellow nominations are considered by the Council of Fellows once yearly, drawing from the community of scientists at the University of Colorado Boulder and NOAA. Project leaders present cases for appointment of new Fellows to the Council of 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.

Diversity Committee

Recent studies highlight that fewer underrepresented minorities are pursuing careers in science, especially in higher education. CIRES has made it a priority to extend its knowledge and community. The Diversity Committee, created in 2010, is working to achieve this goal. The Committee works with the CIRES Education and Outreach program, the Communications Group, and scientists and staff to identify opportunities for CIRES to improve diversity, enrich our science, and enhance our mission.

Members' Council

The CIRES Members' Council, created in 1997, serves as an information and policy conduit between CIRES leadership and Institute members. To provide uniform representation, the CIRES membership is divided geographically into eight groups that comprise various divisions and centers across the Institute, with representation reflecting the size of each group. From the council, two elected delegates serve as the liaison between the Members' Council and the CIRES Council of Fellows and Executive Committee. The Members' Council, which meets monthly, then serves as a direct line of communication to the Member population at large. At meetings, the Council hears members' inquiries and concerns, discusses and develops potential solutions to outstanding issues, and works directly with CIRES leadership to implement these solutions. Additionally, the Members' Council performs regular service to the Institute by, for example, sponsoring the annual CIRES Science Rendezvous, the Awards Committee for CIRES Outstanding Performance Awards, and the CIRES Bike Share Program.

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 Committee, faculty promotion committees, and others. These are created as the need arises, exist to accomplish a specific task, and are then disbanded.

The CIRES Team	FY2013
Faculty Lines	17
Research Scientists	197
Associate Scientists	252
Visiting Scientists	38
Postdoctoral Researchers	29
Administrative Staff	32
Graduate Students	131
Undergraduate Students	83

Other CIRES Committees

- **Visiting Fellows Committee**
- **Distinguished Lecture Committee**
- **Graduate Student Research Fellowship Committee**
- **Innovative Research Program Committee**

Council of Fellows (July 1, 2012–June 30, 2013)

Waleed Abdalati 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 (NSIDC); Associate Director for the Cryospheric and Polar Processes Division

Benjamin Balsley Research Professor Emeritus, Electrical, Computer, and Energy Engineering; CIRES Senior Research Scientist

Stan Benjamin Chief of Assimilation and Modeling Branch, NOAA ESRL Global Systems Division

Roger Bilham Professor of Geological Sciences

Maxwell Boykoff Assistant Professor of Environmental Studies

John Cassano Associate Professor of Atmospheric and Oceanic Sciences

Thomas Chase CIRES Senior Research Scientist

Xinzhao Chu Associate Professor of Aerospace Engineering

Shelley Copley Professor of Molecular, Cellular, and Developmental Biology

Joost de Gouw CIRES Senior Research Scientist; NOAA ESRL Chemical Sciences Division (CSD)

Lisa Dilling Assistant Professor of Environmental Studies

Randall Dole Deputy Director for Research, NOAA ESRL Physical Sciences Division (PSD); Associate Director for the Weather and Climate Dynamics Division

David Fahey Research Physicist and Program Lead, Atmospheric Composition and Chemical Processes; Senior Scientist, NOAA ESRL CSD

Christopher Fairall Chief of the Weather and Climate Physics Branch, NOAA ESRL PSD

Lang Farmer Professor and Department Chair of Geological Sciences

Fred Fehsenfeld CIRES Senior Research Scientist, NOAA ESRL CSD; Co-Associate Director for the Environmental Chemistry Division

Graham Feingold Research Scientist, NOAA ESRL CSD

Noah Fierer Associate 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

Michael Hardesty Associate Director for the Environmental Observations, Modeling, and Forecasting Division; NOAA ESRL CSD

José-Luis Jiménez Associate Professor of Chemistry and Biochemistry

Craig Jones Associate Professor of Geological Sciences

William M. Lewis Jr. Professor of Ecology and Evolutionary Biology; Director of the Center for Limnology; Interim Director of CIRES

Peter Molnar Professor of Geological Sciences

Steve Montzka Research Chemist, NOAA ESRL Global Monitoring Division

William Neff Senior Scientist and Director of NOAA ESRL PSD

Steven Nerem Professor of Aerospace Engineering

David Noone Associate Professor of Atmospheric and Oceanic Sciences

Judith Perlwitz CIRES Research Scientist; NOAA ESRL PSD

Roger Pielke Jr. Professor of Environmental Studies

Balaji Rajagopalan Professor of Civil, Environmental, and Architectural Engineering

F. Martin Ralph Research meteorologist and Chief of the Water Cycle Branch, NOAA ESRL PSD

Prashant Sardeshmukh CIRES Senior Research Scientist; NOAA ESRL PSD

Mark Serreze Professor of Geography; Director of the National Snow and Ice Data Center (NSIDC)

Anne Sheehan Professor of Geological Sciences; Associate Director for the Solid Earth Sciences Division

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

Margaret Tolbert Distinguished Professor of Chemistry and Biochemistry; Co-Associate Director for the 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

Carol Wessman Professor of Ecology and Evolutionary Biology; Associate Director for the Ecosystem Science Division

Tingjun Zhang CIRES Senior Research Scientist, NSIDC

CIRES Centers

The Centers within the CIRES enterprise link NOAA and 11 different departments at the University of Colorado Boulder. CIRES Centers provide an environment conducive to collaboration, facilitating partnerships between federal and academic entities.

Center for Limnology

The Center for Limnology makes ecologically oriented studies of inland waters: lakes, streams, and wetlands. The goals of the center are to provide visibility, continuity, and technical support for interdisciplinary studies involving inland aquatic ecosystems; to maintain undergraduate training programs and individualized undergraduate instruction in the science of aquatic ecosystems; to attract and use research funds for the collection and analysis of data on aquatic ecosystems; to publish and disseminate research findings in the open literature; to participate at the national and international level in the study of important questions relating to aquatic ecosystems; and to help resolve important problems related to either the basic science or applied science of inland waters.

• Find full report for FY13 on page 52.

Center for Science and Technology Policy Research

The Center for Science and Technology Policy Research (CSTPR) was established within CIRES in 2001 to conduct research, education, and outreach at the interface of science, technology, and the needs of decision makers in public and private settings. CSTPR focuses on the intersection of the environment and society and applying the social and policy sciences to problems of environmental change, management, and sustainability. Much of the work at CSTPR involves 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.

• Find full report for FY13 on page 54.

Earth Science and Observation Center

The 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. The aim is to work on all scales of problems, from technique development at 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.

• Find full report for FY13 on page 56.

National Snow and Ice Data Center

The mission of the National Snow and Ice Data Center (NSIDC) is to advance understanding of Earth's frozen realms: the floating sea-ice cover, lake ice, glaciers, ice sheets, snow cover, and frozen ground, collectively known as the cryosphere. Major areas of research at NSIDC include processes driving the downward trend in Arctic sea-ice extent; environmental impacts of this sea-ice loss both within and beyond the Arctic; the behavior of the Greenland and Antarctic ice sheets; Himalayan glaciers and their contributions to sea-level rise; links among snowfall, temperature, and streamflow; and the implications of changes in Earth's permafrost. Informatics research includes developing alternative database structures to search vast data volumes to answer science questions; developing technologies to make NSIDC data more visible to more researchers; and enhancing data discovery through semantic interoperability. NSIDC also has a broad scope of education and outreach efforts.

• Find full report for FY13 on page 58.

Columbia River Gorge, Oregon.
Photo credit: M.J. Post/CIRES

Interdisciplinary Programs

CIRES fosters a vibrant research environment through programs and initiatives designed to stimulate interdisciplinary collaborations among CIRES, NOAA, and CU-Boulder scientists.

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. WWA is one of 11 NOAA-funded Regional Integrated Sciences and Assessments (RISA) programs across the country. Through relationships with networks of decision makers, WWA develops practical research programs and useful information products. 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 crosscutting priorities, as well as other Congressional NOAA mandates, including the U.S. Global Change Research Act and the U.S. Climate Change Science Program.

• Find full report for FY13 on page 60.

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. Its work emphasizes scientific inquiry, access to current research, and foundational concepts in geosciences education. CIRES scientists often partner with CIRES Education and Outreach as part of their research projects; contribute to education projects as presenters, reviewers, and learning-resource providers; and star in scientific video clips. This involvement by scientists helps teachers have confidence that the resources provided by CIRES EO are scientifically sound and up-to-date.

• Find full report for FY13 on page 62.

2013 Innovative Research Program Awards

Project	CIRES and NOAA Investigators
Formation-flying for atmospheric studies using small, autonomous aircraft	Ben Balsley and Dale Lawrence
Observations of wind turbine wakes using unmanned aircraft systems	John Cassano, Julie Lundquist, Brian Argrow, Eric Frew, and Katja Friedrich
Are microbes a significant component of free tropospheric aerosol?	Noah Fierer, Joanne Emerson, Anne Perring, Joshua Schwarz, and David Fahey
Science On a Sphere®: Cognition + Affect = Effect	Shilpi Gupta and Marda Kirn
Passive source imaging of Earth's ionosphere using lightning	Steven Hansen, Anne Sheehan, Paul Bedrosian, and Tim Fuller-Rowell
A new method for real-time monitoring of tsunamis with magnetic observations	Manoj Nair, Stefan Maus, Patrick Alken, Neesha Schnepf, and Arnauld Chulliat
The rise and fall of mid-Holocene Rajasthan lakes	Balaji Rajagopalan, Peter Molnar, and Emily Gill
A compact, sensitive, laser-induced fluorescence instrument for the measurement of SO_2	Andrew Rollins, Troy Thornberry, Ryan Neely, and Ru-Shan Gao

Crestview Elementary School, Boulder, Colo.
Photo credit: CIRES Education and Outreach

Visiting Fellows

CIRES hosts a competitive Visiting Fellows program that promotes collaborative research at the forefront of scientific knowledge. Selected annually, Visiting Fellows conduct interdisciplinary research in areas spanning the scope of the CIRES research portfolio. Fellowships of up to one year are awarded to Ph.D. scholars (postdoctoral fellowships) and faculty planning sabbatical leave (sabbatical fellowships). A committee of CIRES Fellows reviews 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. Selections for the Visiting Fellows program are based in part on the likelihood of interactions between the Visiting Fellows and CIRES scientists 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 more than 100 Visiting Fellowships. Past recipients have included previous CIRES directors Susan Avery and Konrad Steffen.

• Find full report for FY13 on page 64.

Innovative Research Programs

The CIRES-wide competitive Innovative Research Program (IRP) stimulates a creative research environment within CIRES and encourages synergy among disciplines and research colleagues. The program supports 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 of CIRES Fellows selects the award recipients. The committee reviews all proposals and recommends to the CIRES Director those that are the most inventive and bridge boundaries between traditional disciplines. The results of IRP research are presented the following year at a poster reception.

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 master's and doctoral students every other year with the support of NOAA's Earth System Research Laboratory. The fellowships are competitively awarded to new or existing CIRES-affiliated graduate students. A Committee of CIRES Fellows serves as the review and selection committees for both fellowships.

• Find full report for FY13 on page 68.

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 is coordinated by the Communications Group and involves close collaborations with NOAA, CU-Boulder, our centers, and international colleagues in academic and government institutions. Through a coordinated multimedia approach, the Communications Group uses traditional and innovative methods to convey the outcomes of key research endeavors to the public.

The success of the CIRES communications strategy is exemplified by widespread coverage of our scientific work in, for example: *Science News*, *The New York Times*, *Scientific American*, CBS, *Discovery*, *Discovery News*, *National Geographic*, Time, Nature News, BBC, *Business Week*, MSNBC, Fox News, *Science NOW*, *Nature News*, and the *Los Angeles Times*.

• Find full report for FY13 on page 70.

CIRES Ph.D. candidate Dan McGrath displays an ice core at Swiss Camp, Greenland
Photo credit: CIRES

2012 Highlighted Honors and Awards

The breadth and number of achievements by CIRES researchers and staff speak to the quality of research conducted at the Institute. From lifetime achievement awards to recognition of emerging young talent, CIRES scientists are among the best of the best at what they do. Among the premier awards received by CIRES scientists during 2012 were two Presidential early-career awards from the White House and a Colorado Governor's Impact award, for high-impact scientific research.

On this page, we highlight a few of CIRES' award winners; a more complete list can be found in the Appendices, page 139.

Presidential Early Career Award for Scientists and Engineers (PECASE)

In 2012, the White House named CIRES scientists David Noone and Rebecca Washenfelder as recipients of the 2011 Presidential Early Career Award for Scientists and Engineers (PECASE). The PECASE award is the highest honor given by the U.S. government to outstanding scientists and engineers in the early stages of their careers. Noone's award citation acknowledges him for his "innovative use of stable isotope tracers and modeling efforts directed towards an integrated understanding of the cycling of water and carbon dioxide through the atmosphere, and for actively engaging students in cutting-edge research at middle schools." Washenfelder was lauded for her "pioneering work in developing and applying new measurement techniques to study atmospheric chemistry related to climate and air quality and for commitment to science education and outreach."

Governor's Impact Award

Colorado Governor John Hickenlooper presented a team of 34 CIRES and NOAA scientists with the 2012 CO-LABS Governor's Award for High-Impact Research in recognition of their "Rapid-Response Atmospheric Science to Assess the Deepwater Horizon Oil Spill Crisis."

CIRES Awards

This year, CIRES presented Outstanding Performance Awards of $2,000 each to individuals and teams conducting groundbreaking research and working to make science more accessible. 2012 recipients included: Tim Bardsley, Christopher Clack, Eric Gordon, Emrys Hall, Allen Jordan, Jeff Lukas, Julien Lynge, and Walt Meier. Their work is described in greater detail on page 139. CIRES also presented Director's Awards of $1,000 to administrative employees providing exemplary professional service. These included Ted DeMaria, Yvonne Garcia, Lisa Ho, and Nancy Lathrop.

Presidential Early Career Award for Scientists and Engineers winner Rebecca Washenfelder with Rear Admiral David Titley (retired Navy), who was then NOAA's deputy under secretary for operations, and John Holdren, assistant to the President for science and technology. Photo credit: Derek Parks/NOAA

2012 CO-LABS Governor's Impact Award winners. This CIRES/NOAA team won for its "Rapid-Response Atmospheric Science to Assess the Deepwater Horizon Oil Spill Crisis." Photo credit: NOAA

Presidential Early Career Award for Scientists and Engineers winner David Noone.
Photo credit: David Oonk/CIRES

2012 CIRES Outstanding Performance award winners Photo credit: David Oonk/CIRES

FY2013 Highlighted Events

CIRES hosts diverse symposiums, seminars, workshops, and other events throughout the year. The CIRES Rendezvous, the Distinguished Lecture Series, and the CIRES 45th Anniversary are among the highlights of CIRES events during FY13. See page 141 for a complete list.

Allison McComiskey gives introductory speech to the 2013 Rendezvous research symposium.
Photo credit: David Oonk/CIRES

Rendezvous

About 400 people attended the eighth annual Rendezvous research symposium, sponsored by the CIRES Members' Council, on May 2, 2013. This half-day, institute-wide symposium featured more than 130 posters showcasing the depth, breadth, and quality of science being conducted by CIRES scientists, and it provided an avenue for them to share research with each other and NOAA colleagues. Interim Director William Lewis Jr. delivered the "State of the Institute" address and presented awards for years in service, the CIRES Outstanding Performance Awards, and awards for other professional achievements.

CIRES 45th Anniversary

CIRES marked 45 years of "science in service to society" with a day of keynote addresses by current CIRES scientists, including CIRES Fellow Waleed Abdalati (NASA Chief Scientist at the time, now CIRES Director), CIRES Fellow David Fahey, and Interim Director William Lewis Jr.; retrospectives by former CIRES scientists, including past directors Konrad Steffen, Susan Avery, and Robert Sievers; a poster session; and institute-wide fellowship.

Distinguished Lecture Series

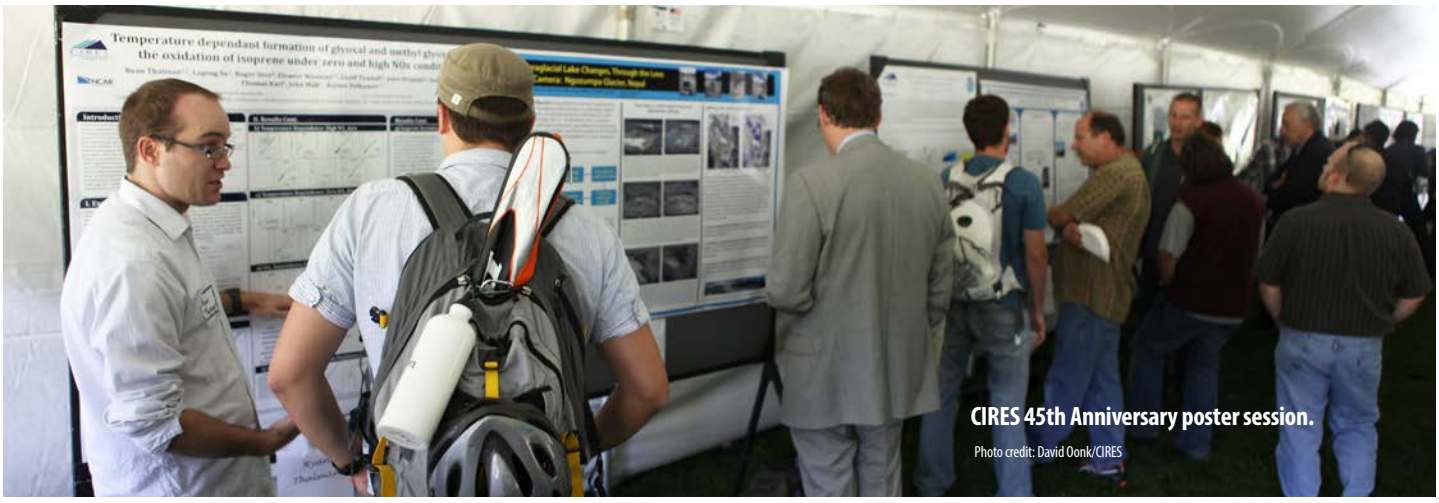
This lecture series was created to bring in outstanding scientists and innovative thinkers who have given thoughtful consideration to environmental and Earth system science issues. A committee of CIRES Fellows determines distinguished lecture invitees.

David Randall
A university perspective on climate modeling
(October 2012)

Christopher Landsea
Hurricanes and global warming: expectations versus observations
(October 2012)

Richard Seager
The Dust Bowl and other great North American droughts of the past, present, and future
(February 2013)

Steven Wofsy
Greenhouse gases across time and space, from the global scale to the urban dome
(March 2013)



CIRES 45th Anniversary poster session.
Photo credit: David Oonk/CIRES

Finance

CIRES continued to grow during the University's FY13 (July 2012–June 2013), with total expenditures of nearly $64 million, not including the University portion (nearly $63 million in FY12). CIRES researchers continue to have great success in obtaining external research awards. As was true last year, contracts and grants expenses (48 percent of total) are greater than those in our Cooperative Agreements (46 percent). The University's monetary contribution to CIRES primarily covers faculty salaries, and it fluctuates from year to year due to changes in our rostered University faculty appointments.

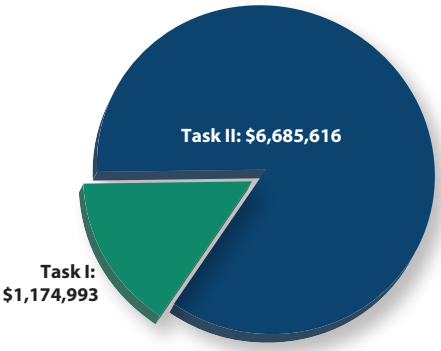
Agreement expenditures by task for FY13 are shown in the top figure at right. As of May 31, 2013, NOAA provided $7,860,609 for the first nine months of our new Cooperative Agreement (NA12OAR4320137, September 2012 to August 2017).

Task I funding is for CIRES administration and internal scientific programs, such as the Visiting Fellows and Graduate Student Fellowship programs; Task II funds CIRES' collaboration with NOAA's Earth System Research Laboratory, the National Geophysical Data Center, and the Space Weather Prediction Center, all in Boulder, Colo.

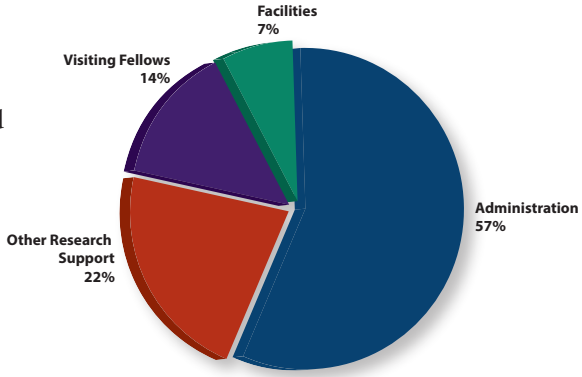
The middle chart at right breaks down Task I expenditures from FY13, including expenditures under our current and new Cooperative Agreements (NA10OAR4320142 and NA12OAR4320137). The largest share (57 percent) of Task I base funds supports CIRES administration, primarily salaries and benefits for the administrative staff. The Visiting Fellows program received 14 percent of Task I base fund support in FY13 and is subsidized by other Institute funding as well. Task I also provides partial support of CIRES' Education and Outreach program, other research support, and the physical plant facilities.

NOAA Task I base funding is augmented by CIRES' portion of the University's indirect cost recovery (ICR), which is distributed annually to University units as a proportion of indirect costs collected from institutional research grants and awards.

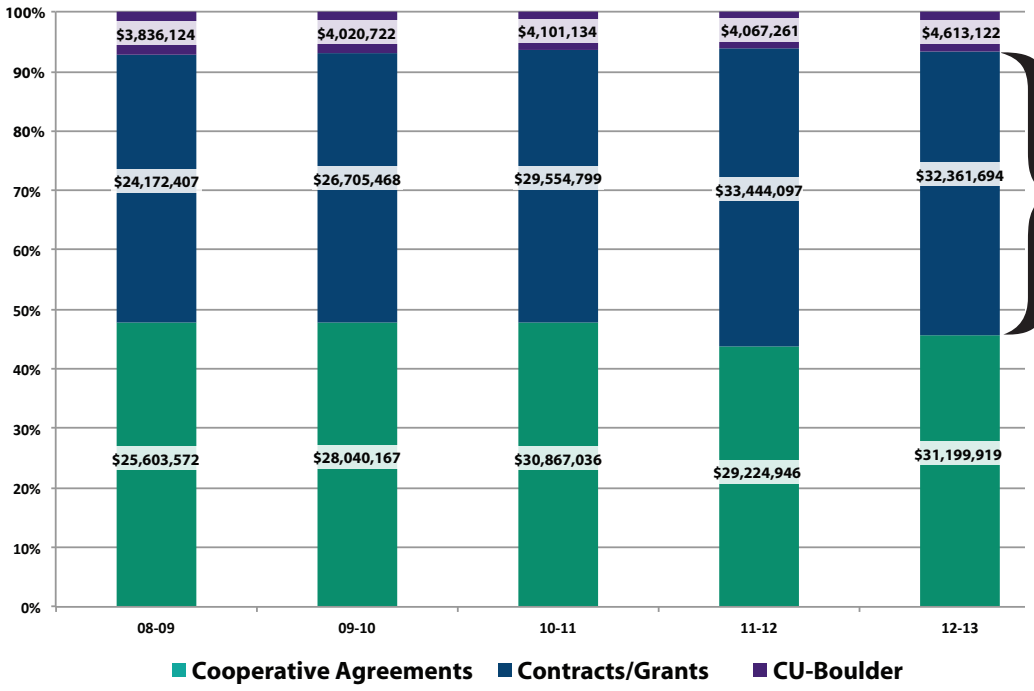
Cooperative Agreement NA12OAR4320137 funding by task (September 2012–May 2013)



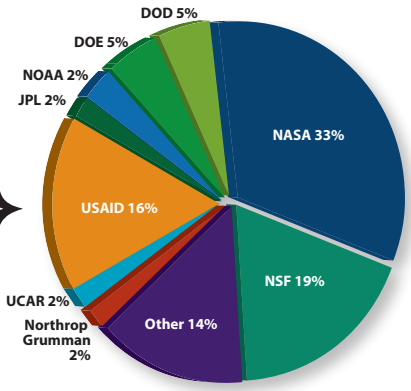
2012–2013 CIRES Task 1 base fund expenses



Expenditures by NOAA Cooperative Agreements, individual awards, and University of Colorado Boulder funds



Breakdown by funding agency



DOD: Department of Defense
DOE: Department of Energy
JPL: Jet Propulsion Laboratory
NSF: National Science Foundation
UCAR: University Corporation for Atmospheric Research
USAID: U.S. Agency for International Development

Na Pali Coast, Kauai. A very remote area on one of Earth's most isolated islands.
Photo credit: Ami Nacu-Schmidt

CIRES starts with people

The following pages highlight the diversity of research conducted at CIRES, beginning with those CIRES Fellows who are University of Colorado Boulder faculty or CIRES scientists. Following are descriptions of CIRES' four centers, 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; graduate and undergraduate programs including fellowship and diversity programs; and CIRES' communication work. A more exhaustive description of CIRES projects, involving CIRES Fellows at NOAA and hundreds of other scientists and staff, can be found in the Project Reports (page 72).

CIRES Fellows

NOAA Scientists

Stan Benjamin
Randall Dole
David Fahey
Christopher Fairall
Graham Feingold
Stephen Montzka
William Neff
F. Martin Ralph

CU-Boulder Teaching Faculty

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

Photo credit: Rui Li/CIRES

CIRES Scientists

Richard Armstrong
Thomas Chase
Joost de Gouw
Fred Fehsenfeld
Timothy Fuller-Rowell
Michael Hardesty
Judith Perlwitz
Prashant Sardeshmukh

Waleed Abdalati

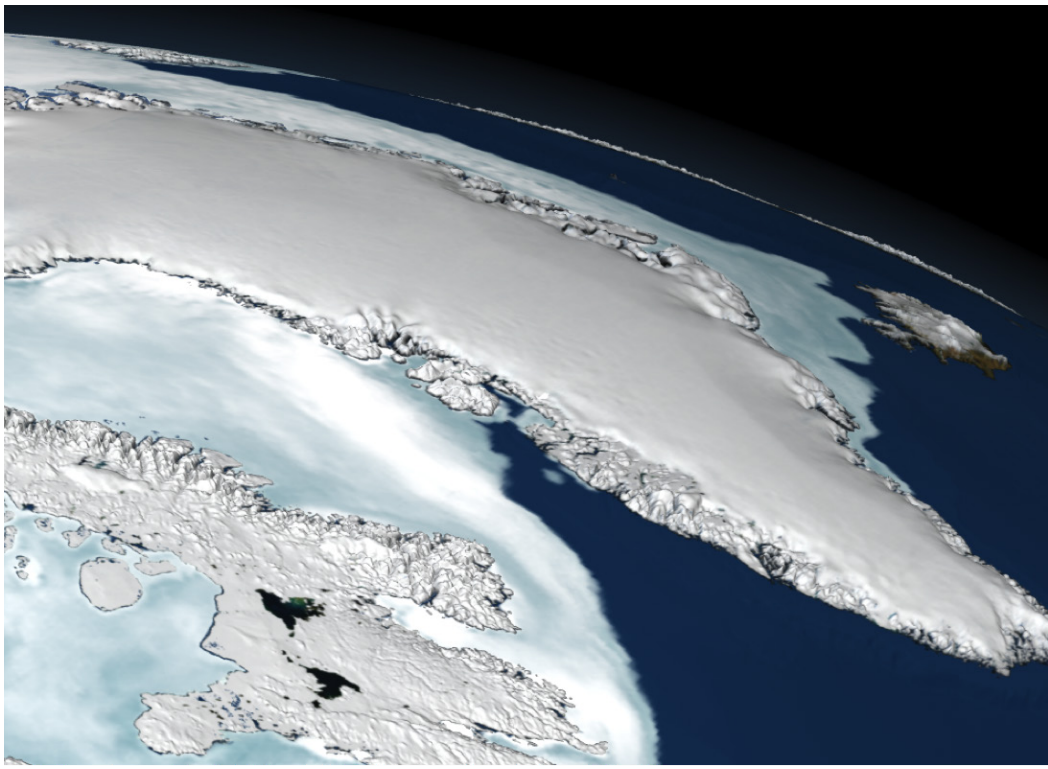
Using satellites, aircraft, and in situ measurements to study polar ice

From January 2011 through December 2012, I was on leave from the University of Colorado Boulder to serve as Chief Scientist of the National Aeronautics and Space Administration. In this capacity, I was the principal science advisor to the NASA Administrator and interfaced with the Executive Office of the President and Congress to ensure alignment among NASA, White House, and Congressional science priorities. The challenges and experiences as Chief Scientist, in particular interacting with an incredibly diverse array of scientists, politicians, and others, will enable me to better serve the CIRES and University community, particularly in my new role as CIRES Director (effective July 1, 2013).

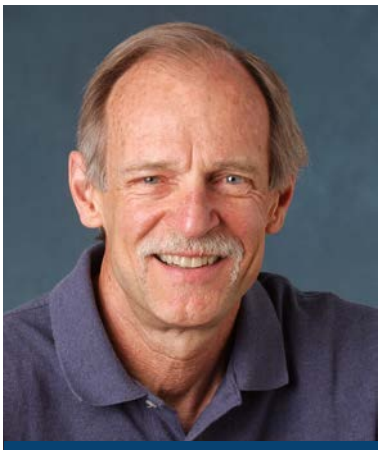
While I was on leave and since my return, I have worked with my graduate students and CIRES research scientists, using space-based observations to study changes in Earth's glaciers and ice sheets. This research is focused on three areas. The first is the development of methods for determining how much meltwater is stored in—and subsequently lost from—melt lakes on the surface of the Greenland Ice Sheet. This meltwater has significant implications for the speed at which the ice sheet flows toward the sea because the meltwater reduces friction between the ice and the bedrock on which it rests and also changes the deformation properties of the ice as the warm meltwater penetrates into the ice.

The second area of research has focused on understanding the nature of compaction of the near-surface firn (snow) on the Greenland Ice Sheet; this will improve the interpretation of satellite altimetry observations of ice-sheet-thickness changes. The third area has involved the use of data from the Gravity Recovery and Climate Experiment (GRACE) mission to separate the sea-level contributions from Greenland's peripheral glaciers and ice caps from those of the main ice sheet. This partitioning helps us understand the relative importance of the mechanisms driving today's ice-sheet changes and what that may mean for the future.

These areas of research are fundamental to our ultimate overarching objective of determining how and why Earth's glaciers and ice sheets are changing and what those changes mean for life on Earth.



Moderate Resolution Imaging Spectroradiometer (MODIS) composite image of the Greenland Ice Sheet and surrounding sea ice of west-central Greenland.
Image credit: NASA Scientific Visualization Studio



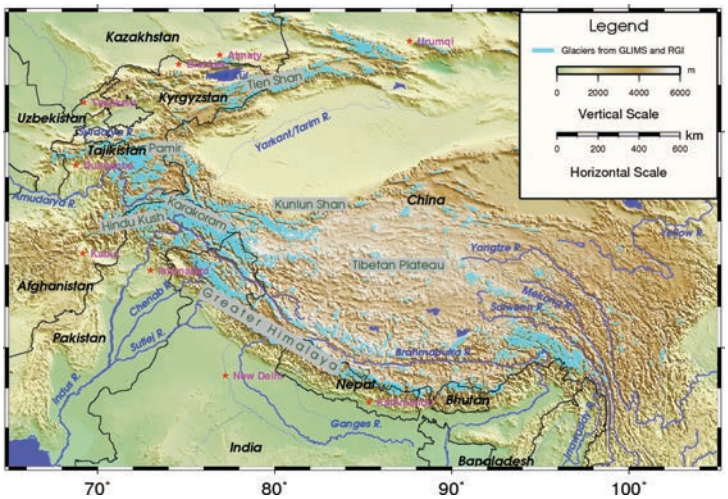
Richard Armstrong

The Contribution to High Asia Runoff from Ice and Snow (CHARIS) project

The fundamental objective of the CHARIS project is to develop a thorough and systematic assessment of the individual contribution of seasonal snow and glacier ice to the water resources originating across the Himalaya, Karakoram, Hindu Kush, Pamir, and Tien Shan mountain ranges, referred to here as High Asia. The headwaters of the Brahmaputra, Ganges, Indus, Syr Darya, and Amu Darya rivers are all located in High Asia. While the scientific community generally accepts that the melting of glacier ice and seasonal snow produces a significant component of the High Asian water resources, the actual water volume available from these two individual sources across this region remains generally unknown. Realistic estimates of the future availability and vulnerability of the region's water resources are not possible until we achieve a better understanding of the current hydrologic regime.

The improved understanding of these regional water resources is a cross-boundary exercise, and the CHARIS project will greatly facilitate the international cooperation required for successful water-resource management across High Asia. The development of the necessary research collaboration has been very successful during the previous 12 months, with formal agreements being finalized between the University of Colorado Boulder and key research institutions located in Bhutan, Nepal, India, Pakistan, Afghanistan, Kazakhstan, Kyrgyzstan, and Tajikistan.

To accomplish project research objectives, my group uses a suite of satellite remote-sensing, reanalysis, and ground-based data (provided by Asian project partners), along with gridded maps of snow and glacier area/elevation, as input to spatially distributed temperature-index and energy-balance melt models. See nsidc.org/charis for details.



Major river systems, mountain ranges, and glacier cover across High Asia.

A fundamental capacity-building exercise took place in Almaty, Kazakhstan, from May 13 to 17, 2013. During this exercise, CU-Boulder CHARIS staff conducted short courses on the topics of mountain hydrology, glacier mass balance, mapping of snow and glacier cover, and isotopic and geochemical tracers. Representatives from all partner organizations attended the short courses and provided summaries of their proposed collaborative field research for the 2013 summer. CHARIS partners will again convene in Nepal in November 2013 to present their most recent research results.

On the Kara Batkak glacier with the Institute of Water Problems and Hydropower, Kyrgyzstan, September 2012. From left to right: Vladimir Shatravin (director, Glaciology Lab), Betsy Armstrong (communications consultant), Marina Lischenko (interpreter), Richard Armstrong (CHARIS principal investigator), and Bakyt Ermenbayev (director, Tien Shan High Mountain Research Center).

Photo credit: Janat Abdrayev/Institute of Water Problems and Hydropower, Kyrgyzstan

Great earthquakes at the ends of the Himalayan Arc

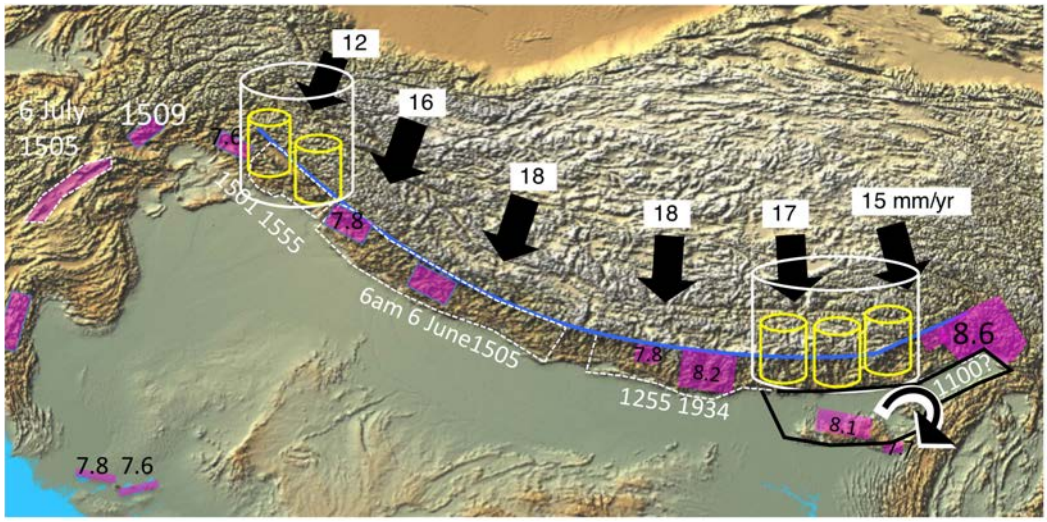
Roger Bilham

The characterization of future damaging earthquakes in the Himalaya depends on quantifying tectonic convergence rates, investigating the history of previous earthquakes, and identifying segments most likely to rupture. The two most recent catastrophic earthquakes in the Himalaya occurred near the ends of the arc—in Assam in 1950 and in Kashmir in 2005—regions now believed to be relatively safe from an immediate recurrence of catastrophic shaking. These earthquakes stressed, however, adjoining regions.

Global Positioning System (GPS) geodesy in Nepal reveals that India converges with southern Tibet at approximately 18 millimeters per year, with stress concentrated near a nucleation zone 18 kilometers beneath the high mountains. Earthquakes occur when this nucleation zone is stressed beyond the ability of Himalayan faults to resist southward slip. We are focusing our measurement efforts at the ends of the arc where no historical earthquake has occurred recently.

GPS results from Bhutan in 2012 reveal that a continental block the size of Colorado has broken from the Indian Plate and is slowly rotating clockwise, carrying with it the Brahmaputra River Valley. From a consideration of the resulting convergence between southern Tibet and this block, we deduce that the seismic behavior of the eastern Himalaya resembles that of the central Himalaya. We recognize three contiguous segments near Bhutan where earthquakes greater than magnitude 8 could occur separately or in combination. Ominously, in at least one of these segments, the last earthquake, circa 1,000 years ago, may have slipped 18 meters; hence, a great earthquake here in the next century would not be unexpected.

At the other end of the Himalayan Arc, our GPS measurements record a very different style of convergence. In Kashmir, we find no well-defined nucleation zone, slower convergence rates, and a doubling in the width of the Himalaya. The slow rates suggest that long intervals occur between great earthquakes, but the greater width permits the earthquakes' maximum magnitude (Mmax) to approach 8.9 Mmax. Recent earthquakes here, however, suggest that convergence may be absorbed by smaller faults, hosting approximately 7.5 moment-magnitude earthquakes that cut through to the surface of the Kashmir Valley instead of shifting the entire Himalaya southward.



Violet or dashed polygons show inferred rupture zones and dates of historical earthquakes. The polygon outlined in black indicates the Shillong/Brahmaputra crustal block rotating at about 1 degree per million years. Black arrows indicate GPS-measured convergence rates in the Himalaya. Large white cylinders are centered on maximum credible earthquakes (8.9 maximum magnitude) in Kashmir and Bhutan. Yellow cylinders indicate smaller ruptures, between 7.5 to 8.2 moment magnitude, considered to represent more probable ruptures based on fault-segmentation studies.

Maxwell Boykoff

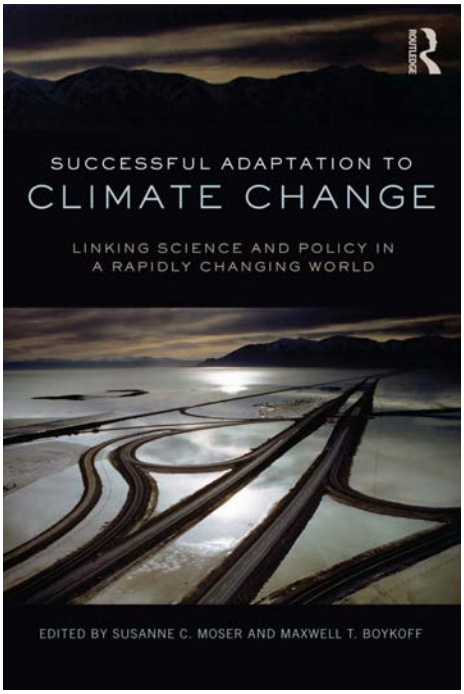
Successful adaptation to climate change

I have ongoing interests in climate adaptation, cultural politics and environmental governance, science-policy interactions, and political economy and the environment. My research concentrates on interactions between state and non-state actors at the interface of environmental science, policy, and practice. I have been working in two primary research areas: 1) issues in the cultural politics of climate change, and 2) transformations of carbon-based economies and societies.

One project involves ongoing monitoring of media attention to climate change, with monthly appraisals at the global and country scales, which include the United States, the United Kingdom, India, New Zealand, Australia, Canada, and Japan. See more at: http://sciencepolicy.colorado.edu/media_coverage/.

Another project is a new, co-edited (with Susanne Moser, Ph.D.) volume called "Successful Adaptation to Climate Change: Linking Science and Policy in a Rapidly Changing World" (www.routledge.com/books/details/9780415525008/). This project unpacks the question of successful adaptation and offers both scientifically informed and practice-relevant answers from various sectors and regions of the world. It brings together chapters from leading experts within the field and demonstrates how the question of success in important ways is normative and context-specific. It identifies the various dimensions of success, such as economic, political, institutional, ecological, and social; explores the tensions among them; and compiles encouraging evidence that resolutions can be found.

The book appraises how climatic and non-climatic stressors play a role; what role science does and can play in adaptation decision making; and how trade-offs and other concerns and priorities shape adaptation planning and implementation on the ground. Adaptation is increasingly recognized as an important climate-risk-management strategy, and on-the-ground adaptation planning activity is becoming more commonplace. Still lacking is clear guidance as to what success would look like, what to aim for, and how to judge progress. This text, therefore, endeavors to bridge the gap between science and practical applications of successful adaptation strategies.



John Cassano

Probing the Antarctic atmosphere with unmanned aerial vehicles (UAVs)

My research group is using UAVs, or drones, to study the Antarctic atmosphere. Aerosonde UAVs, with a 3.6-meter wingspan and a takeoff weight of 20 kilograms, have completed 300 flight hours during flight operations in September 2009 and September 2012. The September 2009 flights were the first wintertime UAV science flights in the Antarctic, and the 2012 flights, with durations of up to 19 hours, were the longest duration UAV flights in the Antarctic.

We are using the Aerosonde UAVs to study air-sea interactions at the Terra Nova Bay Polynya. The Terra Nova Bay Polynya is a region of open water surrounded by sea ice; the sea ice forms when strong winds blowing off the Antarctic continent push sea ice away from the coast. Since sea ice acts to insulate the relatively warm ocean from the cold overlying atmosphere, the presence of a polynya—and lack of insulating sea ice—results in large heat and moisture transfer from the ocean to the atmosphere. The UAVs measure this heat and moisture transfer between the atmosphere and ocean and document the changes in atmospheric state as the cold continental air passes over and downwind of the Terra Nova Bay polynya. As part of this project, the Aerosonde UAVs have flown in temperatures colder than minus 30 degrees Celsius and in wind speeds greater than hurricane force (40 meters per second).

The Cassano research group also is using smaller (0.8-meter wingspan, 580-gram takeoff weight), less expensive, and less logistically difficult UAVs to make local atmospheric measurements. We flew these smaller UAVs, known as small unmanned meteorological observers (SUMOs), in the vicinity of McMurdo Station, Antarctica, in January and September of 2012. We are using observations from these UAVs to study the structure of the atmosphere's lowest 1 kilometer and to document changes in the atmospheric boundary layer during time periods of tens of minutes to hours. The SUMOs have proven capable of measuring very sharp temperature inversions and have observed rapid deepening of the boundary layer.

An Aerosonde unmanned aerial vehicle being launched from the top of a pickup truck at the Pegasus ice runway, McMurdo Station, Antarctica, in September 2012. Photo credit: John Cassano

Trail of light created above the Pegasus ice runway by the wingtip lights of the small unmanned meteorological observer (SUMO) aerial vehicle during a flight near sunset in September 2012. Photo credit: John Cassano

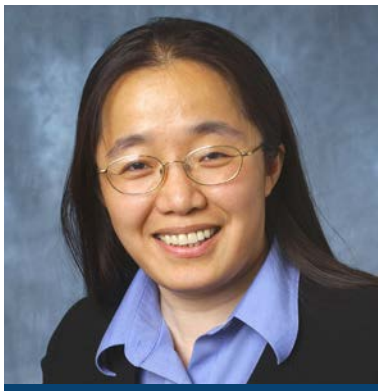
Thomas Chase

Why are observed temperatures in the mid-tropospheric Northern Hemisphere bracketed between minus 5 and minus 42 degrees Celsius?

My group seeks to understand the physical mechanisms behind the magnitude and variability of observed 500-hectopascal temperatures, which appear to be constrained between minus 5 and minus 42 degrees Celsius in the mid-troposphere. We focus here on the northern hemisphere (500 hectopascal). We have documented an approximate minus-42-degree-Celsius minimum cutoff in high northern latitudes and, in a series of previous papers, provided several lines of evidence for the physical mechanism responsible. We also have demonstrated a minus-5-degree-Celsius maximum, which appears to be dominated by tropical mechanisms.

These maximum and minimum temperatures are abrupt (they do not follow a normal distribution) and follow moist adiabatic arguments, implying that the basic mechanism in both cases (maximum and minimum) is convective. This is not surprising in the tropical case of maximum temperatures, which are well-known to be convectively controlled, but is not as obvious in the case of high-northern-latitude minimum temperatures. There are, however, alternate hypotheses that might be responsible for high-latitude temperature regulation—such as equator-to-pole heat transport or processes involving phase changes of water—that need to be addressed.

Cold air masses that migrate over the ocean may play a role in high-latitude temperature regulation.
Photo credit: iStock

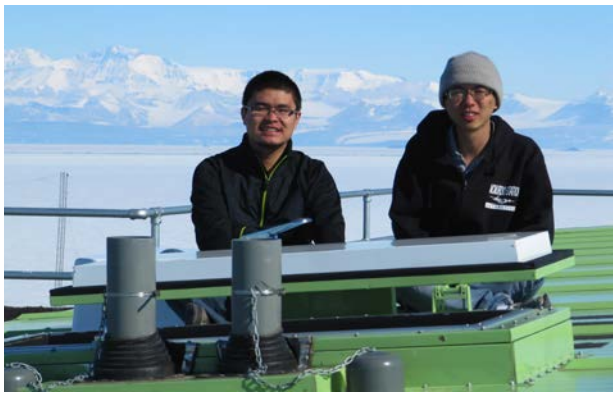


Xinzhao Chu

Cutting-edge lidars deliver new discoveries in atmosphere and space sciences

A new discovery of neutral iron (Fe) layers reaching more than 170 kilometers in the thermosphere is just one of the advances in atmosphere and space sciences brought about by cutting-edge lidar technologies and observations. With this extraordinary observation, made by winter-over lidar student Weichun Fong on June 1, 2013, in Antarctica, we are able to measure the neutral atmosphere temperatures from 30 to 170 kilometers for the first time in the world (Chu et al. 2013). It brings us one step closer to realizing a dream of making whole-atmosphere (0 to 200 kilometers) lidar observations. Certainly, such a discovery challenges our understanding of electrodynamics, neutral dynamics, chemistry, composition, and energetics in Earth's space environment, therefore prompting new research growth points.

The frontier lidar research at CIRES is delivering more discoveries and new insights to the Coupling, Energetic, and Dynamics of Atmospheric Regions (CEDAR) sciences. A remarkable accomplishment is that CIRES lidar students from the Chu Research Group have won the first-place prizes three years in a row in the CEDAR Student Poster Competitions, sponsored by the National Science Foundation. In 2013, Zhibin Yu won for his work titled "Lidar observations and numerical modeling studies of thermospheric Fe/Fe^+ layers." Cao Chen figured out the mystery of inertia-gravity waves at McMurdo Station, Antarctica, and won the first-place prize in 2012. Add to that Chihoko Yamashita's 2011 win, and our group's lidar students have made a new record in CEDAR history. Additionally, the studies by CIRES postdoctoral Visiting Fellow Xian Lu and student Weichun Fong provide insights into the planetary waves and thermal tides in Antarctica. Together, a comprehensive picture of the polar atmosphere and space is emerging.



Cao Chen (left) and Weichun Fong (right) with two invisible ultraviolet lidar beams at the Arrival Heights Lidar Observatory near McMurdo Station, Antarctica, in January 2013. Weichun is stationed there from August 2012 through October 2013, braving through the Antarctic winter of 2013. His lidar observations have led to new science discoveries, and the legend of lidar is being continued in Antarctica. Photo credit: Xinzhao Chu

Creative CIRES graduate students Zhibin Yu and John Smith "painted" the word LIDAR in the atmosphere at the Table Mountain Lidar Facility in north Boulder, Colo.
Photo credit: Zhibin Yu and John A. Smith/CIRES

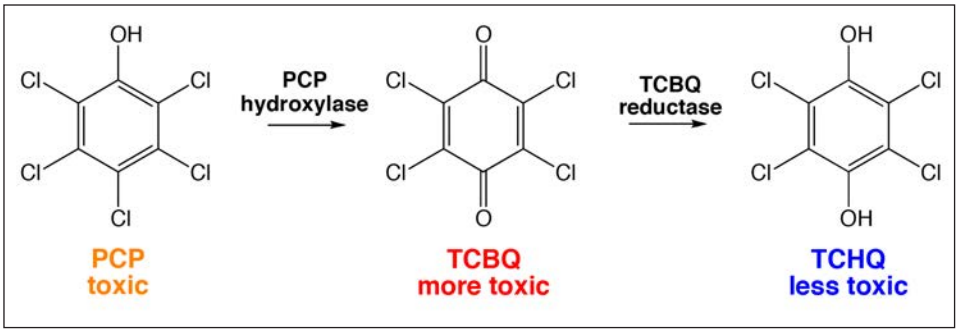
Another key aspect of our FY13 work was development of next-generation lidar technologies. CIRES graduate student John Smith has made outstanding innovations in the Fe and sodium (Na) Doppler lidars. The very high lidar-signal levels are enabling group members to conduct new science studies, such as the simultaneous measurements of Fe, Na, and heat fluxes by research scientist Wentao Huang and the first-ever lidar derivation of eddy flux by student Jeroen Geeraert. In 2012, Bo Tan earned his Ph.D., and Brendan Roberts earned his master's degree. Congratulations to these excellent students and researchers!

Shelley Copley

Evolution of enzymes and metabolic pathways

The Copley laboratory studies the evolution of enzymes and metabolic pathways in the context of the complex metabolic and regulatory networks in cells. Enzymes in extant organisms are highly efficient catalysts for specific reactions. However, they are not perfectly specific. Most, and probably all, enzymes also have low-level "promiscuous" activities that arise because of the highly reactive environment at their active sites. Although these activities are inefficient, they can accelerate reactions by several orders of magnitude relative to the rates of uncatalyzed reactions. Thus, a promiscuous activity provides an excellent starting place for evolution of a new enzyme if that activity becomes important for growth or survival. The presence of hundreds of enzymes, each of which has a number of promiscuous activities, provides the possibility of patching together multiple promiscuous activities to generate a novel metabolic pathway.

Microbes in contaminated environments can evolve new metabolic pathways for degradation of pollutants by recruiting enzymes with promiscuous activities to serve new roles. These newly evolved pathways are often quite inefficient. This is the case for the degradation of pentachlorophenol (PCP) by *Sphingobium chlorophenolicum*, a bacterium isolated from a site that was heavily contaminated with PCP. The rate-determining step for degradation is the first step in the pathway; see Figure 1 (McCarthy et al. 1997). The enzyme responsible for this reaction, PCP hydroxylase, turns over at a rate of only 0.02 s^{-1} (Hlouchova et al. 2012).



The initial steps in the pathway for degradation of pentachlorophenol (PCP) in *Sphingobium chlorophenolicum* (TCBQ stands for tetrachlorobenzoquinone, and TCHQ is tetrachlorohydroquinone).

For comparison, well-evolved enzymes that hydroxylate naturally occurring phenols turn over their substrates at 25 to 50 s^{-1}. We have recently shown that the chemical steps catalyzed by PCP hydroxylase are, in fact, reasonably efficient. Turnover of the enzyme is slow due to a step that occurs after the chemistry is over that is probably involved in release of the products (Rudolph and Copley, in preparation).

The initial step in the degradation of PCP by *S. chlorophenolicum* generates a particularly toxic intermediate, tetrachlorobenzoquinone (TCBQ). We have discovered how the bacterium is protected from the toxic effects of TCBQ. A transient interaction between the enzyme that forms it (PCP hydroxylase) and the enzyme that converts it to tetrachlorohydroquinone (TCHQ) prevents release of TCBQ to the cytoplasm where it could damage small molecules and macromolecules (Yadid et al. 2013).

References

Hlouchova, K, J Rudolph, JM Pietari, LS Behlen, and SD Copley. Pentachlorophenol hydroxylase, a poorly functioning enzyme required for degradation of pentachlorophenol by *Sphingobium chlorophenolicum*. *Biochemistry*. 51:3848-60.

McCarthy, DL, A Claude, and SD Copley. 1997. In vivo levels of chlorinated hydroquinones in a pentachlorophenol-degrading bacterium. *Appl. Env. Microbiol*. 63:1883-1888.

Yadid, I, J Rudolph, K Hlouchova, and SD Copley. 2013. Sequestration of a highly reactive intermediate in an evolving pathway for degradation of pentachlorophenol. *Proc. Natl. Acad. Sci. USA*. 110:E2182-90.

Joost de Gouw

Sources and chemistry of organic carbon in the atmosphere

Concerns over climate change, fossil fuel resources, and energy security have all led to recent changes in the U.S. energy supply and infrastructure. For example, the production of natural gas from shale formations has grown strongly during the last decade. Also, ethanol made from corn has been used increasingly as a transportation fuel. In our research, we study how these changes in our energy use are affecting the atmosphere.

Measurements in the Denver-Julesburg Basin in Colorado and in the Uintah Basin in Utah have clearly shown the presence of hydrocarbons associated with natural-gas production in the atmosphere. We found small alkanes, in particular, to be strongly elevated and much higher than in other areas with significant urban and/or industrial development such as Los Angeles and Houston. Because of their high concentrations in Colorado, we found that the alkanes associated with natural-gas production can provide significant fuel for ground-level ozone formation, outweighing the contributions from other sources such as cars and trucks.

In the Uintah Basin, because of the unique meteorology in the winter, the emissions associated with oil and natural-gas production can get trapped under very strong inversions and react chemically to form ground-level ozone. Ozone pollution is typically a summertime phenomenon that is most efficient when it is warm, sunny, and humid. In sharp contrast, ozone in the Uintah Basin formed most efficiently when it was extremely cold and dry. The scientific understanding of these chemical processes is very limited, and research is in progress to improve the understanding.

Natural gas equipment in Utah's Uintah Basin, and plumes from a distant power plant.

Photo credit: David Oonk/CIRES

During the last decade, corn ethanol has increasingly been used as a transportation fuel to the point where 10 percent of gasoline now consists of ethanol. As a result, the concentrations of ethanol in the atmosphere have increased. We have used our measurements to analyze the effects this increase has had on air quality. Also we are interested in the other atmospheric emissions that are associated with the increased use of corn ethanol, notably emissions from the growing of corn plants and from biorefineries that produce ethanol out of corn.

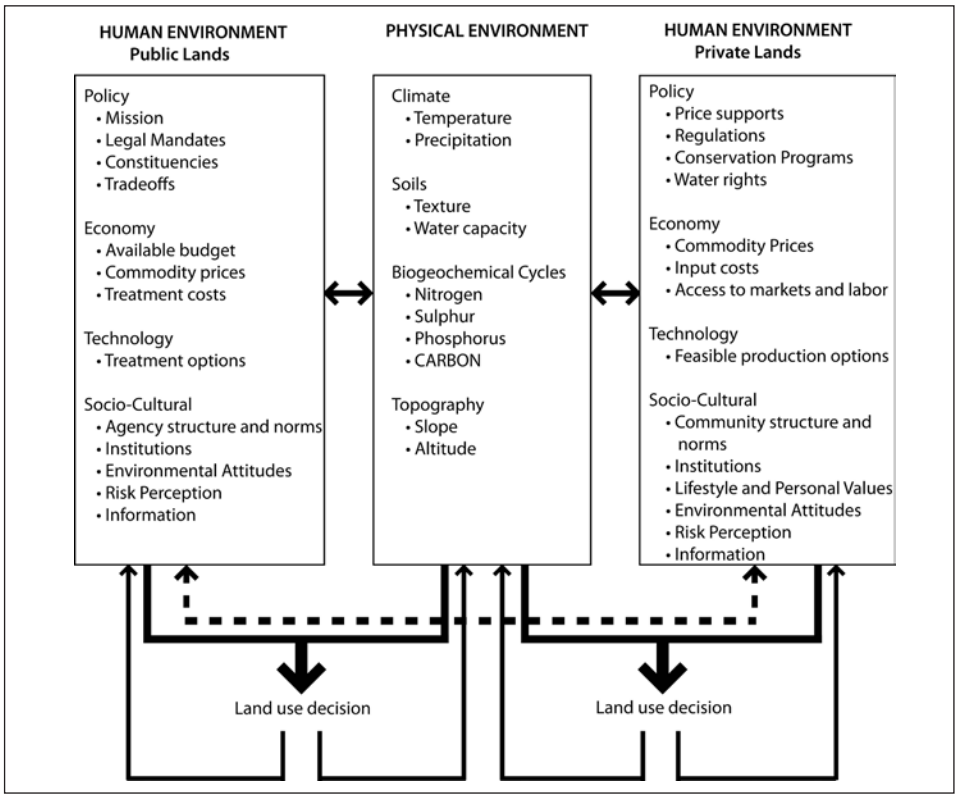
Lisa Dilling

Climate change and U.S. public lands management

During the last few years, it has become increasingly clear that Earth is committed to a certain amount of climate change, despite energy emission mitigation activities. Attention is, therefore, now focusing on adaptation and how people and ecosystems might be able to respond to changes in their environment. In the past few years, federal agencies have been directed to create adaptation plans and to consider adaptation to climate change as part of the decision processes. However, my research group's previous work has indicated that uncertainty at the local-office level about how to consider climate change raises the question of whether adaptation is happening "on the ground."

Last year, we published several studies investigating the drivers of land-use decision making for federal and private lands; perceived barriers to climate adaptation and carbon management; and how scientific information might more effectively inform decision making.

In a study based on a large survey and semi-structured interviews completed in collaboration with former graduate student Kelli Archie and CU-Boulder professors Jana Milford and Fred Pampel, our group found that managers across four federal agencies (the U.S. Forest Service, Bureau of Land Management, Fish and Wildlife Service, and National Park Service) were beginning to engage with adaptation but not yet substantially implementing adaptive actions. Some barriers to adaptation planning included lack of information at relevant scales, budget constraints, and lack of specific agency direction. Lack of public awareness and demand for action also were important barriers to implementation.



Conceptual representation of underlying physical and human environment drivers of land-use decision making and feedbacks. Human-environment drivers are separated into those influencing public-land managers and those influencing private-land managers, as those human drivers can be quite different.

Figure credit: Adapted from Riebsame et al. 1994

In a separate study on decision making related to carbon management for climate change on both public lands and private lands, similar challenges emerged. In addition, other factors—including many competing, higher-priority objectives, lack of market incentives, and negative perceptions of carbon offsets—may contribute to limited penetration of carbon management as a response to climate change. We suggest four avenues for enhancing the potential for carbon to be managed through land use. These include: clarifying mandates for public lands; providing compelling incentives for private landowners; improving understanding of the co-benefits and tradeoffs of managing for carbon; and creating more usable science to support decision making.

Lang Farmer

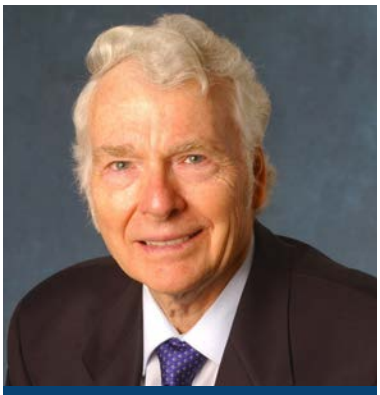
The provenance of "Grenville" age detrital zircon in western North America and the Neoproterozoic to early Paleozoic evolution of southwestern Laurentia

My research group began a new project in 2013 involving the combined use of hafnium and uranium-lead isotopic data from detrital (sedimentary) zircon crystals to assess the sources and distribution of sediments transported across the North American continent during the Early Cambrian period some 500 million years ago. Zircon grains, which are naturally occurring zirconium silicate minerals, are common in continental rocks and are exceptionally resistant to weathering and erosion. As a result, these grains are preserved in continentally derived sediments. The hafnium and uranium-lead isotopic compositions of detrital zircons provide a measure of the original continental source of the zircons and their transport in past continental river systems.

In this study, our goal is to assess the significance of changes in the age spread and relative peak height of specific detrital zircon age populations in sedimentary successions. We are targeting Mesoproterozoic to Cambrian sedimentary successions in the southwestern United States and Mesoproterozoic (1.0 to 1.3 giga-annum, Ga) granitic rocks from throughout North America, including the Pikes Peak granite in Colorado (see photo). Our data reveal that the hafnium isotopic compositions of detrital zircon derived from Mesoproterozoic source rocks vary over a huge range and demonstrate that circa 1.0 Ga detrital zircons in North America do not share the same provenance, as was previously assumed based on their uranium-lead ages alone. These results will require fundamental modifications to existing models of the Precambrian to early Paleozoic tectonic and paleogeographic evolution of North America.

Visiting Fellow Jeff Amato and CIRES master-of-science student Amanda Howard sampling the Mesoproterozoic Pikes Peak granite in 2012.

Photo credit: Lang Farmer



Fred Fehsenfeld

Air quality research

One of the principal goals of the Environmental Chemistry Division of CIRES/University of Colorado Boulder and the Chemical Sciences Division (CSD) of the NOAA Earth System Research Laboratory (ESRL) has been, and will be, to use our research to build a better scientific understanding of the chemical sources and processes that determine Earth's atmospheric composition. The information we garner from this research is required to wisely deal with and protect our atmospheric resources. Changes in atmospheric composition, whether natural or human-caused, can have important ramifications for Earth's atmosphere. These changes lead to the most important challenges for the protection of our atmospheric environment: forcing global climate change and degradation of air quality. In this research, we are committed to undertaking research that not only addresses national concerns, but also research that is unequivocally outstanding science.

An important component of this research involves field studies carried out at fixed ground sites, aircraft, and ships. The results are compared with modeling analyses in order to determine our ability to accurately simulate atmospheric processes and emission sources. In the framework of this research, several such studies were carried out in 2012.

As well as undertaking additional measurements in the field, the research also involves ongoing analysis and interpretation of air-quality and climate-change studies. These included the combined 2006 Texas Air Quality Study II and Gulf of Mexico Atmospheric Composition and Climate Study that were carried out in 2006 and 2000 and the 2004 New England Air-Quality Study and International Consortium for Atmospheric Research in Transport and Transformation study. It also involved the results from the special deployment of the NOAA WP-3 research aircraft to investigate the influence of the Deepwater Horizon oil spill on atmospheric chemical composition in the area around that location.

Burning of surface oil during the Deepwater Horizon oil spill.
Photo credit: U.S. Coast Guard

This research also involved planning for future climate and air-quality studies on air chemistry. I acted as the CIRES supervisor for five CIRES research scientists in the Environmental Chemistry Division of CIRES. In this capacity and working with other CIRES and NOAA scientists in the Troposphere Chemistry group of CSD, I provided input for the planning of regional air-quality/climate change studies that will be undertaken by CSD beyond 2012. The next major study being planned, Southeast Nexus, will address the transport and chemical transformations involving ozone, aerosols, and their chemical precursors in the Southeastern United States. A white paper for the overall study has been posted on the NOAA ESRL CSD website (http://esrl.noaa.gov/csd/projects/senex/) and is available for distribution to interested scientists in CIRES.

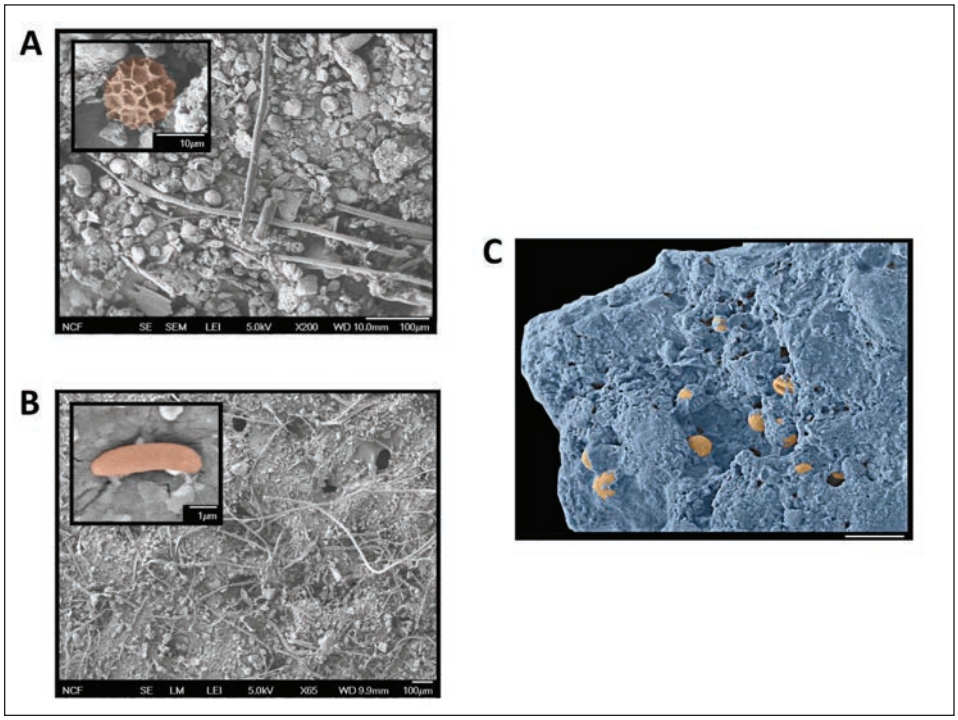
I assisted in the planning and made arrangements for the Nitrogen, Aerosol Composition, and Halogens on a Tall Tower Data Meeting that was held in September 2011 at CIRES, and now I am helping in the development of plans for future climate change and/or regional air-quality studies beyond 2011 in CSD and CIRES. I am participating in the initial stages of planning of a new CIRES initiative on the impact of energy development and generation on the environment with, emphasis on the impact of energy development and generation on the air quality and climate forcing. In the future, I will continue to assist in the formulation of the integrated science plans for future studies.

Noah Fierer

A microbial perspective on indoor air quality

We spend a sizable portion of our lives within our homes, where we are exposed to a broad array of microbes. The microbes found in our homes can cause disease, trigger allergies and allergenic asthma, degrade and discolor building materials, reduce the efficiency of heating and cooling systems, and produce odors. But they also can have unknown or unnoticeable effects (even positive effects) on our homes and quality of life. Despite their importance, the microbial diversity found in indoor air remains poorly studied. We have a limited understanding of the variability in airborne bacterial and fungal communities within and among homes and what factors influence this variability. In particular, we do not know how house design, occupancy, and location influence the types of microorganisms found in our homes.

To address these knowledge gaps, my group has been using recent advances in high-throughput DNA sequencing to describe bacterial and fungal diversity across 1,000 homes located throughout the United States. The homes were sampled as part of a unique citizen-science project, Wildlife of Our Homes (www.yourwildlife.org/projects/wild-life-of-our-homes/). We have combined this broadscale survey with more detailed investigations of the seasonal variability in the microbial diversity found in the indoor air of 20 homes located near Boulder, Colo. Although we are still analyzing the samples from these projects, we have already found a number of interesting patterns. For example, we have shown that dogs can have a significant effect on indoor-air bacterial communities—with dog-occupied homes harboring more diverse communities and higher relative abundances of dog-associated bacterial taxa.



Scanning electron micrographs show images of surface-associated microbes on selected locations within a home. A) Door trim outside the house (with the inset shows a fungal spore); B) door trim inside the house (inset shows a bacterial cell); and C) bacteria living in a biofilm on the kitchen counter.

Furthermore, we found a significant correlation between the types of bacteria deposited on surfaces outside the home and those found inside the home. Our data suggest that environmental conditions outside the home (including land cover, proximity to livestock, and local environmental conditions) can have a direct effect on the types of microbes found within the home. Together this work is yielding the first comprehensive analysis of the microbial communities found in the air inside homes and the factors that shape the structure of these communities both within and between homes.

Timothy Fuller-Rowell

Lower-atmosphere forcing of space weather

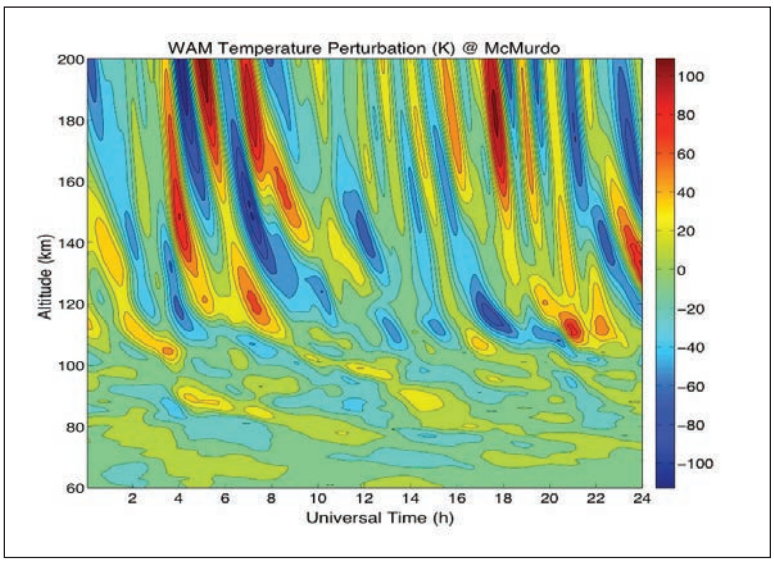
My main interest is space weather. The term "space weather" was coined several years ago and refers to the impacts of the space environment on technological systems. These include, for example, the disruption of radio signals traveling through Earth's ionosphere and the impact on satellite communication and navigation; and changes in mass density of the upper atmosphere that impact orbital drag, satellite positioning, and collision avoidance.

At NOAA's Space Weather Prediction Center, we need to understand the physical system to a level where we can make accurate predictions, which hopefully can mitigate these detrimental impacts. Until now, the conventional wisdom was that all space weather comes from the Sun. Certainly this is the case during big solar events, such as when a solar flare occurs or when plasma from the Sun, in the form of a coronal mass ejection (CME), strikes Earth and the ensuing geomagnetic storm dominates the impact on these technological systems.

However, these big solar events are rare, and we now know that regular terrestrial weather down in the troposphere also can have a big impact on space weather. The scientific community has long understood that the lower atmosphere is a source of variability for the ionosphere, but a coherent connection between a particular atmospheric event and space weather was elusive. A recent breakthrough in our group has revealed that a change in large-scale atmospheric dynamics, such as during a sudden stratospheric warming, imparts a coherent change in thermospheric dynamics, electrodynamics, and ionospheric structure in the upper atmosphere.

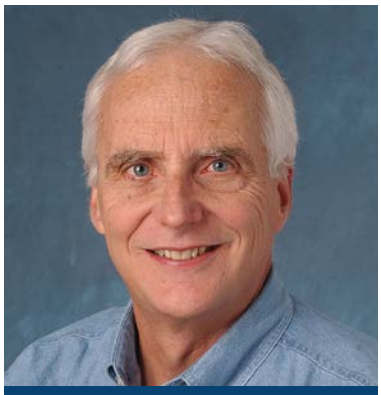
We now have a whole-atmosphere weather model extending from the ground to the top of the atmosphere that can model these planetary-scale events. The model is built upon the National Weather Service operational weather forecast model, so along with modeling the large-scale structure, it also produces much of the smaller-scale regional and local higher-frequency variability in the upper atmosphere from all the sources in the troposphere and stratosphere.

The figure at left shows an example of the sort of variability in upper-atmosphere temperature the model produces at a particular location, in this case McMurdo Station in Antarctica. In addition to the main diurnal and semidiurnal variations, there is a rich spectrum with strong amplitudes at one- to two-hour periodicities, which are also present in all the other basic atmosphere state parameters such as wind and density. These neutral atmosphere waves propagate upward from sources in the lower atmosphere and create similar structure and variability in the ionospheric plasma density, affecting communications and navigation. This source of space weather, induced by forcing from the lower atmosphere, is superimposed on that from solar and geomagnetic activity. We also hope to use the model to interpret some of the fascinating lidar observations made at McMurdo by CIRES Fellow Xinzhao Chu and her team.



First simulation of plasma bubble formation without the need for artificial seeding.

Photo credit: John Retterer/Boston College



Michael Hardesty

Laser probing of the boundary layer for climate and pollution studies

Gases generated by industrial activity can have a major impact on climate and human health. Greenhouse gases such as carbon dioxide and methane affect the radiative balance of Earth's atmosphere, while high concentrations of ozone can cause breathing problems and lung damage. Quantifying emissions of these gases and understanding the mechanisms that transport and distribute them is important for maintaining healthy populations and ecosystems in an industrial world.

Much of the "action" associated with pollution processes occurs in the atmospheric boundary layer, where most gases are emitted. Boundary-layer winds carry pollutants downwind from the source, while vertical mixing dilutes concentrations and facilitates transport into the free troposphere. Laser remote sensors, or "lidars," are unique tools for observing winds, turbulence, ozone, and particulates in the atmosphere. Lidars analyze the returns from laser-generated pulses to measure atmospheric properties to ranges of several kilometers. Our group deploys lidars both for long-term surface operation as well as on aircraft and ships to investigate important pollution problems.

During the two previous winters, we co-deployed wind and ozone lidars to Utah to investigate high wintertime ozone levels during cold, stable conditions in the oil and gas fields of the Uintah Basin. The lidars measured the temporal evolution of surface-based high-ozone-layer depth—an important characteristic because shallow layers concentrate both ozone and its precursors. We also observed shallow, terrain-driven flows that can potentially "slosh" ozone to different parts of the basin during the pollution episodes, affecting local concentrations.

Wintertime stable conditions with measurable snowpack are often characterized by high ozone concentrations in the Uintah Basin oil and gas fields in northeastern Utah. Photo credit: NOAA

Our lidars can be used to characterize mixing and transport in the boundary layer for mass-balance estimates of greenhouse gas emissions from large-area sources. As part of the studies of oil and gas fields in Utah, Colorado, and Texas, an aircraft measured concentrations of CO_2 and/or methane upwind and downwind of the source region concurrent with surface lidar observations of the mixing-layer depth and horizontal wind evolution. We then combined the measurements to compute fluxes and calculate emissions from the region. The mass-balance technique provides an alternative to "bottom-up" estimates of emissions, which combine contributions from individual sources to produce an estimate for the source region and often exhibit significant uncertainties.

José-Luis Jiménez

Sources, properties, and fate of organic aerosols

Aerosols are small particles suspended in air, with typical lifetimes of one to two weeks in the atmosphere before they are returned to Earth's surface. They have major effects on climate forcing, human health, regional visibility, crops, and ecosystems. About half of the mass of the longest-lived ("submicron") aerosols is composed of organic compounds—i.e., molecules composed of chains of carbon atoms with other elements such as hydrogen, oxygen, and nitrogen. Important sources of these organic aerosols (OA) include anthropogenic pollution, biogenic compounds; and biomass burning, and gas-to-particle conversion leading to secondary organic aerosols (SOA) is a key component of all sources. The amount, properties, and evolution of the OA from each of these sources are poorly characterized, and our group combines field, laboratory, and modeling research to better constrain them.

Using a new type of chemical analyzer capable of speciated analysis of organic acids in gases and aerosols simultaneously, we performed the first field measurements at a pine forest in the Manitou Experimental Forest near Woodland Park, Colo. This allowed us to characterize for the first time their bulk gas/particle partitioning, which is a critical control on the amount of properties of the aerosol and, thus, on its effects. Figure 1 shows that the partitioning of bulk organic acids can be predicted when their composition (carbon number and oxygen content) are known. Figure 2 shows that this partitioning responds quickly to changes in ambient temperature, and again these changes are well-predicted with a theoretical model. These findings run contrary with much current literature that concludes, based on laboratory experiments, that partitioning should favor the particle phase more strongly and respond far more slowly than we observe. Future research will investigate whether the measured partitioning depends on the sources (i.e., urban areas, deciduous forests, biomass-burning smoke etc.), environment (temperature, humidity), and age of the aerosols.

Reference:

Yatavelli, RLN, H Stark, SL Thompson, JR Kimmel, MJ Cubison, DA Day, P Campuzano-Jost, BB Palm, JA Thornton, JT Jayne, DR Worsnop, and JL Jimenez. 2013. Semi-continuous measurements of gas/particle partitioning of organic acids in a ponderosa pine forest using a MOVI-HRToF-CIMS. *Atmos. Chem. Phys. Discuss.* 13:17327-17374.

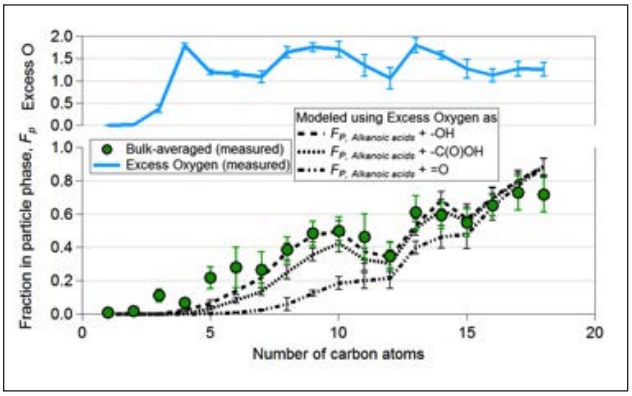


Figure 1. Campaign average of (bottom) particle-phase fraction (F*p*) for organic acids of a given carbon number and (top) excess oxygen (above the two oxygen needed for alkanoic acids). Also shown is modeled F*p* using excess oxygen and different composition assumptions.

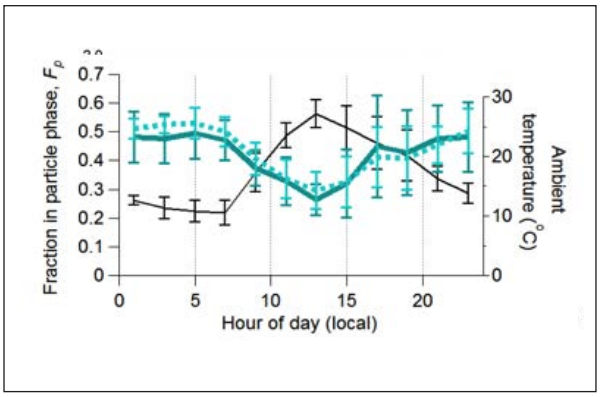


Figure 2. Diurnal cycle of measured and modeled particle-phase fraction (F*p*) for C10–C12 organic acids.

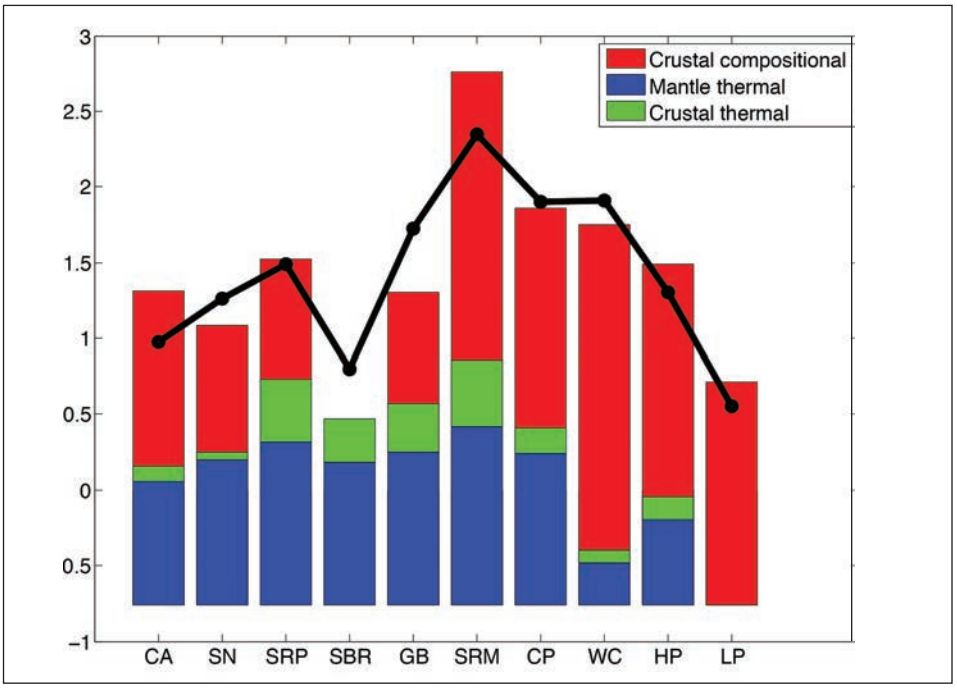
Craig Jones

Why is Denver the Mile High City?

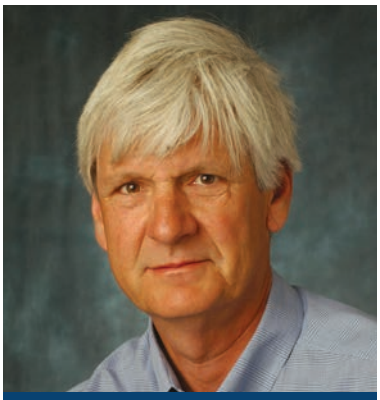
The overall elevation of the western United States makes it the second widest continental plateau on Earth. Why the whole region is elevated remains disputed: Maybe the crust thickened; maybe the denser upper mantle fell away; or maybe forces generated by flow in deeper parts of the mantle push it up much as water waves develop in rapids.

During the past few years, my research group has been working from a couple of angles to untangle these effects. The first angle is spearheaded by Ph.D. student Will Levandowski, who uses new seismological models developed by Weisen Shen of Mike Ritzwoller's group in the CU-Boulder Department of Physics. We can convert this model into density and calculate how high things should be from density variations in the top 150 kilometers of the earth. We find only a few places where this disagrees with observed topography more than our uncertainties; most of these places are probably because of melt in the crust. Most of the western United States is almost 1 kilometer higher than areas to the east because of a warm and buoyant mantle. Within the U.S. West, differences are mostly in the crust: For instance, the southern Rocky Mountains rise above the Colorado Plateau because of a thicker and warmer crust. The Colorado Plateau is higher than the geologically similar eastern Great Plains because of the buoyant mantle below and extra heat.

A second angle explores how some of the crust came to be buoyant. Many xenoliths from the lower crust have been hydrated since they were formed more than 1 billion years ago, and many of these had garnet convert into lower-density minerals. Our initial work has explored how prevalent this might be, and examination of published seismological work is consistent with widespread hydration potentially producing 1 kilometer of uplift between about 80 million and 50 million years ago. Recent dating of one hydrated xenolith by Lesley Butcher, a master's student with Geological Sciences collaborator Kevin Mahan, reveals that significant hydration did occur during this time interval. This would represent an altogether different mechanism for widespread uplift of continental regions than those usually discussed.



Comparison of the magnitude of the different contributions to modern topography across geographic provinces (California, CA; Sierra Nevada, SN; Snake River Plain, SRP; Southern Basin and Range, SBR; Great Basin, GB; Southern Rocky Mountains, SRM; Colorado Plateau, CP; Wyoming Craton, WC; High Plains, HP; and eastern Great Plains, LP). The differences in the lengths of each bar correspond to the differences in support from variations in the composition and thickness of the crust (red), temperatures in the crust (green), and in the mantle (blue). Actual mean elevations are illustrated by the solid line; differences between the actual and calculated elevations are near the uncertainty of the technique but could reflect systematic variations in the amount of quartz in the crust (e.g., the Great Basin and Sierra Nevada might be richer in quartz), in compositional variation in the mantle (e.g., the southern Rockies might still have garnet-rich mantle rocks present), or in melt in the crust or mantle (possibly the southern Rockies again).



William M. Lewis Jr.

Limnology 66 million years ago

Extinction of more than half of Earth's plant and animal species, including all dinosaurs not capable of flight, occurred 66 million years ago, following the Chicxulub asteroid impact. The impact created a fierce infrared blast from hot particles distributed throughout the atmosphere and, subsequently, an impact winter caused by particles shading Earth's surface.

Mechanisms of extinction following the asteroid impact have been widely and hotly debated. Led by CIRES Fellow Emeritus Doug Robertson, a team including atmospheric scientist Brian Toon, with CU-Boulder's Department of Atmospheric and Oceanic Sciences; paleontologist Peter Sheehan, with the Milwaukee Public Museum; and myself developed a set of ideas (forthcoming in two papers published by the *Journal of Geophysical Research*) that explain mechanisms of extinction. Robertson et al. propose that the firestorm immediately following impact and the subsequent impact winter were two separate mechanisms of extinction.

The initial heat burst likely had severe effects on terrestrial organisms but not on aquatic organisms because of water's capacity to intercept long-wave radiation. Clues supporting this contention include differentially low extinction of freshwater species and, among terrestrial species, selective survival of species that live primarily underground.

An unresolved puzzle is differential extinction rates between marine taxa, which showed severe extinction, and freshwater taxa, which showed moderate extinction. Robertson et al. argue that marine species are less resilient physiologically and less likely to show dormancy than freshwater organisms. Freshwater organisms occupy habitats that are much less stable than the marine environment and, thus, are favored evolutionarily by adaptations, including dormancy, that allow them to survive environmental instability.

In addition, freshwater organisms have access to a network of aquatic refugia provided by points of groundwater entry into drainage networks. These refugia would have been much warmer than surface waters at the lowest temperatures expected during impact winter. Furthermore, freshwater taxa that feed on nonliving (detrital) organic matter would have been favored by continuous supplies of new detrital organic matter entering freshwater ecosystems from terrestrial sources via surface or groundwater runoff, whereas marine organisms in the open ocean would not have been. These factors, taken together, explain why the impact winter was a much less potent source of extinction for freshwater organisms than for marine organisms (see figure).

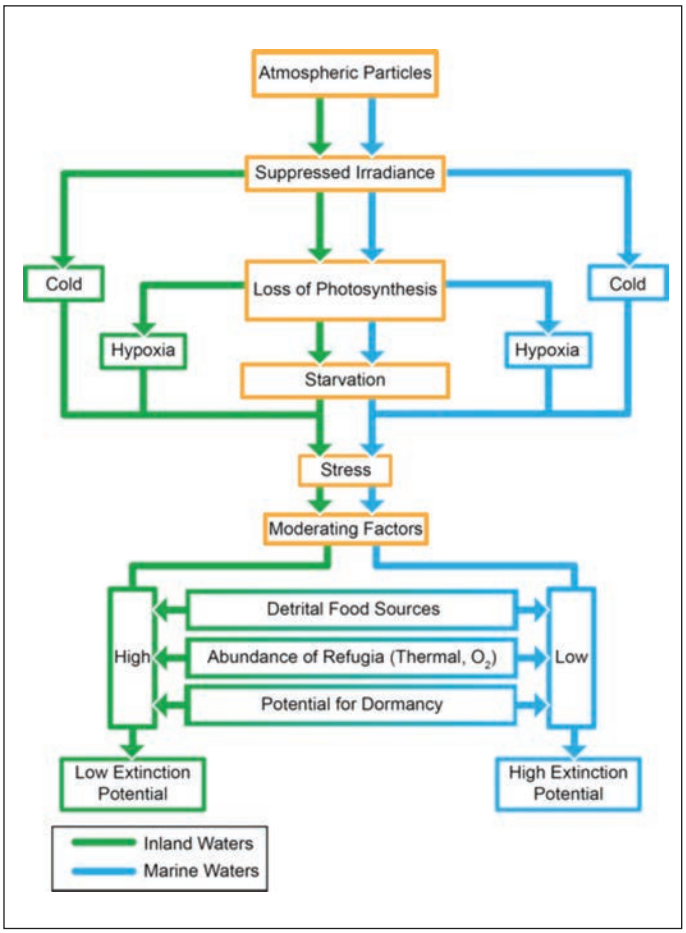
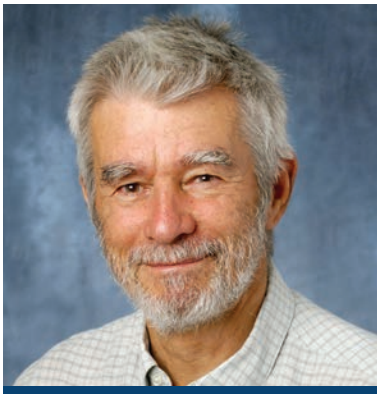


Diagram of contrasts between freshwater and marine environments for factors potentially causing extinction in aquatic environments after the Chicxulub impact.



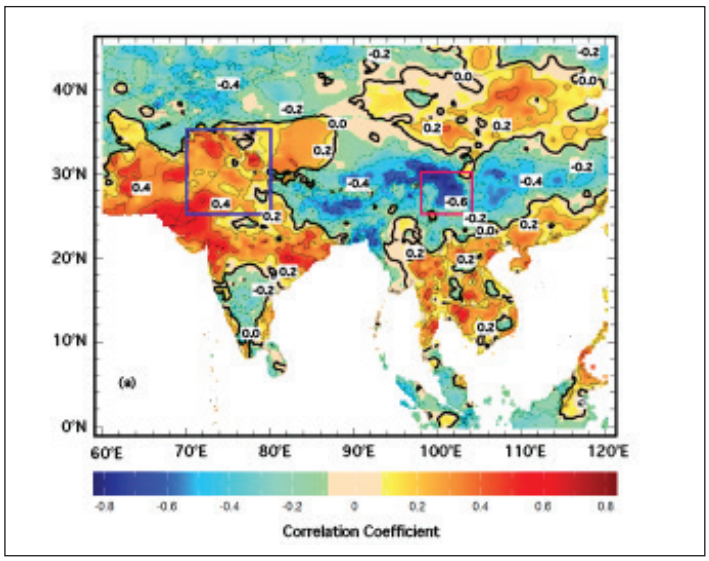
Peter Molnar

Late Miocene upward and outward growth of eastern Tibet and decreasing monsoon rainfall over the northwestern Indian subcontinent since approximately 10 mega-annum (Ma)

In collaboration with CIRES Fellow Balaji Rajagopalan, I devoted part of my research effort in FY2013 trying to understand how the growth of Tibet may have affected Asian climate and, in particular, the South Asian monsoon. Some recent work suggests that Tibet's role might have been small. Yet, there is a rough concurrence of climate change in Asia and apparent growth of the plateau since ±10 Ma. With these facts in mind, we sought an understanding of how they might be linked (Molnar and Rajagopalan 2012).

First, several observations suggest that eastern Tibet has grown upward and outward since approximately 10 Ma. Second, other evidence suggests that northwestern India and Pakistan were wetter, with forests rather than the current grasslands, before approximately 10 Ma. We argue that with the growth of eastern Tibet, orographic precipitation increased, that enhanced precipitation heated the atmosphere there, and then that heating induced subsidence farther west over northwest India and Pakistan. To test that idea, we calculated correlation coefficients of outgoing longwave radiation (OLR) over eastern Tibet with rainfall over Asia. They show that when rain is heavy over eastern Tibet, it is small over northwest India and, hence, support the logic that we propose (see figure).

Concerning the significance of this, we suggest that the rise of eastern Tibet at approximately 10 Ma facilitated a weakening of precipitation over northwest India, which led to a weaker, not stronger, monsoon there.



Map of correlation coefficients for July-August rainfall over eastern Asia and outgoing longwave radiation over eastern Tibet (region in red box).

Reference

Molnar, P, and B Rajagopalan. 2012. Late Miocene upward and outward growth of eastern Tibet and decreasing monsoon rainfall over the northwestern Indian subcontinent since ~10 Ma. *Geophys. Res. Lett.* 39:L09702.

R. Steven Nerem

Assessing the impacts of future sea-level rise at NASA centers and facilities

Global average sea level is expected to rise by 2 to 3 feet by 2100 due to the warming of the oceans (thermal expansion) and the melting of ice on land. We have been studying the impacts of future sea level rise at a few of NASA's facilities that are particularly vulnerable to sea-level rise. These assessments involve making geodetic measurements of the land topography and then establishing the present-day mean sea level relative to this topography via tide gauge and Global Positioning System (GPS) measurements. We then use these measurements with projections of future sea-level rise to assess future vulnerability to storm surge as a result of rising sea level.

In recent accomplishments, we collected our initial set of field measurements at NASA's Wallops Flight Facility launch range along the eastern shore of Virginia in May 2013. Graduate student Lynda Bell led the field campaign. We collected Terrestrial Laser Scanning (TLS) measurements with the assistance of UNAVCO and staff at Wallops. We are using the TLS measurements to compute a precise local topography model. We are using the GPS measurements to tie the TLS measurements to a precise reference frame, and also to position tide gauges for the purpose of establishing present-day mean sea level.

Future sea-level rise will affect many low-lying coastal regions during the coming decades. Projections of future sea-level rise coupled with precise geodetic measurements can be used to assess the local impacts and develop future plans. In some cases, stakeholders may decide not to invest in permanent infrastructure if that infrastructure has a high probability of experiencing flooding during the coming decades. Decisions such as this can only be made on the basis of well-informed science.

R. Steven Nerem standing next to the Terrestrial Laser Scanner set up along the beach at NASA's Wallops Flight Facility launch range in Virginia.

Photo courtesy of R. Steven Nerem

The NASA Wallops Flight Facility launch range along Virginia's eastern shore. In the distance is a launch pad recently used to launch an Antares rocket. In the foreground are storm-mitigation measures put in place after Hurricane Sandy. The Atlantic Ocean is on the right.

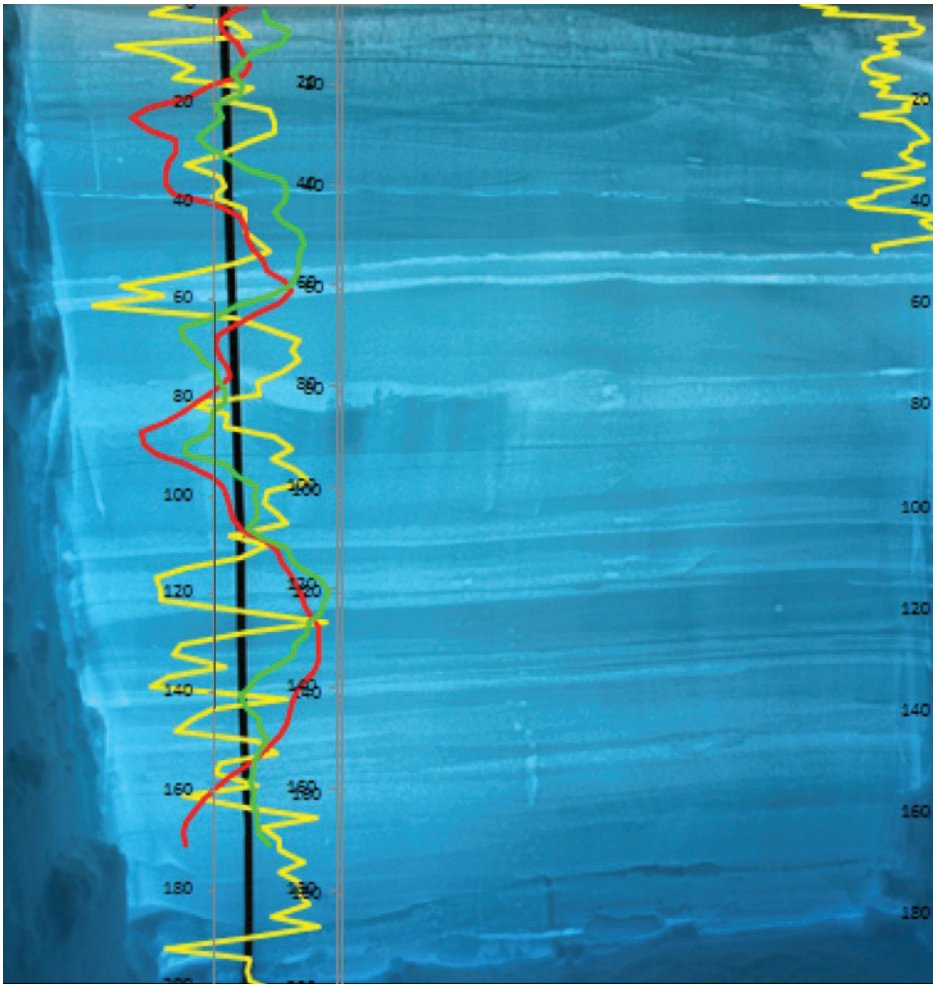
Photo courtesy of R. Steven Nerem

David Noone

Improving estimates of past climate by study of processes controlling isotope ratios in ice cores

The stable isotopic records from snow in Greenland stand as the gold standard for understanding climate variations in the Arctic during the last 100,000 years. While the basic tenets that underlie interpretation of isotopic information appear robust in a mean sense, many specific meteorological and glaciological processes can confound simple interpretations. Processes of interest include variations in moisture sources, cloud processes, surface ablation, blowing snow, and vapor diffusion in the firn. The limitations exist because direct measurements to evaluate the influences of processes have been lacking. With advanced instrumentation and an understanding of cloud and snowpack physics, we can now resolve fundamental uncertainties on the controls on the isotopic composition of the ice sheet.

In recent accomplishments, we used isotope ratios from layers of snow that build up the ice sheet to understand climate history. The signal, however, is far more complex than simply understanding the weather conditions at the time snow is formed. The figure shows that while the individual layers are easily observable though optical imaging of the snowpack and simple density measurements, the isotope ratios reflect a different history associated with molecular exchange both within the snowpack and exchange between surface snow and ambient vapor. Our results challenge existing interpretations of polar ice-core records because the vapor-exchange process is larger than previously considered. The findings strengthen previous interpretations because of the more complete accounting for relevant physics rather than focusing only on correlations with temperature.



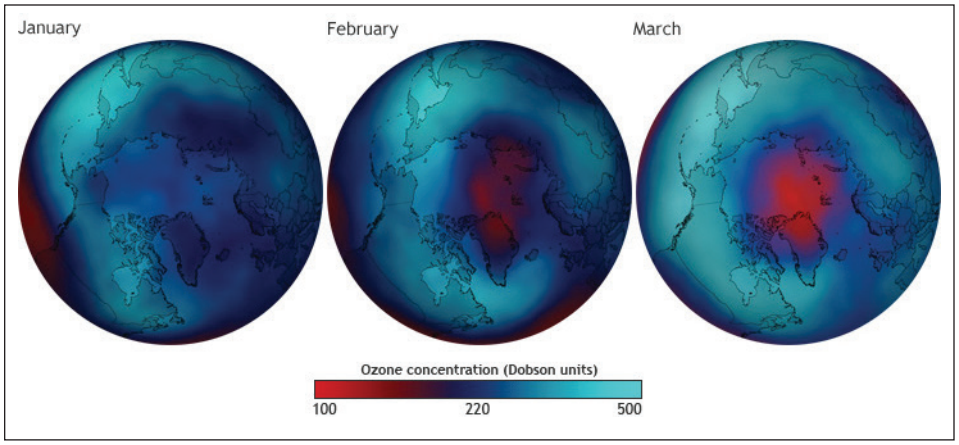
Layers of snow at Summit Camp, Greenland, through a depth of 2 meters, which spans approximately three years of accumulation. Visual layering is matched with snowpack density (yellow), which largely reflects individual storms and weather conditions. Isotope ratios ($^2H/H$, red) show a smoother pattern, which results from exchange of heavy nuclides as snow undergoes metamorphosis and becomes firn. The second order "deuterium excess" (green) reveals that the seasonal change in isotope ratios is associated with changes in atmospheric circulations potentially linked to the seasonality of sea ice. Photo credit: David Noone

Judith Perlwitz

Research on the causes of the record 2011 Arctic ozone loss

In spring 2011, we observed unusually low stratospheric ozone levels over the Arctic. For the first time, the chemical ozone destruction in the Arctic was comparable to that in the Antarctic ozone hole. The latter currently occurs every austral spring because high levels of ozone-depleting substances are still present in the stratosphere. As part of our research on the interactions between stratospheric ozone chemistry and climate, we studied the dynamical mechanics that can lead to very cold winter stratospheric polar temperatures in the Arctic. Low temperatures cause the formation of polar stratospheric clouds and, subsequently, the large ozone loss.

Based on reanalysis data, we identified for the first time a mechanism that leads to a dynamical cooling of the polar stratosphere. Normally, planetary waves propagate upward from the troposphere to the stratosphere and cause a residual circulation with rising of air over mid-latitudes and sinking of air over high latitudes and, thus, warming of the polar stratosphere. However, we showed that episodically, waves propagate downward from the stratosphere to the troposphere. Consequently, the stratospheric residual circulation is reversed. This leads to a transport of air from the Arctic to the mid-latitudes, producing a significant cooling tendency throughout the Arctic stratosphere.



In March 2011, a large area of the Arctic stratosphere had ozone concentrations far below the threshold of 220 dobson units (dark blue) that scientists have traditionally used for mapping the extent of the ozone hole in the Southern Hemisphere.

Image credit: Dan Pisut/NOAA Environmental Visualization Lab, based on NOAA TOAST data and courtesy of climatewatch.noaa.gov

This behavior is consistent with the circulation acting like a refrigerator that transports air from cold polar regions to relatively warm mid-latitude regions. We showed that this mechanism was enhanced during the 2011 winter and caused the extreme polar cooling. Previous studies have suggested that cold stratospheric winters are getting colder because of the increase in greenhouse gas concentrations and, thus, enhancing Arctic ozone loss. Our study implies, however, that the winter 2011 represents a unique dynamical regime, which is not part of a trend. Thus, it is very unlikely that we will observe such extreme stratospheric ozone loss like occurred in 2011 more often in the future.

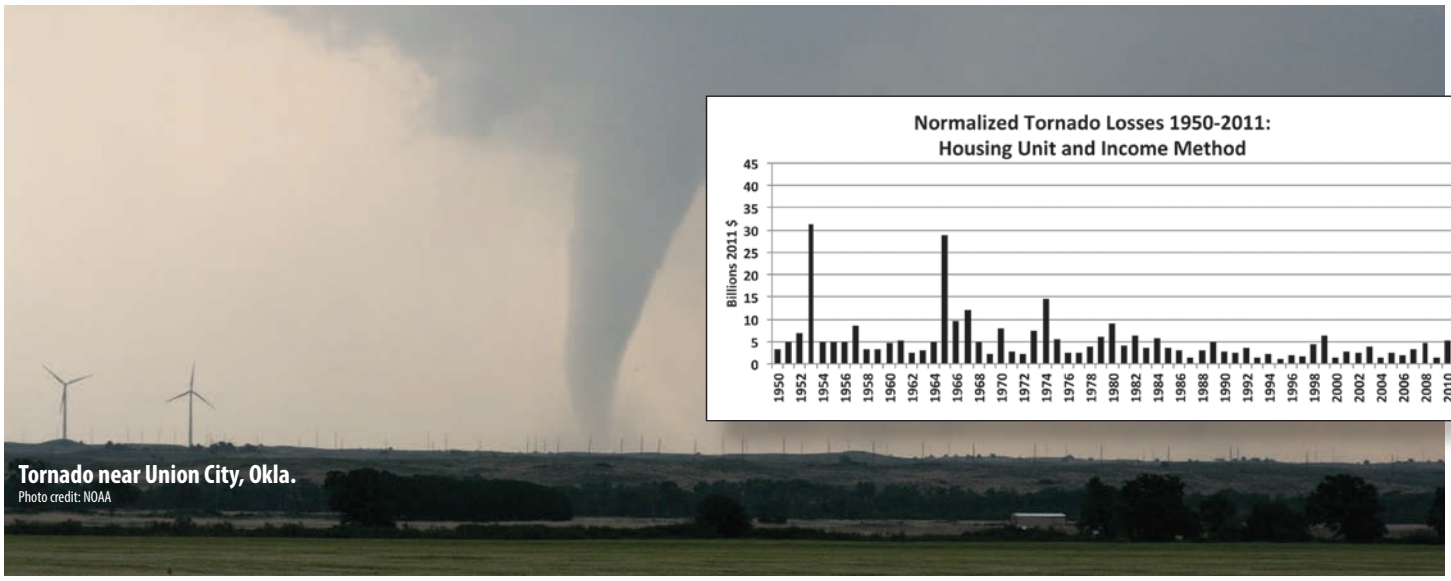
Roger Pielke Jr.

Normalized tornado losses in the United States: 1950–2011

In 2011, thunderstorms in the United States resulted in 550 deaths from tornadoes and more than $28 billion in property damage, with tornadoes causing the vast majority of economic losses, according to data from NOAA. We published a key paper in 2012 that by using several methods, normalized U.S. tornado damage from 1950 to 2011. A normalization provides an estimate of the damage that would occur if past events occurred under a common base year's societal conditions. This is the first paper to comprehensively "normalize" historical economic losses from U.S. tornadoes. Normalization methods have been widely applied to phenomena around the world, including U.S. hurricanes and Australian bushfires.

We normalize for changes in inflation and wealth at the national level and changes in population, income, and housing units at the county level. Under several methods, there has been a sharp decline in tornado damage. This decline corresponds with a decline in the reported frequency of the most intense (and thus most damaging) tornadoes since 1950. However, quantification of trends in tornado incidence is made difficult due to discontinuities in the reporting of events over time. The normalized damage results suggest that some part of this decline may reflect actual changes in tornado incidence, beyond changes in reporting practices. The paper further finds:

- Of the 56,457 tornadoes in our data set, 33,746 caused some recorded damage.
- Overall, we find a decrease in damages since 1950.
- Even so, 2011 was one of the three most costly years in our data set.
- Since 1950, tornadoes resulted in about half the normalized damage as from hurricanes and about twice that of earthquakes.
- The strongest two categories of tornadoes (called EF4 and EF5) represent about 1 percent of all reported events but have caused almost 45 percent of all normalized damage.
- The most damage per square mile from 1950 to 2011 occurred in Massachusetts and Connecticut.
- The most damage overall from 1950 to 2011 occurred in Texas and Alabama.
- During the calendar year, 80 percent of damage occurs January through June.
- The most damaging months are April (31 percent), May (20 percent), and June (16 percent).



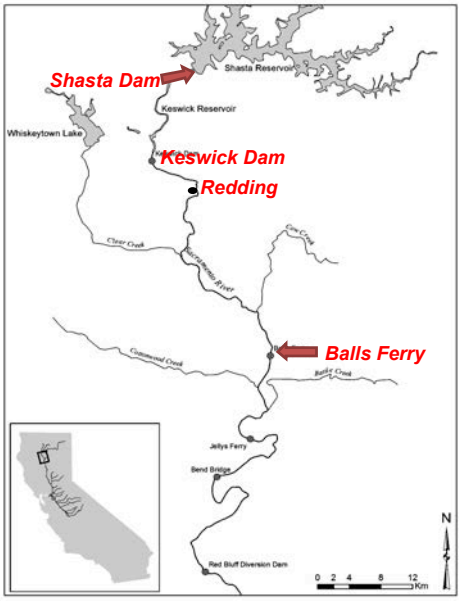
Tornado near Union City, Okla.
Photo credit: NOAA

Balaji Rajagopalan
with graduate student
Raymond Jason Caldwell

A decision support system for mitigating stream-temperature impacts on fish habitat in the Sacramento River

Increasing demands on the limited and variable water supply across the U.S. West can result in insufficient stream flow to sustain healthy fish habitat and populations. In the late summer and early fall, high air temperature and low flow conditions can cause rapid increases in water temperature, creating critical conditions, particularly for cold-water fish such as salmon. In addition, construction of dams and diversions along rivers for the purpose of storing and distributing the limited supply of water can further deteriorate natural flow regimes and often obstruct important migratory pathways for fish reproduction and development. The thermal impacts on the ecology of river ecosystems have been well-documented, yet there is no comprehensive modeling framework in place for skillfully modeling climate-related impacts. In regulated systems, such as the Sacramento River system, these impacts are an interaction of volume and temperature of water release from the reservoir and the subsequent exchange with the environment downstream.

In this research, we develop an integrated decision support system for modeling and mitigating water-temperature impacts and demonstrate it on the Sacramento River system. The approach has four broad components that can be coupled to produce decision tools toward efficient management of water resources for stream-temperature mitigation. These are: 1) a suite of statistical models for modeling stream-temperature attributes by using hydrology and climate variables of critical importance for fish habitat, such as average daily stream temperature and number of hours of temperature threshold exceedance, etc.; 2) a reservoir thermal model for modeling the thermal structure and, consequently, the water-release temperature; 3) a stochastic weather generator to simulate weather sequences that are consistent with long-range (e.g., seasonal) outlooks; and 4) a set of decision rules (i.e., rubric) for water releases from the reservoir in response to weather sequences and the reservoir thermal structure obtained from the above components. These components are coupled to develop tools that will help water managers plan for efficient mitigation of stream-temperature impacts on fish habitat.



Map of the study area on the Sacramento River.

The decision support system incorporates forecast uncertainties and reservoir operating options to help mitigate stream-temperature impacts for fish habitat, while efficiently using the water and cold-pool storage in the reservoir. We find that using the decision support system substantially reduces the number of violations of thermal criteria, while ensuring maintenance of the cold-pool storage throughout the summer.

References

Caldwell, RJ. 2013. An integrated framework for modeling and mitigating water temperature impacts in the Sacramento River. Ph.D. dissertation, University of Colorado Boulder.

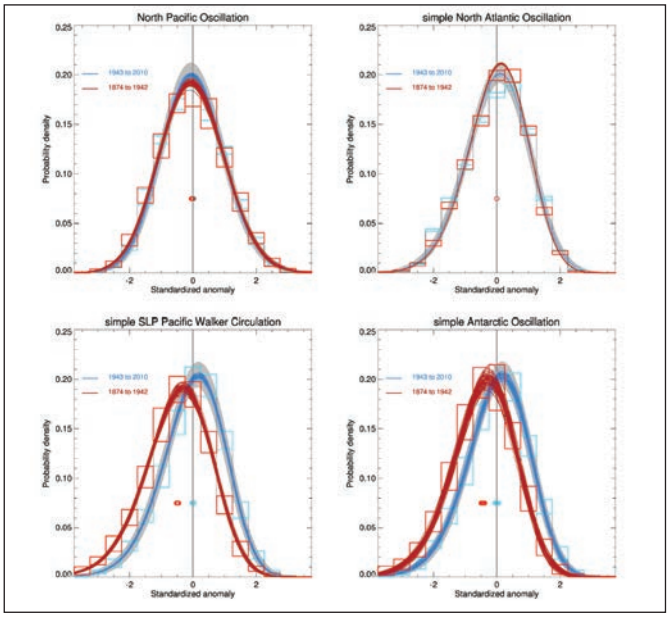
Prashant Sardeshmukh

Is global warming significantly affecting daily weather extremes?

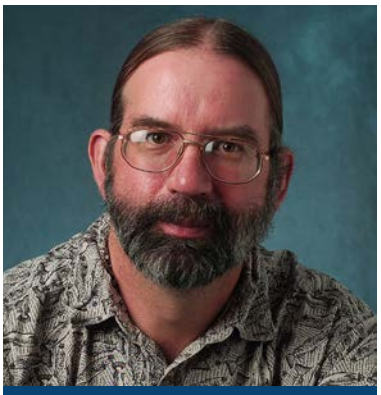
The answer to this trillion-dollar question depends not just on the mean shift of the probability density function (PDF) of daily weather anomalies, but also on changes in the width and shape of the PDF. The PDFs of daily weather are generally not Gaussian and are, therefore, not characterized by their mean and variance. One also has to account for their generally asymmetric and heavy-tailed character when assessing changes in tail probabilities. We are addressing this important issue using the longest global-atmospheric-circulation data set currently available, an ensemble of 56 equally likely estimates of the global atmospheric state within observational error bounds generated for every six hours from 1871 to the present in the Twentieth Century Reanalysis (20CR) project, a major international effort led by CIRES and NOAA (Compo et al., *QJRMS*, 2011).

Specifically, we are using the mean, variance, skewness, and kurtosis of the daily data to fit so-called SGS (stochastically generated skewed) PDFs (Sardeshmukh and Sura, *J. Clim.*, 2009) to the histograms of the daily values, and then using the fitted PDFs to draw inferences about tail probabilities. We have initially focused on the PDFs of daily indices of four prominent modes of sea-level pressure variability: the North Atlantic Oscillation (NAO), the North Pacific Oscillation (NPO), the tropical Pacific Walker Circulation (PWC), and the Annular Antarctic Oscillation (AAO). We have fitted SGS distributions to the histograms of these indices separately in the first and second halves of our 136-year record (1874 to 1942 and 1943 to 2010) and assessed the statistical significance of changes in the PDFs through extensive Monte Carlo integrations with a "weather generator" model whose parameters are consistent with those of the fitted distributions.

Applying this rigorous significance-testing procedure, we find no significant change in the mean of the NAO and NPO, and a small but significant positive shift in the mean of PWC and AAO from the first to the second half of the 136-year period. For the PDF as a whole, we find no significant changes in the PDFs of the NAO and NPO. The small positive mean shifts of the PWC and AAO PDFs are associated with increased probabilities of large positive values and reduced probabilities of large negative values, but these changes are much smaller and statistically insignificant for extreme positive values, beyond about 2.5 standard deviations. These are important results and also underscore the danger of drawing inferences about changes in extreme-value statistics merely from shifts of the mean.



Probability density functions (PDFs) of standardized anomalous daily sea-level-pressure-based indices of the North Pacific Oscillation (NPO), North Atlantic Oscillation (NAO), Pacific Walker Circulation (PWC), and Annular Antarctic Oscillation (AAO). The PDFs are estimated for two 68-year periods, 1874 to 1942 (red) and 1943 to 2010 (blue), both as raw histograms (rectangles) and as fitted stochastically generated skewed (SGS) PDFs (curves). Results are shown for each one of the 56 members of the observational Twentieth Century Reanalysis ensemble. There are, thus, 56 red and 56 blue curves in each plot. Upper and lower segments of the red and blue rectangles show the range of raw counts for each anomaly size bin. The gray swath indicates 95 percent confidence intervals on the PDFs associated with using limited 68-year records, estimated from Monte Carlo simulations. The spread among the red and blue curves is, thus, a measure of observational uncertainty, whereas the gray swath is a measure of sampling uncertainty. The figure shows no statistically significant change in the PDFs of the NPO and NAO from the first to the second 68-year period, and a mean positive shift for the PWC and the AAO. Note, however, that there is no significant change in the extreme positive values of the PWC and AAO.

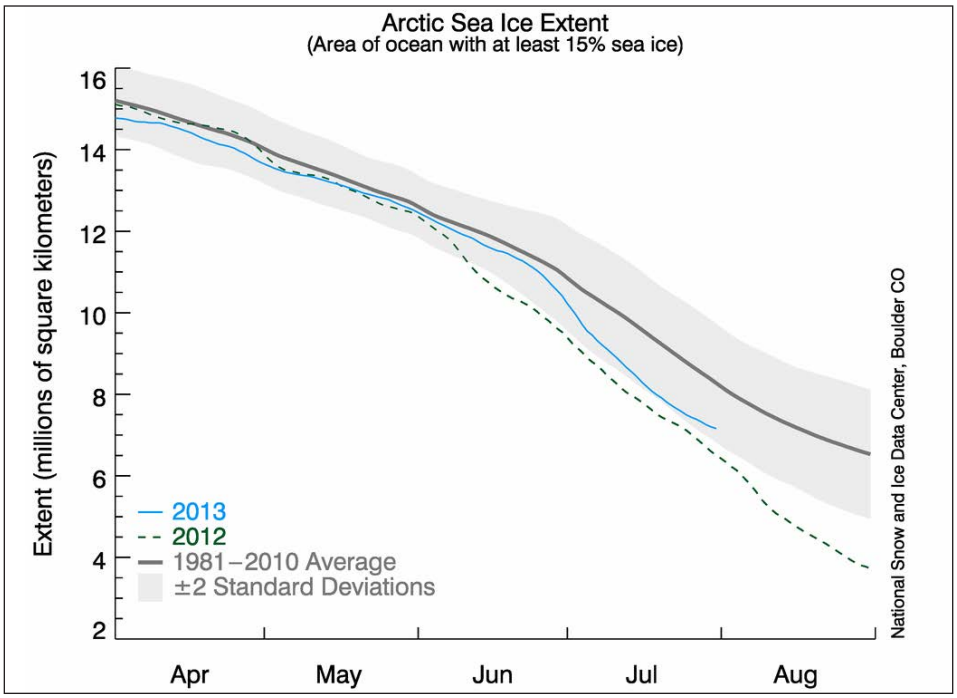


Mark Serreze

Environmental impacts of a rapidly changing Arctic

Arctic sea-ice extent at the end of the summer melt season has declined sharply during the past 30 years. Summers with an essentially ice-free Arctic Ocean are likely to be realized well within this century, perhaps as early as 2030. Ice extent for September 2012 was the lowest observed in the satellite record (1979 to present), and the six lowest September extents during the period of satellite coverage have all occurred in the past six years. While part of my research has continued to focus on trying to better understand the factors responsible for this rapid trend, during the past several years my attention has increasingly shifted toward addressing the environmental and societal consequences of current and future sea-ice loss.

Ice loss is already contributing to increased wave action and coastal erosion, since, with less sea ice in summer, winds now have a longer fetch over open water. While the decline in ice extent fundamentally represents a response to a warming Arctic, research with CIRES colleagues also has shown that the loss of ice is itself contributing to strong rises in Arctic air temperature during autumn and winter—not just at the surface, but extending through a considerable depth of the atmosphere. This is because with less ice in spring and summer, which exposes dark, open-water areas, the Arctic Ocean now absorbs much more of the Sun's energy than was the case a few decades ago. This extra heat is then released back upwards to the atmosphere in autumn and winter.



Graph showing levels of Arctic sea-ice cover in late spring and summer months.

This strong warming, known as Arctic amplification, is starting to extend beyond areas of ice loss to influence Arctic land areas. Continued loss of the ice cover is likely to influence patterns of atmospheric circulation and precipitation not just within the Arctic, but also in middle latitudes. While this idea finds support in many numerical modeling studies, including those conducted with colleagues at CIRES, there is tantalizing observational evidence that such effects have already occurred.

Finally, as the ice cover retreats, the Arctic is becoming more accessible for marine shipping and oil and gas exploration, increasing the economic and strategic importance of the region.

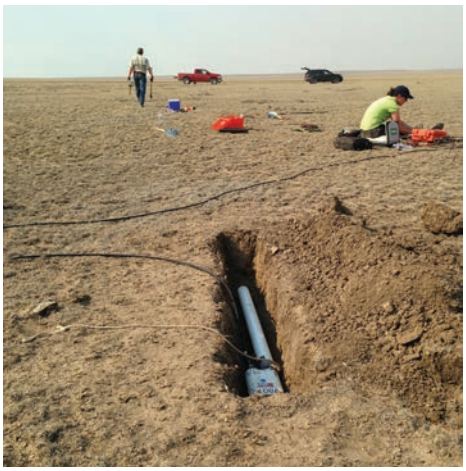
Anne Sheehan

Magnetotellurics: Using lightning and the solar wind to determine subsurface electrical properties beneath Colorado and New Mexico

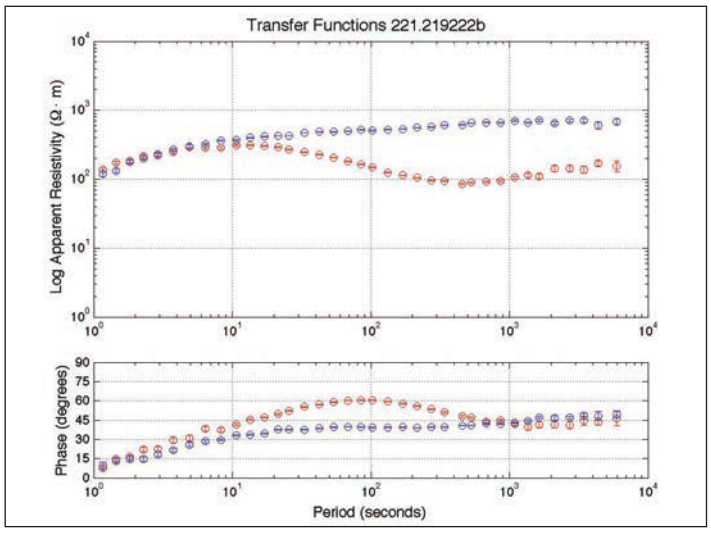
In collaboration with Paul Bedrosian at the U.S. Geological Survey in Denver and CIRES graduate student Daniel Feucht, a magnetotellurics experiment is underway to determine deep electrical properties of the crust and upper mantle beneath Colorado and New Mexico. Magnetotellurics is an electromagnetic-sensing method that makes use of electrical currents in the earth that are induced by Earth's varying magnetic field. The method uses that information to determine Earth's subsurface electrical properties. The natural fluctuations in Earth's magnetic field are typically caused by the solar wind and lightning strikes. Electrical conductivity is a unique physical property influenced by factors hard to evaluate other ways, such as very small amounts of fluids (including melts). Magnetotellurics provides information complementary to seismic tomography for deep Earth imaging; has applications to geothermal exploration; and is very sensitive to the presence of subsurface fluids, including melt and aqueous fluids.

Our 2012–2014 magnetotelluric experiment across the Rio Grande Rift in Colorado and New Mexico will provide constraints on the thermal and rheological state of the lithosphere beneath this region of intracontinental extension. The Rio Grande Rift formed between 35 million and 29 million years ago when the crust began to spread apart, triggering volcanism in the region. The Rio Grande Rift extends hundreds of miles from Colorado's central Rocky Mountains south into Mexico. In collaboration with CIRES Fellow Steve Nerem and using a CIRES Innovative Research Program award to start the project, we have been monitoring since 2006 the active tectonics of the Rio Grande Rift by using Global Positioning System (GPS) geodesy. The GPS results indicate that the rift is still active but that the strain rates are very low.

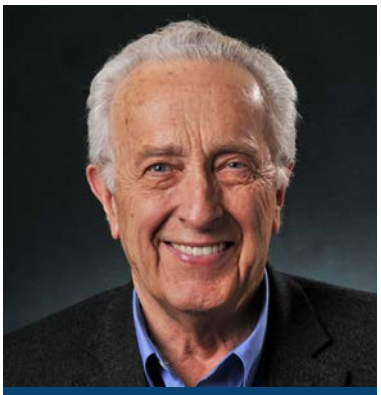
The magnetotellurics experiment provides imaging that will help us understand the rifting process. Important questions about continental rifting remain unresolved, including the role of magmatism, volatiles, and inherited lithospheric structure in the initiation and development of rifting. Recent seismic-imaging studies show thinned crust and low seismic wave speeds in the upper mantle beneath the Rio Grande Rift. New geodetic work confirms the low strain-rate environment of the region and shows surprisingly broad and uniform deformation over an area far wider than the rift's physiographic expression. Electrical conductivity models from the magnetotelluric experiment will provide information complementary to seismic studies, and will be combined with seismic models to assess the relative contribution of thermal and compositional heterogeneity to the rifting process. A comparison of results from northern and central rift segments will be used to assess extent and hypothesized northward propagation of the rift into Colorado.



Magnetotelluric deployment in New Mexico, June 2013. Photo credit: Anne Sheehan



Apparent resistivity and phase curves for a magnetotelluric site in northeastern New Mexico. Apparent resistivity and phase versus period can be used to determine subsurface electrical properties. Longer-period data sample deeper into Earth than short-period data.

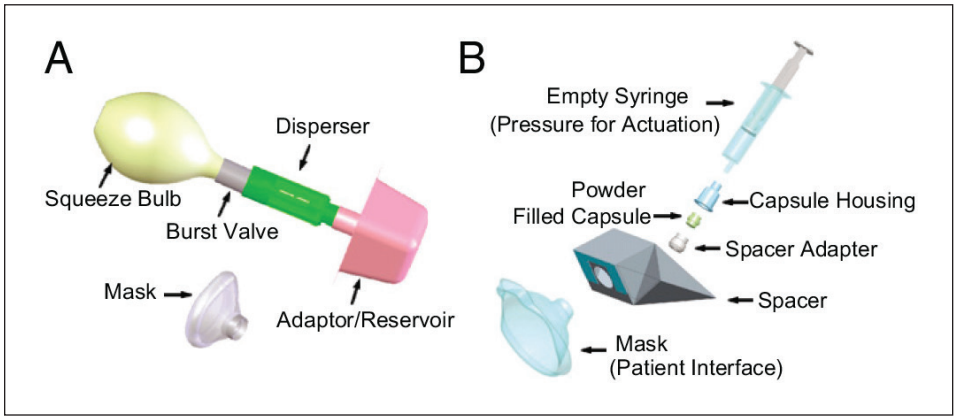


Robert Sievers

Improving global health with CIRES-developed aerosol vaccines

In 2012, the CIRES Global Health Group filed for patents to document aerosol innovations that may lead to major advances worldwide in the control of infectious diseases. The invention is to stabilize and dry measles or other live attenuated virus vaccines as microparticles via a process called Carbon dioxide Assisted Nebulization with a Bubble-Dryer (CAN-BD). These microparticles are sealed in high-barrier blister packs or capsules and then opened just before use; active dry-powder inhalers disperse the resulting aerosols into the respiratory tracts of humans.

The person inhales the fine microparticles through a facemask or tube, and the microparticles deposit on the moist surfaces throughout the respiratory tract; there, the microparticles rapidly dissolve to induce protective immune responses to measles or other diseases. This vaccine delivery system requires no electricity and no water for reconstitution beyond that already in the respiratory tract of each vaccinee. We have demonstrated the system in preclinical trials for measles vaccine, and it is potentially applicable to a wide variety of other vaccines such as, but not limited to, rubella, human papilloma virus, and influenzas. Now underway are Phase I clinical trials of the needle-free dry-powder aerosol measles vaccine developed and stabilized by CIRES and Aktiv-Dry LLC. As of July 1, 2013, there have been no serious adverse events reported for 60 adult male volunteers who inhaled the new aerosol measles vaccine beginning in March 2012.



A) PuffHaler active dry-powder inhaler; B) Solevent. A mask or a nasal adapter can also be attached when necessary.

I recruited and led an international team upon being awarded $20 million dollars in one of the 42 grants given by the Foundation for the National Institutes of Health through the Grand Challenges in Global Health Program. This program was created by the Bill and Melinda Gates Foundation to develop an inexpensive and effective needle-free aerosol vaccine delivery system that would serve as a transformative platform technology for vaccine delivery. Each member of the team brought special expertise including immunology, virology, toxicology, formulation, supercritical-fluid technology, aerosol and microparticle science, and medicine. We created inventions and filed patents dealing with active dry-powder inhalers, stabilization and formulation, a new excipient (myo-inositol), and drying and micronization. A video of these highlights is available on the Gates Foundation website.

Margaret Tolbert

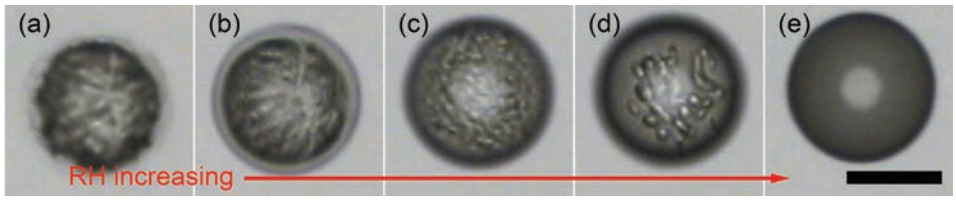
Heterogeneous atmospheric chemistry: Earth and beyond

Research in the Tolbert Group is focused on heterogeneous atmospheric chemistry—specifically determining the chemical, physical, and optical properties of atmospheric particulate. In addition to fundamental studies of particles, we are also exploring how atmospheric particulate affects current problems such as stratospheric ozone depletion, global climate change, urban smog, and visibility degradation.

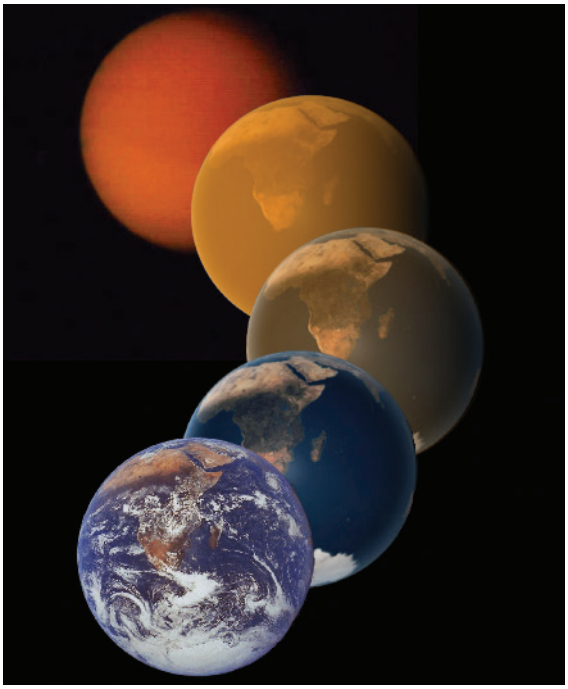
As well as studies of atmospheric aerosols on current-day Earth, we are also probing the particles that might have been present at the earliest times in Earth's history. We are interested in how those particles might have impacted the climate of early Earth and the development of life on Earth. As a parallel to early Earth, we are also studying aerosols and clouds on other planetary bodies such as Mars and Titan. For studies relevant to Mars, we are probing salt deliquescence and efflorescence to help predict the formation of aqueous solutions on Mars today. For Titan, we are studying the formation of organic haze particles to gain insight into the particles that completely shroud this Saturnian moon.

Our work is primarily laboratory-based, using state-of-the-art instrumentation to explore particle composition, morphology, phase changes, optical properties, and ice-nucleating ability. One focus of the work is understanding complex structures in secondary organic aerosol particles and how those structures change as the relative humidity in the atmosphere changes.

In addition to laboratory work, the Tolbert Group is also involved in collaborations with theory teams and those performing fieldwork around the world. A recent collaboration focused on studying particles in Ulaanbaatar, Mongolia, one of the most polluted cities in the world in terms of particulate matter. Primary support for our work comes from the National Science Foundation and NASA.



Simulated secondary organic aerosol particle containing ammonium sulfate undergoes phase changes during deliquescence as the relative humidity (RH) is increased.



Collage showing Earth, Titan, and possible early Earth with varying amounts of haze.

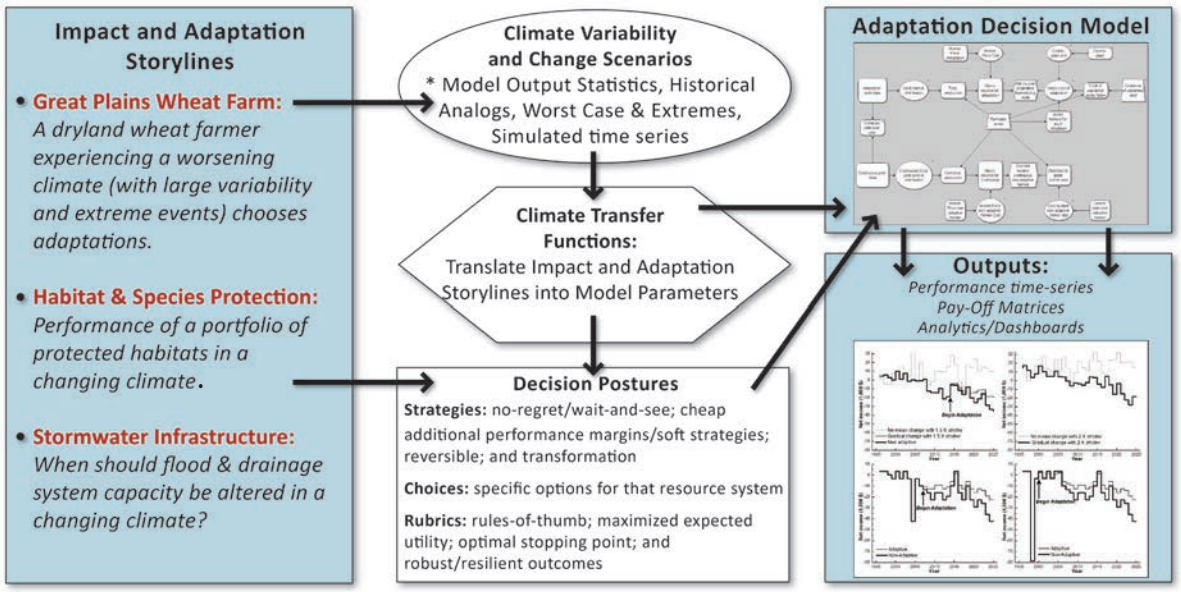
William Travis

Understanding adaptation decision making under climate uncertainty

Colleagues and I study how people make decisions in adapting to climate variability and change. With support from NOAA, the Western Water Assessment, and CIRES, we have combined several software tools into an "adaptation test-bed" that allows us to test hypotheses about adaptation in systems like agriculture and species conservation (see figure). Our main focus is on the role of extreme events. We found cases in our first round of simulations last year where extremes trip premature and inefficient adaptation by farmers experiencing worsening climate. Our goals this year have been to extend the analysis to other sectors, such as infrastructure maintenance, wastewater management, and habitat conservation, and to explore adaptation decision alternatives that avoid this over-adaptation trap.

Though the test-bed is built around quantitative decision models, qualitative, empirical studies of the choices and policy contexts faced by actual decision makers are an important part of the work. Former CIRES master's student Kristin Gangwer interviewed ranch families in the Rockies to build a rich roster of the options and constraints they face in adapting to drought. Now CIRES graduate student Katie Clifford is surveying land managers in the Gunnison Basin about how climate affects their decisions. Mary Huisenga, a recent geography master's graduate, has remained with the team part time to develop a decision model for wastewater dischargers attempting to stay within stream-temperature guidelines.

Pressure to adapt is greatest in response to extreme events and in post-disaster situations. But extremes are difficult for climate models to simulate, so our approach was simply to force an arbitrary extreme (often based on a historical event) into the decision simulation. A better method will treat extremes as members of climate distributions, so their occurrence changes as climate varies. Field interviews indicate the need also to include transient events that aren't necessarily extreme but still dramatically affect decision makers, such as rapid spring snowmelt in the mountains or cold spells in otherwise mild winters that can kill off a crop meant to survive winter dormancy. We want to know more about how transients and extremes act as pacemakers of adaptation.



The adaptation test-bed is a virtual structure that allows simulation of climate impacts and adaptations in resource-management systems such as a farm or wastewater treatment plant.

Greg Tucker

Storms, sediment, and saltcedar

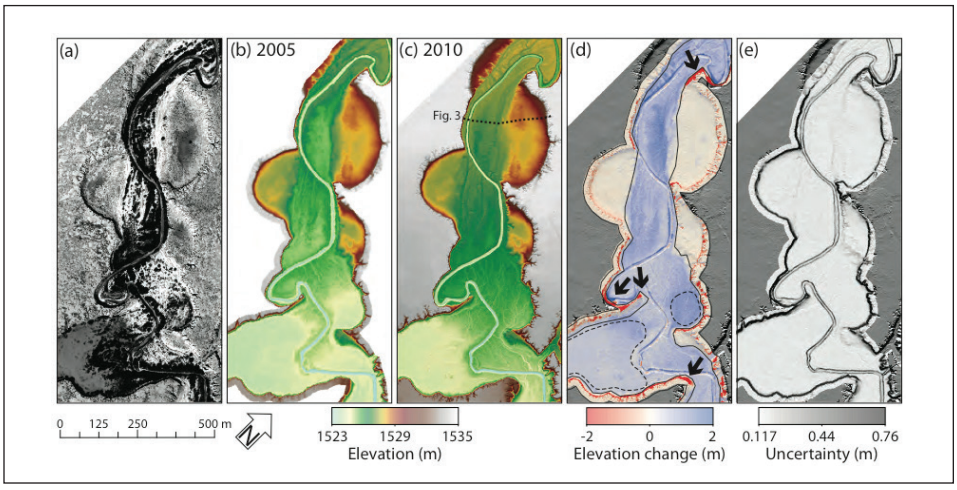
Large floods can strongly impact river valleys. A powerful flood can alter channel geometry and conveyance capacity; erode or bury riparian vegetation; enhance or degrade the fertility of floodplain soils; and in extreme cases even change the entire channel pattern. A fundamental goal in fluvial geomorphology is to understand these impacts at a quantitative and ultimately predictive level.

Currently, our ability to forecast potential flood impacts is limited by a lack of good test cases and a lack of fully coupled morphodynamic models. We are addressing this knowledge and technology gap by analyzing and modeling a remarkable case study from the Rio Puerco, a high-desert river in northern New Mexico.

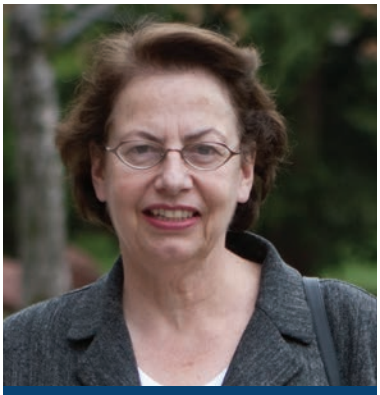
In 1926, the exotic shrub saltcedar (*Tamarix*) was introduced to the Rio Puerco watershed to limit erosion and prevent the infilling of Elephant Butte Reservoir, which is located downstream on the Rio Grande. Since then, recognition of the adverse impacts of saltcedar in river valleys throughout the western United States has inspired widespread efforts to control it. In September 2003, herbicide spraying along a 12-kilometer section of the Rio Puerco killed all woody vegetation. A major flood three years later caused extensive erosion and channel widening along the defoliated reach; the eroded material was deposited downstream where living vegetation prevented erosion. Because the vegetation was the only factor that varied significantly, the 2006 Rio Puerco flood makes an excellent natural experiment for studying feedbacks among vegetation, erosion, and river morphology.

We obtained airborne lidar topography data from before and after the 2006 flood. These data reveal, in unprecedented detail, the patterns of erosion and sedimentation along the river valley. Among other things, the data show that most of the sediment that eroded from the defoliated reach ended up being deposited along a stretch of floodplain several kilometers downstream. This finding suggests that the erosional impact of limited saltcedar control may be confined to within several kilometers of the control area. On the other hand, the impact of more widespread saltcedar death remains to be discovered. The recent introduction of the tamarisk leaf beetle as a biocontrol agent adds urgency to this question.

Riverbank erosion has re-exposed these buried saltcedar trunks in the floodplain of the Rio Puerco, New Mexico. Photo credit: Greg Tucker



A typical segment of the Rio Puerco arroyo: a) Quickbird II satellite; b) shaded relief map of 2005 lidar data set; c) shaded relief map of 2010 lidar; d) ground-elevation differences between 2005 and 2010, with cool colors showing positive topographic change (aggradation), warm colors showing negative change (erosion), and arrows indicating sections of the arroyo wall that collapsed as large blocks; and e) map of differencing uncertainty. Image credit: Mariela Perignon/CIRES; reproduced from Perignon et al. 2013.

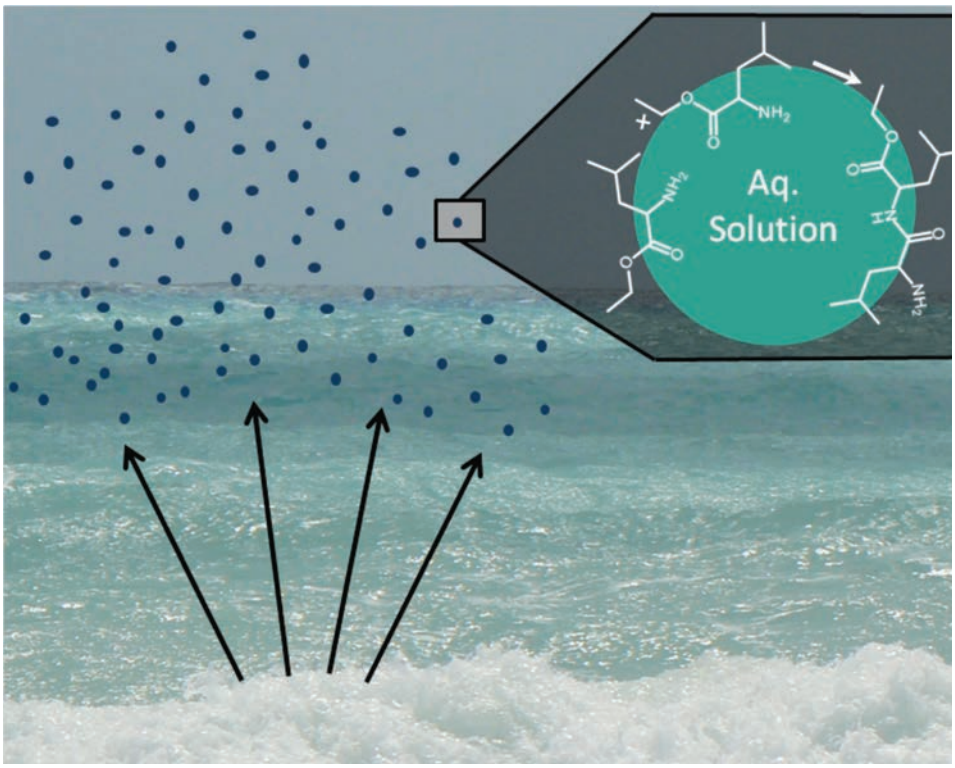


Veronica Vaida

Multiphase atmospheric photochemistry

Our program explores water- and sunlight-mediated processes in planetary atmospheres including the contemporary and prebiotic Earth. My approach aims to provide new inputs for models of atmospheric chemistry and climate, using fundamental chemical physics to address complex multiphase chemistry. Using solar simulators in experimental studies in our lab, our group has been showing fundamental differences in the photochemistry of organic species involved in isoprene oxidation as a function of water in the environment. Water in all its phases is implicated in catalysis and/or suppression of atmospheric reactions. Especially interesting and novel is the establishment of the catalytic role of water surfaces—as available at the surface of oceans, lakes, and atmospheric aerosols—in promoting reactions not favorable in aqueous phase (see figure for illustration of chemistry occurring at water surfaces in the absence of enzyme catalysis). We have scaled fundamental processes investigated in our lab to realistic atmospheric conditions by using environmental chamber studies. Specifically we are using the CESAM (French acronym for Experimental Multiphasic Atmospheric Simulation Chamber) at the Université Paris–Est Créteil Val de Marne (UPEC) in collaboration with Professor Jean-Francois Doussin with UPEC. These combined laboratory and chamber studies resulted in multiphase aqueous photochemical mechanisms connecting volatile organic compounds to aerosol nucleation and growth.

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



Condensation reactions producing biopolymers can occur at the surface of environmental water such as the surface of oceans, lakes, and atmospheric aerosols. This chemistry does not occur in bulk aqueous solution unless biological catalysts (enzymes) are present.

To bring this research to a broader community, I have included environmental chemistry topics in teaching chemistry at all levels. Simultaneously, I developed lectures that have been delivered to public and academic audiences nationwide during my tenure as Sigma Xi Distinguished Lecturer. Recent international research collaborations and student exchanges include Canada (University of Toronto), Brazil, France, and the Czech Republic.

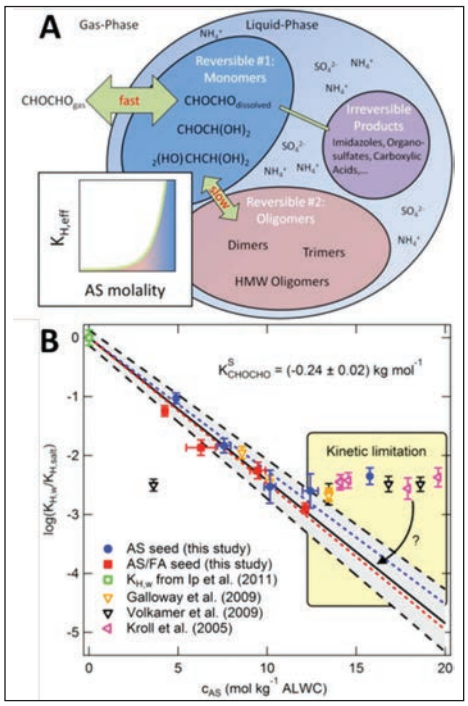
Rainer Volkamer

Atmospheric waters: multiphase chemistry in clouds and aerosols

Water is a major metastable component of the lower atmosphere (see photo) and present at most atmospheric interfaces, including aerosols. We are interested in understanding the multiphase chemistry of glyoxal, an unexplained component in arctic, marine, forest, and urban aerosols, and its indicator properties to understand phase partitioning and chemical processes in aerosol water. Multiphase chemistry in aqueous aerosols is largely missing in atmospheric models for lack of data, missing information about precursors and reaction pathways, and difficulties with assessing contributions from multiphase chemistry to ambient secondary organic aerosol mass.

The effective Henry's law coefficient, K_H, describes the partitioning of a molecule between the condensed water phase and the gas phase in the limit of infinite dilution. K_H also determines the reaction rates of multiphase chemical reactions in the bulk of aerosols ('A' in figure) and clouds. We have determined $K_{H,salt}$ for the first time by time-resolved measurements of gas-phase and particle-phase glyoxal concentrations in sulfate-containing aerosols. From the exponential increase in $K_{H,Salt}$ over that in pure water, we determine the Setschenow salting constant of glyoxal, K^S_{CHOCHO}. This is the first determination of K^S in a dynamically coupled gas-aerosol system ('B' in figure). We find that aqueous ammonium sulfate (AS) and internally mixed ammonium sulfate/fulvic acid (AS/FA) aerosols both show an exponential increase of $K_{H,Salt}$ with AS concentration (Kampf et al. 2013). Activity coefficients of approximately 1/500 are caused by electrical forces in aerosol water due to a "salting-in" mechanism (Kampf et al. 2013) and help explain field measurements in Mexico City (Waxman et al. 2013). Salting constants provide a framework that is novel in atmospheric models, yet may prove critical with predicting multiphase chemistry of other polar molecules in the atmosphere.

Clouds and aerosol water are chemical reactors for multiphase chemistry.



The Henry's law partitioning coefficient is an exponential function of salt concentration. As the ammonium sulfate (AS) concentration exceeds the AS solubility (12 mol kg^{-1}), a phase transition is observed (adopted from Kampf et al. 2013).

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Carol Wessman

Forest disturbance interactions, management, and implications for future carbon sequestration

We continue to focus on ecosystem resilience and response to disturbance, particularly when multiple disturbances occur and interact. Our projects are situated in the southern Rocky Mountains and concern disturbance types that are widespread, increasing in frequency, and have the potential to significantly impact ecosystem services important to Western populations.

One research focus is concerned with the strong role of disturbance in the carbon balance of forest ecosystems. Our ongoing National Science Foundation project focuses on northern Colorado subalpine forests experiencing several catastrophic events—such as wind, logging, insects, and fire—that have occurred during the last two decades. We are surveying all major pools, such as live or dead trees, coarse woody debris, regeneration, and soils, and contrasting them with neighboring undisturbed forests as a reference.

Results from 2011 fieldwork in areas of high-severity fire show that the multiple disturbances had an additive effect on carbon loss, with increasing numbers of disturbances resulting in progressively decreasing carbon/black carbon stocks. We interpret this as resulting from substrate availability and fire intensity, and there was no significant difference between unburned and burned plots in terms of total black carbon. Given literature-derived charcoal decay rates, it appears that high-intensity fires may actually reduce net black carbon in these forests during the entire fire return interval, with additional disturbances compounding the loss.

Left to right: Brooke Regan (behind the tree), Becky Poore, and Kelsey Bickham surveying conifer regeneration 15 years following the 1997 blowdown in Routt National Forest, Colo.

Photo credit: Carol Wessman

Fieldwork in 2012 surveyed unburned landscapes disturbed by blowdown, insects, and logging. We are analyzing those data for impacts on carbon stocks. Simulations using a forest-growth model will indicate how these landscapes and their carbon stocks will develop during the coming decades, especially under the influence of a changing climate. Our preliminary results across the burned multiple disturbances suggest that high-intensity disturbances remove a large amount of carbon, and multiple disturbances compound this effect.

This project has involved many students. In spring 2013, Brian Buma, a principal investigator in this project, received his Ph.D. Also graduating in the spring were Brooke Regan (Ecology and Evolutionary Biology), Danielle Cluckey (Environmental Studies), and Kelsey Bickham (Environmental Studies), all of whom received highest honors for their theses based on components of this project.

Former CIRES Director Konrad Steffen leans over a moulin on the Greenland Ice Sheet. Melted surface water travels through the moulins down to the bedrock below the ice sheet.
Photo credit: Jim Kastengren/CIRES

Center for Limnology

During 2012, the CIRES Center for Limnology continued its research and graduate programs based on studies of the biogeochemistry and food-web dynamics of freshwater ecosystems, including streams, lakes, and wetlands. One new development during 2012 was the arrival of Lindsay Chipman, Ph.D., from Florida State University. Chipman, a Visiting Fellow, brought some new technology of interest to the Center for Limnology.

Chipman's instrument is called an Acoustic Doppler Velocimeter (ADV). Chipman is interested in estimating the net flux of dissolved oxygen vertically in a water column over short time intervals. Application of the ADV to the study of gas transmission in water is based on the eddy correlation method and was recently developed for marine environments. Chipman, who participated in these pioneering development efforts, was recruited to the Center for Limnology with the idea that the ADV also could be deployed in streams as a way of solving a problem that heretofore has not been resolved.

Aquatic ecosystems have a metabolism that can be measured in terms of simultaneous oxygen uptake and output. The standard method for estimating stream (or river) metabolism is to measure oxygen concentrations at the upper and lower end of a stream reach, which might be several kilometers in length. By use of a gas tracer, the gas exchange rate at the surface is estimated. The difference in oxygen concentrations between two stations, with travel time taken into account and correcting for gas exchange at the surface, gives the average metabolic rate per square meter for a stream reach. This method fails to reveal the great heterogeneity of metabolism within a stream reach, which could be demonstrated with the ADV method.

A second new research topic at the Center for Limnology was stimulated by the state of Colorado's adoption of a rapid bioassessment method for judging the ecological integrity of stream communities. The method requires collection of benthic (bottom) invertebrates in a quantitative way at a given site. The invertebrates are counted and identified to species. An index is then used to estimate whether the species diversity and composition of the community at a given site meets with the expectations for a stream in the region where the data were collected. This is called the multimetric index (MMI) method for stream evaluation.

The Center for Limnology became involved in the MMI application through a study that showed extreme negative deviation of the MMI index below the outfall of Dillon Reservoir in Colorado. According to the MMI, the Blue River below the outfall point is highly divergent from expectations. The causes of this adverse condition are not obvious. Very near a dam, the outfall water often is a deepwater withdrawal that originates within the hypolimnetic zone of the reservoir.

Above: Lindsay Chipman, Ph.D., deploys her Acoustic Doppler Velocimeter. Photo credit: Tommy Detmer
Below: Attached algae conduct photosynthesis, leading to the release of oxygen. Photo credit: Jimmy McCutchan

Benthic insect larvae used in the multimetric index evaluation of stream habitat quality.
Above: Plecoptera (stonefly), a taxon with high sensitivity to habitat impairment. Photo credit: Jimmy McCutchan
Below: Diptera (blackfly), a tolerant taxon that resists habitat impairment. Photo credit: Jimmy McCutchan

For this reason, it is abnormally cold in summer as compared with ambient stream temperatures. It also lacks terrestrial organic matter that might serve as food for benthic insects and lacks a fresh sediment supply, as the hypolimnion of a lake traps sediments. In summer 2012, the Center for Limnology studied these possible causes of adverse diversity and community composition for the Dillon Reservoir outflow area.

The 2012 study showed that none of the obvious possible causes were likely responsible for the unusual MMI index in regions near the reservoir outfall. The study suggests that the Blue River downstream of the dam, where the Colorado Department of Natural Resources conducts stocking operations to accommodate sport fishing, likely is overstocked given with the productive capacity of the stream supply of stream invertebrate food organisms. Therefore, the entire region below the dam, extending as far as five miles, has MMI indices that are either below the MMI acceptability threshold or near it, as compared with much higher MMI indices in montane waters generally for Colorado. The current conclusion of the study, still tentative, is that stocking suppresses invertebrate food abundances because the maintenance requirements for stocked fish exceed the growth capacity of the invertebrates. This effect is most pronounced near the dam, where low growth rates due to cold water and possibly lower abundance of suspended nutritious foods suppress the ability of benthic invertebrates to withstand predation.

Center for Science and Technology Policy Research

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

Much of our work poses questions about how people and institutions make decisions under uncertainty; how perception and technical information influence choices; and how, through time, those choices affect the coevolution 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; problems in adapting to both environmental extremes and changes at the local scale; and ethics and trends in environmental management and policy, including efforts to limit greenhouse gases in the atmosphere, manage natural hazards, and adapt to environmental change. Our work is reported via research articles, books, reports, and several outreach methods, including a regular newsletter, briefings for decision makers, faculty blogs, news media, and frequent seminars and workshops.

CSTPR recently added several new projects. One is a NOAA grant led by Bill Travis, "Building Climate Science into Land and Water Conservation Planning and Decision-Making in the American Southwest." This new project will connect the climate expertise of the Western Water Assessment and the Climate Assessment for the Southwest with regional conservation planners and decision makers through collaboration with The Nature Conservancy's Southwest Climate Change Initiative to improve climate-adaptation planning and implementation by land managers in the American Southwest. A National Science Foundation grant, "Deliberation and Communication—Building Practical Skills in the Next Generation of Environmental Scientists,"

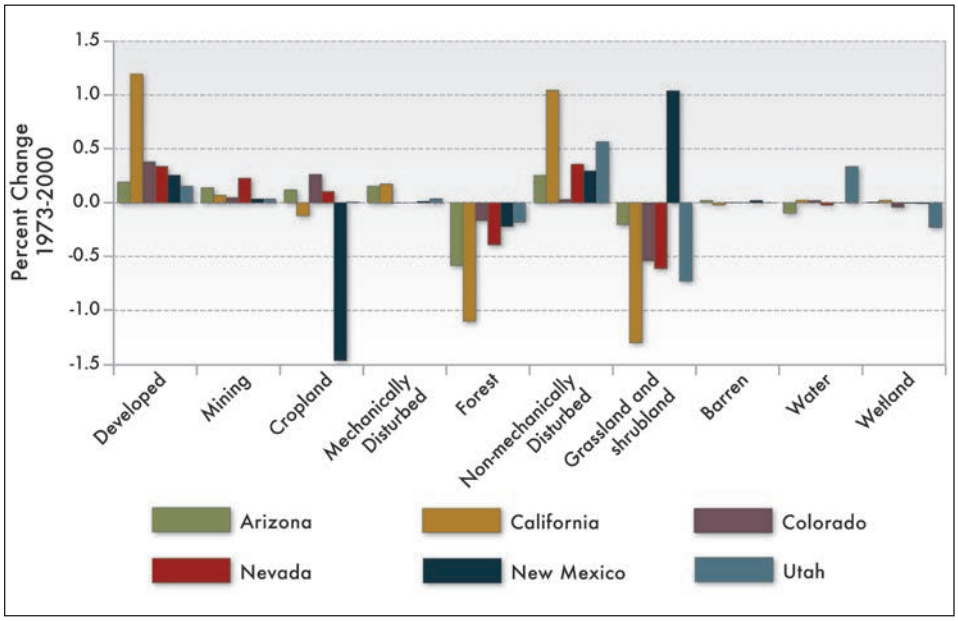
John Holdren—assistant to the President for science and technology, director of the White House Office of Science and Technology Policy, and co-chair of the President's Council of Advisors on Science and Technology (PCAST)—giving the keynote address at the CSTPR 10th anniversary. Photo credit: David Oonk/CIRES

Elizabeth McNie, Susan Avery, Shannon McNeeley, and Carl Mitcham participating in a panel discussion, "Usable Science: The Promise and Peril of Directing Research Toward Practical Outcomes," at the CSTPR 10th anniversary. Photo credit: David Oonk/CIRES

will support Ben Hale and a team of students in the creation of 10 short ethics videos on the normative dimensions of climate change. Finally, a Nathan Cummings Foundation grant led by Roger Pielke Jr., "How Philanthropy Can Improve Its Effectiveness in Policy and Politics," will clarify a broader scope of practical options for how philanthropy can contribute to policy and politics, building upon the model of engagement first introduced in Pielke's book, "The Honest Broker."

Highlights of the last 12 months include the celebration of our 10th anniversary in September 2012. Susan Avery, Ph.D., who, as director of CIRES in 2001, was instrumental in the center's creation, was among the many guests. Avery is now president of Woods Hole Oceanographic Institution. President Obama's science advisor, John Holdren, Ph.D., keynoted the event with a detailed look at the role of the science advisor and the Office of Science and Technology Policy. Other highlights include the significant contributions of Bill Travis, Lisa Dilling, Max Boykoff, and Ami Nacu-Schmidt to the new Southwest Climate Assessment, one component of the ongoing National Climate Assessment; the cross-disciplinary International Conference on Culture, Politics, and Climate Change organized by CSTPR Assistant Professor Deserai Crow, which attracted more than 350 scholars; and the launching of a new internship program by CIRES Fellows Lisa Dilling and Max Boykoff, and CIRES doctoral student Meaghan Daly that connects humanitarian practitioners from the Red Cross/Red Crescent Climate Centre with science policy graduate student researchers at the University of Colorado. In the first year of the program, interns have been placed in Kenya, Uganda, and Zambia. Seventeen graduate students worked at the center this past year, two of whom received degrees (one doctorate, one master's). Center faculty and students gave 70 presentations last year at events including the Climate Adaptation Futures: Second International Climate Change Adaptation Conference; American Meteorological Society Annual Meeting; Consortium of Universities for the Advancement of Hydrologic Science Third Biennial Colloquium on Hydrologic Science and Engineering; and Society for Risk Analysis Annual Meeting.

Roger Pielke Jr. participating in a panel discussion at the CSTPR 10th anniversary. Photo credit: David Oonk/CIRES



Percent of total state area affected by net change in land-use and land-cover types from 1973 to 2000, for the six Southwestern states.
Image credit: Ami Nacu-Schmidt

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.

Cryospheric research

During FY2013, our cryospheric research focused on understanding the physical processes of glacier and ice-sheet surfaces either through the use of remote-sensing observations or for the purpose of interpreting observations made by space-borne and airborne instruments. These activities include detecting and understanding the surface meltwater characteristics and influences on the ice flow rates; understanding the role of crevasses in stability of Antarctic ice shelves by combining satellite imagery with in situ measurements of ice thickness and ice shelf bottom–crevassing; examining the near-surface processes of the Greenland ice sheet that affect retrieval of ice-sheet elevation changes from satellite altimetry; and quantifying the sea-level contributions from Greenland's peripheral glaciers and ice caps by using the joint NASA/German Aerospace Center Gravity Recovery and Climate Experiment. All of these efforts are targeted at understanding how and why Earth's glaciers and ice sheets are changing and what those changes mean for life on Earth.

Ecosystem disturbance dynamics

We continue to focus on ecosystem resilience and response to disturbance, focusing on those that have the potential to significantly impact ecosystem services important to Western populations. Mountain pine beetle (MPB) and deposition of dryland dust on snow have the potential to influence spring snowmelt runoff behavior and subsequently impact downstream water availability. We are investigating the relative impacts of competing stream-flow alteration drivers through assessing system sensitivities to individual and combined disturbances. Preliminary results indicate that MPB-related canopy degradation leads to greater snow accumulation as a result of less canopy interception and reduced sublimation. Combined with a loss in root-water uptake during the warm season, the increased soil moisture availability translates into an overall increase in stream flow on the order of 3 to 15 percent. The primary control of dust-on-snow is on the timing and rate of melt, with earlier and more rapid melt rates associated with more extreme dust deposition. Our research is leading toward a clearer understanding of system components and will better inform mitigation strategies and planning efforts.

Atmospheric lidar development and application

The polar middle and upper atmosphere remains one of the least understood regions of the atmosphere. In particular, very little is known about the neutral atmosphere in the altitude range of 100 to 200 kilometers because observations are extremely difficult to make. Using cutting-edge lidar technologies and observations, our lidar group made a new discovery of neutral iron (Fe) layers reaching more than 170 km in the thermosphere, enabling us to make the first scientific measurements of the neutral atmosphere temperatures from 30 to 170 kilometers. This new capability will prompt new research in the areas of electrodynamics, neutral dynamics, chemistry, composition, and energetics in the Earth's space environment. Moreover, our researchers are providing new insights into planetary waves and thermal tides in Antarctica and are developing next-generation lidar technologies that are paving the way for new insights and discoveries in the atmosphere-space environment.

Oceanographic studies

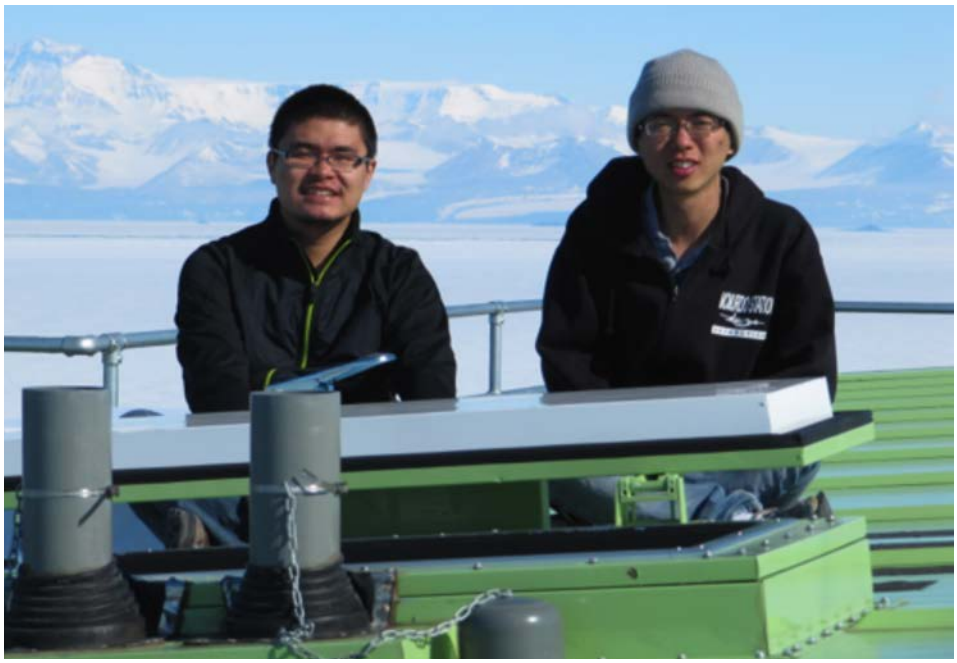
Global and regional observations of ocean processes are biased toward signals at the surface and in the upper ocean that are

Images acquired by the Landsat-5 Thematic Mapper tool of lodgepole pine forests near Grand Lake, Colo., September 11, 2005, and September 28, 2011—before and after a severe infestation led to die-off of the tree canopy.
Image cedit: NASA Earth Observatory

detectable from space-borne observing systems. In situ ocean observations are far fewer and more intermittent than is the case for the atmosphere (e.g., weather observing systems) and the land surface. We have been developing a probabilistic approach to modeling ocean processes with the goals of: a) maximizing the utility of the information content in sparse and spatially biased ocean observations that are available; and b) quantifying uncertainty in ocean process models that arise from data and model approximations. We have been using this Bayesian Hierarchical Modeling approach to: 1) identify model error in an ocean forecast system for the California Current; and 2) identify key parameters of an ocean ecosystem model for primary production in the Coastal Gulf of Alaska. These efforts will improve our modeling abilities, enabling more accurate forecasts of key oceanographic processes.

Climate processes: modeling

Through our modeling efforts, we have been working to understand the physical mechanisms behind the magnitude and variability of observed 500 hectopascals temperatures. We have documented an approximate minus 42 degree Celsius minimum cutoff in high-northern latitudes and provided several lines of evidence for the physical mechanism responsible. We also demonstrate a minus 5 degree Celsius maximum temperature, which appears to be dominated by tropical mechanisms. These maximum and minimum temperatures are abrupt, and the underlying mechanisms appear to be convective. While it is not surprising in the tropical case of maximum temperatures, it is not as obvious in the case of high-northern latitude minimum temperatures. There are, however, alternate hypotheses that might be responsible for high-latitude temperature regulation, such as equator-to-pole heat transport or processes involving phase changes of water, which will be the focus of future studies.



Cao Chen (left) and Weichun Fong (right) with two invisible ultraviolet lidar beams at the Arrival Heights Lidar Observatory near McMurdo Station, Antarctica, in January 2013.

Climate processes: observations

The Climate Processes Research Group in ESOC has established state-of-the-art measurements and advanced models to evaluate the way in which changes in climate modify, and are linked to, water and carbon cycles. In a partnership with NOAA scientists, we examined the exchange of carbonyl sulfide (COS) between the atmosphere and land surface to evaluate the uptake of CO_2 by plants to a precision of about 5 parts per trillion. We found that while COS is consumed by plants, as expected, there was a source of COS in arid soils. This finding complicates the naïve expectation that COS can be used as a simple tracer of gross uptake of carbon by plants; however, it also offers opportunities to further track the fate of carbon within ecosystems when paired with other more common ecosystem measurements. Satellite remote sensing has also developed an estimate of gross COS uptake based on fluorescence. Our measurements of COS provide a method for independent validation of an important emerging global data set.

Satellite and aircraft missions

We continue to play a role in NASA's Ice Cloud and land Elevation Satellite-2 (ICESat-2) laser altimetry mission, planned for launch in 2017, providing input to the science definition team on scientific considerations for ice-sheet and vegetation observations. We work extensively with data from the GRACE mission; the Total Emission Spectrometer (TES) on the Aura Spacecraft; and MODIS (Moderate Resolution Imaging Spectroradiometer). This year, we completed our work on the detection of potential geothermal heat sources by using high-resolution thermal infrared data from Landsat, MODIS, and Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), identifying candidate sites for drilling.

National Snow and Ice Data Center

The mission of the National Snow and Ice Data Center (NSIDC) is to improve our understanding of Earth's cryosphere, including sea ice, lake ice, glaciers, ice sheets, snow cover, and frozen ground. NSIDC manages, distributes, and stewards cryospheric and related data from Earth orbiting satellites, aircraft, and surface observations, from NASA, NOAA, and the National Science Foundation. NSIDC also facilitates the collection, preservation, exchange, and use of local Arctic knowledge and observations; and conducts research into the changing cryosphere. Selected highlights from FY13 include:

Recovering 1960s satellite data

Recently, NSIDC acquired stacks of 49-year-old film from the NOAA National Climate Data Center. The film, from one of the first U.S. Earth observing missions, the Nimbus 1 satellite, could give scientists a look back at climate to 1964. Studies of changes in sea-ice extent currently depend on a satellite record beginning in 1979.

Nimbus 1 tested weather satellite technology and included a video camera. The satellite orbited Earth from August to September 1964, transmitting stills to a television monitor, which researchers photographed and archived. In 2009, NSIDC learned of the film and took steps to acquire and process it.

The NSIDC team scanned, aligned, and stitched nearly 40,000 frames to produce maps of the sea-ice edge in 1964 and an estimate of September sea-ice extent for both the Arctic and the Antarctic. The 1964 Arctic estimate is reasonably consistent with 1979 to 2000 conditions, suggesting that September extent in the Arctic may have been generally stable through the 1960s and the early 1970s.

NSIDC will be making these images available to researchers in mid 2013, along with high-resolution infrared data from Nimbus 1, and is currently working on film from Nimbus 2 and 3.

Greenland Ice Sheet today

During summer 2012, nearly 97 percent of the Greenland Ice Sheet surface melted, the most extreme melt extent seen in three decades of satellite records. Although the extreme melt was tied to an unusually warm mass of air parked over Greenland for several weeks, it occurred as Arctic sea ice extent was declining to a record low later in the year.

The extreme summer melt of 2012 caught many by surprise and prompted NSIDC to develop a new website. Greenland Ice Sheet Today (http://nsidc.org/greenland-today) features images of daily melt and cumulative melt days, updated daily, with a one-day lag. A daily graph charts the current melt percentage against the average. NSIDC also posts periodic analyses of conditions in Greenland.

Arctic sea-ice decline

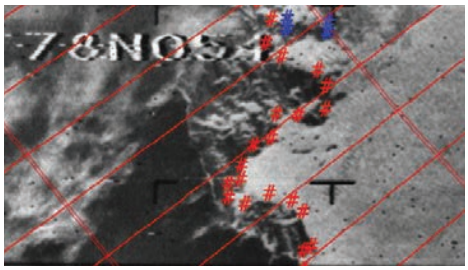
Summer Arctic sea-ice extent set a new record low in 2012. One big question is how soon the Arctic Ocean could become virtually ice-free by summer's end, exposing more of the darker ocean surface to absorb the Sun's heat.

Computer climate models help look at such questions, but tuning these models is a work in progress. Previous studies revealed that the actual downward trend in September ice extent exceeded simulated trends from most models participating in the World Climate Research Programme Coupled Model Intercomparison Project Phase 3 (CMIP3). Since then, researchers have worked to refine the models.

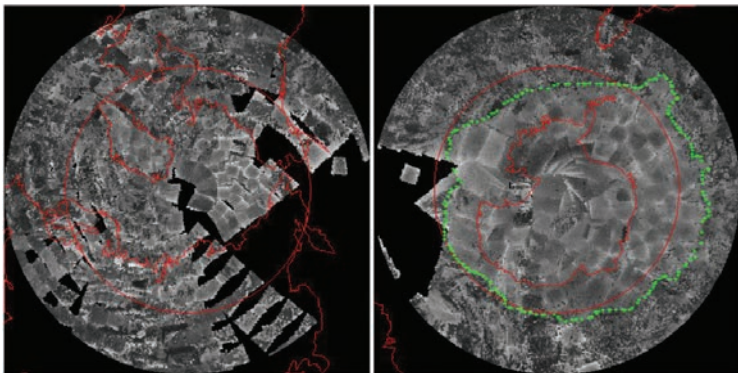
A study led by NSIDC scientist Julienne Stroeve shows that as a group, simulated trends from the next generation of models, CMIP5, are more consistent with observations over the satellite era (1979 to 2011). Nevertheless, the trends from most models remain smaller than the observed rate of decline.

CMIP5 models presently suggest that the Arctic will be seasonally ice-free sooner than 2035, as CMIP3 suggested. Thinning sea ice and natural variability complicate sea-ice decline, and are hard for models to account for. Still, it is clear that if greenhouse gases continue to rise, the Arctic Ocean will eventually become seasonally ice free.

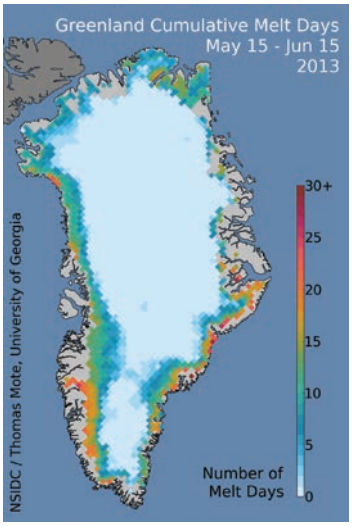
The National Snow and Ice Data Center acquires dozens of canisters of 35-millimeter film containing images of the 1964 Arctic sea-ice minimum and the Antarctic maximum. The images were collected by the Nimbus 1 satellite, which circled the globe from August 28, 1964, to September 23, 1964. Photo credit: NSIDC



A single-frame image of the Arctic ice edge north of Russia near Franz Josef Land (centered at 78 degrees North and 54 degrees East) on September 4, 1964, after processing by the National Snow and Ice Data Center. The estimated boundary between the ice and ocean is marked by red hash tags; openings, or leads, within the ice are marked by blue hash tags. Image credit: NSIDC



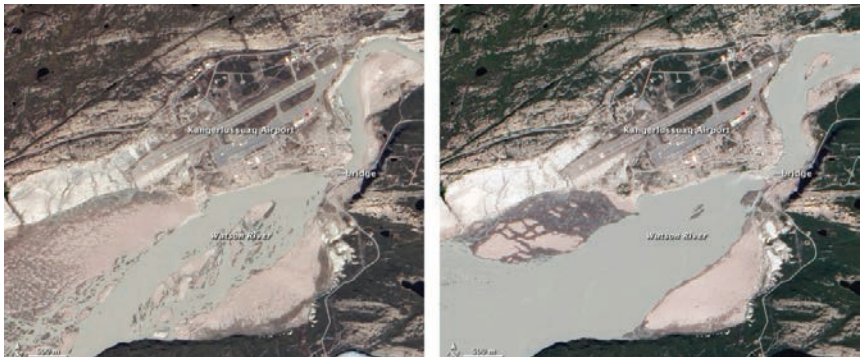
The National Snow and Ice Data Center scanned close to 40,000 images from Nimbus 1 satellite data to produce the earliest satellite images of Arctic and Antarctic sea-ice extent. The left image is a composite of the Arctic, and the right image is a composite of the Antarctic. Image credit: NSIDC



Greenland Ice Sheet Today features remote sensing–based melt images of the ice sheet, updated daily with a one-day lag.

Image credit: NSIDC; Thomas Mote/University of Georgia

A large stream of meltwater, about 5 to 10 meters wide, emerges from an upstream supraglacial lake in the Greenlandic ice. This photograph was taken during the summer of 2012, when a record 97 percent of the ice-sheet surface experienced melting. Photo credit: M. Tedesco/CCNY



Although the Greenland Ice Sheet undergoes seasonal melting each summer, surface melt during July 2012 reached record levels. Runoff from the ice sheet flooded the Watson River and swept away parts of a bridge in the town of Kangerlussuaq. The left image is from May 31, 2012, prior to the melt. The right image is from July 25, 2012, after the record surface melt.

Image credit: NASA Earth Observatory

Arctic animals such as these Bering Sea walruses depend on the ice edge as a platform for hunting and breeding

Photo courtesy of Brad Benter, U.S. Fish and Wildlife Service

Western Water Assessment

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

In FY13, the WWA research team worked on continuing projects and new initiatives aimed at supporting a broad community of federal, state, local, and private stakeholders. Several efforts that produced particularly noteworthy results in the past year are highlighted below.

Water use implications of electricity generation

Although the electricity sector accounts for a substantial portion of the total water withdrawn and consumed in the United States, recent WWA-led research demonstrates major shortcomings in the current understanding of how much water is used for different technologies, lifecycle stages, and fuel types within this sector. WWA researchers Kristen Averyt and James Meldrum, in collaboration with scientists from several other organizations, reviewed the published literature to develop consistent estimates of water use for many aspects of the electricity sector and applied these factors to investigate current and future links between electricity generation and water supplies. Among their results published in the last year is that the estimated water use reported by power producers to the Energy Information Administration (EIA) deviates substantially from that calculated with literature-based estimates. Based on calculated values, recent research (published in *Environmental Research Letters*) indicates that water supplies are stressed in more than 9 percent of watersheds in the United States, and that even a single power plant has the potential to stress water supplies at the watershed scale. The U.S. West is particularly sensitive to low-flow events and projected long-term shifts driven by climate change. These findings have been communicated directly to a number of high-level policymakers tackling water and energy issues.

Federal land managers' attitudes and progress toward climate adaptation

Recent mandates have compelled federal land management agencies to begin climate change adaptation planning, but the degree

Colorado National Monument near Grand Junction, Colo. Photo credit: Eric Gordon

to which that planning has occurred, as well as whether those plans have motivated on-the-ground actions, is unclear. To assess these efforts across agencies, WWA researchers Lisa Dilling and Kelli Archie conducted a survey and semi-structured interviews with managers from the four major federal land management agencies in the WWA region. Their results showed that although the agencies have begun some adaptation planning efforts, few concrete adaptation projects have actually been implemented to date. In addition, adaptation activity levels varied across the agencies. Their work also identified the most common barriers to adaptation, including the lack of information at relevant scales, budget constraints, lack of specific agency direction, and lack of useful information. Dilling and Archie's work was published in *Ecology and Society*.

Major drivers of snowmelt in the Upper Colorado River Basin

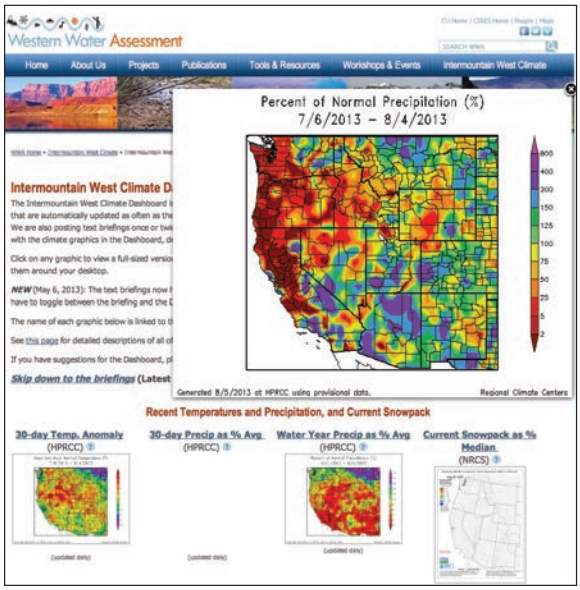
During the past decade, the Upper Colorado River Basin has experienced unusual runoff patterns resulting in anomalously high errors in peak and daily streamflow forecasts issued by NOAA. Both water managers and hydrologic forecasters suspected that bark beetle infestations and/or increased dust55 deposition on snowpack might be causing these runoff anomalies, but they lacked a framework for assessing these and other likely causes—and for improving the runoff forecasts. A multidisciplinary team of WWA researchers (including Jeff Deems, Visiting Fellow Ben Livneh, Joseph Barsugli, Klaus Wolter, and CIRES Fellow Carol Wessman) with expertise in climatology, meteorology, snow hydrology, and landscape ecology has brought together a novel combination of methodologies to investigate the contributions of various snowmelt perturbations. Project researchers have used the Distributed Hydrology Soils and Vegetation Model to assess sensitivity to bark beetle infestation and dust deposition scenarios in four study basins in Colorado. Initial model results indicate that bark beetle infestation alone can cause an increase in annual water yield of 3 to 15 percent over the selected basins.

WWA's Ben Livneh and Dominik Schneider measure canopy albedo in a beetle-killed forest.

Photo courtesy Ben Livneh/CIRES

Climate information tool for decision makers

In 2005, WWA began producing the Intermountain West Climate Summary (or IWCS), a semi-monthly digest of climate and hydrology conditions and forecasts for Colorado, Wyoming, and Utah. To provide more timely information in a clearer format for a variety of stakeholders, WWA researcher Jeff Lukas led the effort to create the Intermountain West Climate Dashboard (available at http://wwa.colorado.edu/climate/dashboard.html). The Dashboard contains an array of many of the same climate information graphics as in the IWCS, but directly feeds them from their original providers (such as the NOAA Climate Prediction Center) so they automatically update, often daily, creating a single source of real-time climate information for stakeholders. To provide additional context and analysis, Lukas and other WWA researchers also write and post bimonthly briefings on the Dashboard.



Western Water Assessment's Intermountain West Climate Dashboard, available at http://wwa.colorado.edu/climate/dashboard.html.

Since it was put online in October 2012, the Dashboard has received numerous plaudits from water managers and other decision makers who find it to be the best available "one-stop shop" for the climate information they need.

Education and Outreach

The CIRES Education and Outreach (EO) group is active across the spectrum of geosciences education, including teacher and scientist professional development, digital learning resources and courses, pre-college student programs, and more. Some example projects are described below.

Climate education

EO has developed strengths within climate education because so much of CIRES research focuses on climate-related sciences. In FY2013, EO climate-education projects focused on teacher professional development, a collection of climate and energy learning resources now syndicated through climate.gov, and climate communications training for scientists and educators.

The Climate Literacy and Energy Awareness Network (CLEAN) Collection is a peer-reviewed educational resource collection syndicated through the NOAA climate.gov portal. The CLEAN Pathways project features teaching materials centered on climate and energy science for grades 6 through 16. Each teaching resource has undergone a rigorous review process and provides expert teaching tips on how to implement the resource in the classroom. All materials are aligned with frameworks of big ideas that lead to scientific literacy. Funding for CLEAN is currently provided through the NOAA Climate Program Office. Learn more at climate.gov/teaching under "educational resources" or go to cleannet.org.

The Inspiring Climate Education Excellence (ICEE) draws from CLEAN as a professional development program for science educators. ICEE online courses help educators learn the fundamentals of climate science, develop strategies for forestalling controversy in the classroom, and get connected to the climate community. Course participants include educators across varied contexts, from elementary through undergraduate classroom settings, and informal educators working in nature center, school assembly, or museum settings. CIRES and NOAA scientists teach class sessions while climate science graduate students support participants online. Each interest group works with an expert coach, and each participant tests a course project with their learners. For more, see http://cires.colorado.edu/education/outreach/ICEE/workshop.

EO collaborated with CIRES Communi-

David Noone presenting about water resources to a classroom as part of the Waterspotters project. Photo credit: David Oonk/CIRES

Students sample macro-invertebrates as part of a Project Extremes field trip. Photo credit: Thomas Detmer

Students practice tree coring as part of a Project Extremes field trip.

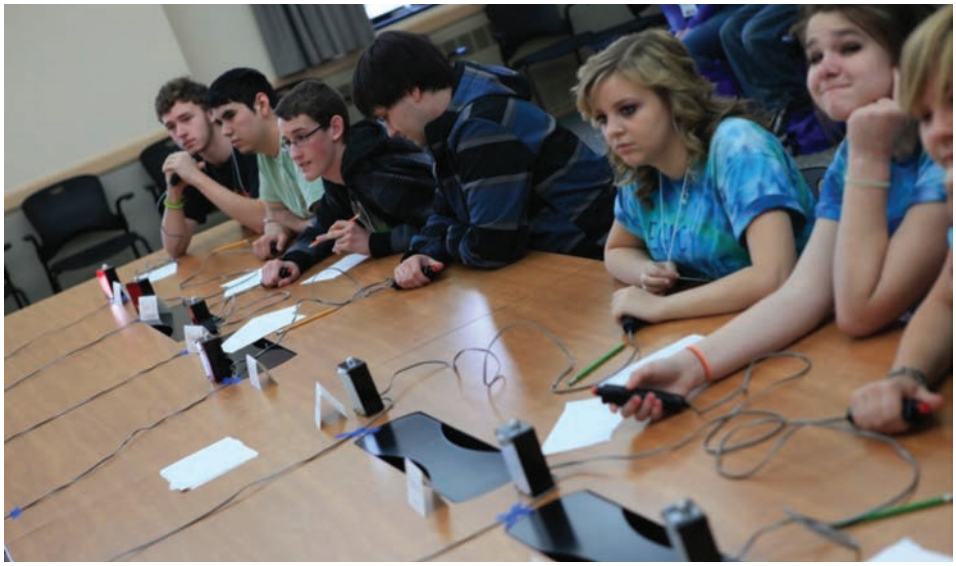
cations, NOAA ESRL, and the Cooperative Institute for Climate and Satellites (CISC) to provide climate communications training for Boulder-area climate scientists. Participants learned best practices for working with the media and for communicating about climate science, and learned more about resources available through NOAA. Small groups crafted messages about their research, responded to frequently asked questions about climate change, and shaped their communication for particular audiences. Participants expressed a desire for more ongoing training in collaboration with one another.

Reaching students

EO projects for students include an after-school student-scientist project and field trips to the University of Colorado Mountain Research Station. Also, Waterspotters is an after-school project developed as part of a research project studying the Front Range water budget. In partnership with a program serving students underrepresented in science, participating schools receive a weather station, curriculum, and equipment to study water resources and weather with support from graduate students and project scientists. As part of the research, students collect precipitation samples to send back to CIRES for isotope analysis and compare data with other participating schools. For more information, see http://cires.colorado.edu/education/outreach/waterspotters/.

CIRES Outreach leads Project Extremes, a program that during the last five years has supported up to a dozen graduate student "Fellows" per year to assist teachers in the classroom. During the course of the project, graduate students have worked with 15 Boulder Valley School District (BVSD) schools that serve diverse students. 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 2012, the project served 1,200 students, including hosting all BVSD fifth graders on field trips to the Mountain Research Station, and leading field trips to University of Colorado Boulder laboratories for 450 students.

CIRES Susan Buhr Sullivan working with NOAA and CIRES scientists during climate communication training. Photo credit: Barb Deluis/NOAA



High school students compete in the 2013 Trout Bowl, a regional competition of the National Ocean Sciences Bowl and another Education and Outreach activity. Photo credit: David Oonk/CIRES

Visiting Fellows

With partial sponsorship by NOAA, CIRES offers Visiting Fellowships at the University of Colorado Boulder. Every year, CIRES awards several fellowships to visiting scientists at many levels, from postdoctoral to senior. These fellowships promote collaborative and cutting-edge research. Since 1967, more than 100 people have been Visiting Fellows at CIRES, including previous CIRES Directors Susan Avery and Konrad Steffen.

Jeffrey Amato

Sabbatical
Ph.D., Stanford University
Project: Using Hf isotopes and U-Pb ages of detrital zircons to characterize the provenance of Cambrian and Grenville-age sandstones in the Cordillera
Sponsor: Lang Farmer

Jeffrey Amato is a professor at New Mexico State University in Las Cruces. His main research interests are structural geology, tectonics, geochronology, and isotope geochemistry.

While at CIRES, Amato is working with Lang Farmer to use the age and isotopic composition of zircons (a type of mineral) to match sediment to its source region. "If we can determine the source areas of sediment, it will significantly improve our understanding of the paleogeography during the early Paleozoic," he says. "One possible implication of the work is that we may be able to improve our ability to determine the transportation directions of ancient rivers, as well as evaluate longshore drift directions on the coastline 500 million years ago." Amato is also studying the origin of the distinctive 1080 Ma (megayears) and 510 Ma igneous rocks in the western United States.

Franco Biondi

Sabbatical
Laurea (Italian Doctorate), Università di Firenze
Ph.D., University of Arizona
Project: Using tree-ring records to quantify spatial and temporal patterns of dry and wet episodes
Sponsor: Thomas Chase

Franco Biondi is a professor in the Department of Geography at the University of Nevada, Reno, where he is also the DendroLab Director. His main areas of research include ecoclimatology (the relationship between living organisms and their climatic environment); forest and landscape dynamics; spatial processes; and environmental change.

While at CIRES, he is working with Balaji Rajagopalan and Tom Chase, along with Roger Pielke Sr.'s research group and Jeff Lukas at the Western Water Assessment (WWA). He is investigating how to best combine proxy records of climate at annual to seasonal timespans with instrumental observations and models used to manage environmental resources, especially water. Additionally, he is studying how to incorporate long-term perspectives in the analysis (and management) of disturbance effects on tree-dominated ecosystems. "Proxy records, such as tree-ring chronologies, can help improve regional assessments of environmental (and societal) vulnerability to future environmental changes," he says.

Stuart Bradley

Sabbatical
Ph.D., The University of Auckland, New Zealand
Project: Remote sensing of turbulent generated acoustic noise
Sponsors: William Neff and Mike Hardesty

Stuart Bradley is a professor of physics at The University of Auckland, New Zealand. His research focuses on atmospheric boundary layer processes, particularly using sound to remotely sense atmospheric turbulence and winds for applications such as wind energy.

While at CIRES, Bradley is conducting research into the background noise—much of it likely caused by turbulence—that affects the quality of acoustic 'radars' known as sodars, which are used in remote sensing of the atmosphere. "I am modeling and measuring this noise with the objectives of improving acoustic remote sensing using sodars," Bradley says. "I'm also investigating whether the spectral signatures of this noise allow for a new, entirely passive, microphone-based method of profiling atmospheric turbulence." The results of his work may provide the basics for a leap forward in acoustic remote sensing of atmospheric winds and turbulence.

Lindsay Chapman

Postdoctoral
Ph.D., Florida State University
Project: Application of the eddy correlation technique to shallow running waters: A test of the fate of organic carbon in Colorado plains rivers
Sponsors: William M. Lewis Jr. and James McCutchan

Lindsay Chapman is working with the Department of Limnology to evaluate the use of the eddy correlation method for estimating oxygen metabolism in shallow rivers. She will then use these measurements to investigate the

fate of organic matter transported by rivers. "This research will help to answer questions related to the fate and global cycling of carbon and nitrogen and contribute to our understanding of how changes in climate, human population, and land use will affect the delivery of carbon to the world's oceans," she says.

Aditya Choukulkar

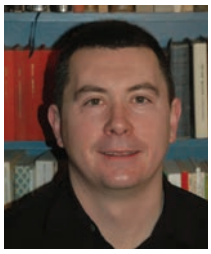
Postdoctoral
Ph.D., Arizona State University
Project: Quantitative analysis of mass flux parameterization using observations from the DYNAMO (Dynamics of the Madden Julian Oscillation) field program
Sponsor: Michael Hardesty

Aditya Choukulkar is working with NOAA's Atmospheric Remote Sensing Group and the Physical Sciences Division. Using measurements from the DYNAMO field program on the equatorial Indian Ocean, Choukulkar is investigating mass flux transport in shallow convection cases, which is expected to be an important mechanism in the transport of moisture from the boundary layer into the lower troposphere. "Weather forecast models are challenged to capture this process in cumulus parameterization schemes due to unavailability of sufficient data sets studying this process," he says. "Our work will enable, for the first time, characterization of mass flux profiles from close to the surface up to the cloud top. This will allow us to understand the role of shallow convection in the transport of moisture." In addition, by directly observing the governing variables, this study will also help gain insights on commonly used boundary layer parameterizations.

Andrew Dessler

Sabbatical
Ph.D., Harvard University
Project: Understanding long-term variations in stratospheric water vapor
Sponsor: David Fahey

Andrew Dessler is a professor of atmospheric sciences at Texas A&M University. His research focuses on climate feedbacks and the effect of clouds on the climate system. While at CIRES, he is working with ESRL's Chemical Sciences Division to investigate the response of stratospheric water vapor to climate change. Because stratospheric water vapor is itself a greenhouse gas, if it increases as the climate warms, that could amplify the initial warming—resulting in a stratospheric water vapor feedback. Additionally, changes in stratospheric water vapor impact both climate and ozone abundance, so it's possible that climate change might affect ozone. "It turns out that not too many people have thought about the climate impacts of stratospheric water vapor," Dessler says. "It's possible that a better understanding of this might help us resolve the differences among various climate models' predictions of warming during the 21st century and help us better constrain the climate sensitivity."



Jean-Francois Doussin

Sabbatical
Ph.D., University of Paris 7
Project: Interaction between water and carbonyls—a multiphase approach of the isoprene chemistry contribution to secondary organic aerosol formation in the atmosphere
Sponsor: Veronica Vaida

Jean-Francois Doussin is a professor in chemistry at the University of Paris East at Créteil. He studies atmospheric chemistry, specifically the experimental simulation of organic carbon's atmospheric fate. While at CIRES, he is working with Veronica Vaida's group to investigate production of secondary organic aerosol (SOA)—a type of air pollution—from the multiphase oxidation of the compound isoprene. Produced by plants, isoprene is the major volatile organic compound (VOC) emitted on a global scale. In the atmosphere, isoprene can react with the sun and ozone to yield other compounds such as water-soluble VOCs. These secondary compounds can lead to the formation of significant additional amounts of SOA. This may "deeply modify the current yield estimation of SOA on the global scale and its climatic impact," Doussin says. His work will lead to a better account of isoprene's contributions to air pollution.

Brian Ebel

Postdoctoral
Ph.D., Stanford University
Project: From ridgetops to rivers: Advancing understanding of hydrologically driven sediment transport following wildfire
Sponsor: Greg Tucker

Brian Ebel is working with Greg Tucker's group to investigate the water-driven transport of sediment following wildfire. The principal field site is the 2010 Fourmile Canyon Fire outside of Boulder, Colo. Wildfire is one of the most significant disturbances in mountainous landscapes and commonly leads to major sediment loads into streams, Ebel says. These enhanced sediment loads impact stream ecology and the built environment. "I feel fortunate to have the opportunity to improve our understanding and predictive capability of natural hazards such as flash floods and debris flows," Ebel says.

Steve Hansen

Postdoctoral
Ph.D., University of Wyoming
Project: Investigation of the North American lithosphere with receiver function imaging
Sponsor: Anne Sheehan

Steve Hansen is earning a doctorate in geophysics at the University of Wyoming. He is working with Anne Sheehan's group and also collaborating with Craig Jones's and Peter Molnar's groups. Using seismic data recorded from distant earthquakes, he is imaging the structure of North America's subsurface. Hansen is particularly interested in the mantle lithosphere and lithosphere-asthenosphere boundary (LAB), which is the mechanical boundary between the rigid plates and the deep convecting mantle. "The LAB is critical to the theory of plate tectonics and yet is poorly understood," Hansen says.

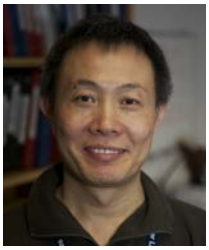
Visiting Fellows

Mark Hemer

Sabbatical
Ph.D., University of Tasmania, Australia
Project: Surface wave driven feedbacks in the coupled climate system
Sponsor: Baylor Fox-Kemper

Mark Hemer is a research scientist at the Centre for Australian Weather and Climate Research and is based in Hobart, Tasmania. His research focuses on how wind-waves behave in a variable climate system.

Hemer is working with Baylor Fox-Kemper's research group and also collaborating with researchers at NOAA and NCAR. He is working to couple a spectral wind-wave model with a global climate model. Current models do not adequately account for wind-wave effects on climate. "We hope that parameterization of wind-wave dependent processes in global general circulation models reduces model biases—improving climate simulations and understanding of how wind-waves influence the climate system," he says.



Shao-Meng Li

Sabbatical
Ph.D., Florida State University/National Center for Atmospheric Research Advance Study Program
Project: Volatile organic compounds off the coast of California: results from the CalNex 2010 studies
Sponsor: Joost de Gouw

Shao-Meng Li is a senior research scientist for the Canadian government, working in the Air Quality Research Division, based in Toronto, for the Department of Environment. Li's main research interest is regional air quality, primarily in aerosol chemical composition and its various impacts.

While at CIRES, Li is working with Joost de Gouw's group to investigate volatile organic compounds (VOCs) over California's coastal areas. Li is using data gathered from the CalNex 2010 (Research at the Nexus of Air Quality and Climate Change) field study. Li is particularly interested in the VOC compositions over the area where there has been a well-documented methane seepage from underwater coal deposits off the coast of Santa Barbara and is comparing the data with NOAA's results from over the Deepwater Horizon oil spill. "Increased explorations for fossil fuels to meet increased demands have increased public awareness about potential environmental impacts these days, and among them, the emissions into the atmosphere have the potential to cause regional air quality problems, health issues, and related climate effects," Li says. "Better fingerprinting and better quantifications of these emissions will enable models to better predict the consequences of the increased emissions, allowing for assessment of existing and/or new policies regulating the industry."

Björn-Ola Linnér

Sabbatical
Ph.D., Linköping University
Project: Science, politics, and the Green Revolution
Sponsor: Roger Pielke Jr.

Björn-Ola Linnér is a professor in water and environmental studies at the Centre for Climate Science and Policy Research, Linköping University, in Sweden. His research focuses on international policy-making on climate change, food security, and sustainable development.

While at the CIRES Center for Science and Technology Policy Research, Linnér is unraveling and contextualizing the lessons of the Green Revolution for how we think about innovation policy—in agriculture and beyond. The world is seeking to provide massive quantities of energy by mid-century while at the same time dramatically reducing the carbon intensity of the global economy. "To have any chance of succeeding will require a sustained and intensive commitment to energy innovation," Linnér says. "We believe that the notable successes in sustained improvements in agricultural productivity gains over the past half-century offer fruitful lessons for energy policy innovation." Linnér and his colleagues' analysis has direct relevance to policies for agriculture, which seek to produce enough food for more than 9 billion people by 2050, while at the same time reducing the environmental footprint of those practices.

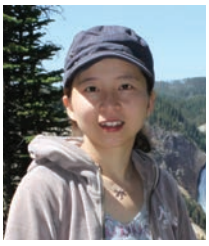
Anne Monod

Sabbatical
Ph.D., Aix-Marseille University, France
Project: Atmospheric chemistry
Sponsors: Graham Feingold and Veronica Vaida

Ben Livneh

Postdoctoral
Ph.D., University of Washington
Project: Hydrology modeling of desert dust and mountain pine beetle disturbance under current and future climate scenarios
Sponsor: Carol Wessman

Ben Livneh is working with CIRES' Environmental Observations, Modeling and Forecasting Division and also in close collaboration with CIRES' Cryospheric and Polar Processes Division and Ecosystem Science Division. His research addresses crucial aspects of water-resource management in the Colorado River Basin. Specifically, he is investigating dust deposition on snow and its impact on snowpack evolution and the onset of spring snowmelt under current and future climates. "The findings will have implications for freshwater resources within the region," he says. Livneh is also studying the drivers behind the anomalously large runoff experienced by the Colorado headwaters region in 2010.



Xian Lu

Postdoctoral
Ph.D., University of Illinois at Urbana-Champaign
Project: Lidar and modeling studies of atmospheric wave dynamics in Antarctica
Sponsor: Xinzhao Chu

Xian Lu is working with CIRES Fellow Xinzhao Chu's research group and also collaborating with Timothy Fuller-Rowell in NOAA's Space Weather Prediction Center.

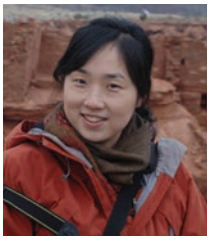
Using lidar, radar, and satellite data, she is investigating the characteristics of gravity waves and thermal tides from the lower to the upper atmosphere at the McMurdo Station in Antarctica. She will then compare them with the Whole Atmosphere Model simulations and examine their impacts on the polar dynamics. "Gravity waves and tides are the two most dominant wave activities, which drive the whole middle atmosphere away from the radiative equilibrium and affect its momentum budget and mean circulation," she says. "Due to this importance, insufficient observations of gravity waves make it challenging to parameterize their effects and difficult to realistically simulate the middle atmosphere in climate and space weather models." This project will provide new knowledge of gravity waves and tides in Antarctica and the observational validations of climate and space-weather models.

Ralph Milliff

Sabbatical
Ph.D., University of California, Santa Barbara
Project: Development of the TropSat Observatory
Sponsor: Baylor Fox-Kemper

Ralph Milliff is an adjunct associate professor with the Atmospheric and Oceanic Sciences Department at the University of Colorado Boulder and a senior research scientist at Colorado Research Associates (CoRA). Milliff's research interests focus on air-sea interaction processes on regional and global scales.

Milliff is the science team lead for a new earth-observing satellite mission concept called the TropSat Observatory. TropSat is intended to measure properties of convective-system evolution in the mesoscale (meaning weather systems measuring horizontally five to several hundred kilometers and often involving heavy rainfall, wind, hail, and lightning)—system by system—throughout the global maritime tropics. This is achieved in part by a very low-inclination orbit and broad-swath design.



Kyung-Eun Min

Postdoctoral
Ph.D., University of California at Berkeley
Project: Development of a broadband cavity enhanced spectroscopy (BBCES) instrument to characterize wavelength-dependent optical properties of brown carbon
Sponsor: Fred Fehsenfeld

Kyung-Eun Min is working with Fred Fehsenfeld, Steve Brown, and Rebecca Washenfelder. She is developing an instrument for measuring how an aerosol, a particle suspended in the atmosphere, scatters and absorbs light, specifically short-wavelength light. Light extinction (meaning scattering and absorption of light) by atmospheric aerosols represents the single largest uncertainty in researchers' understanding of Earth's radiation balance. And recent work has shown that some organic aerosols, so-called "brown carbon," may absorb ultraviolet light, which was previously unknown. "This finding adds additional uncertainty to estimates of aerosol radiative forcing as brown carbon's optical properties are poorly constrained," Min says. "Through this project, I'm expecting to improve our understanding of the role of brown carbon aerosols in Earth's radiation budget."

Arnaud Temme

Sabbatical
Ph.D., Wageningen University in the Netherlands
Project: Digging deeper—adding soil formation to landscape evolution models
Sponsor: Greg Tucker

Arnaud Temme is an assistant professor in soil geography and geomorphology at Wageningen University in the Netherlands. While at CIRES, he is working with Greg Tucker to study the relation between geomorphic processes (for instance, landslides) and soil formation in the high Rockies. Soil and landscape change are intimately related, Temme explains, not only in lowland deltas such as the Netherlands, but also in high mountain areas, where hillslope processes alter soil parent material and soil formation alters erodibility and opportunities for vegetation to grow. "If we understand how soils and landscapes interact, we will be better able to predict soil patterns in high mountain regions," he says. "This allows better estimates of water retention and ecological succession in these areas."

Volker Wulfmeyer

Sabbatical
Ph.D., University of Hamburg, Germany
Project: Land-surface-atmosphere (LSA) feedback by a combination of observation and modeling effects
Sponsors: Graham Feingold and Michael Hardesty

Dan Yakir

Sabbatical
Ph.D., Hebrew University of Jerusalem
Project: Exploring the links between COS and ^{18}O-CO_2 in biosphere-atmosphere exchange—combining process understanding and atmospheric observations
Sponsors: David Noone and Steve Montzka

Dan Yakir is a professor of biogeochemistry at the Weizmann Institute of Science in Israel. His main research interests are biogeochemistry and plant-atmosphere interactions.

While at CIRES, Yakir is working with David Noone, Steve Montzka, and Jim White, director of INSTAAR. Yakir is investigating two tracers (tracers are radioactive atoms present in a material and are used to study the material's distribution and pathway)—oxygen-18 content in CO_2 and carbonyl sulfide—and how they can be used to better estimate the exchange of CO_2 between land vegetation and the atmosphere. "Accurately estimating carbon uptake by land vegetation will improve estimates of the rate of global warming and climate change," Yakir says. "Tracing specific fluxes of CO_2 between the atmosphere and the land vegetation will also provide a powerful tool to understand the process underlying the biosphere response to climate change."

Graduate Research Fellowships

CIRES supports two prestigious student fellowship programs, the ESRL- CIRES Fellowship, begun in 2008 with the support of NOAA's Earth System Research Laboratory, and the long-established CIRES Graduate Student Research Fellowship. For FY2013, CIRES awarded CIRES Graduate Student Research Fellowships (GSRF) to nine students. This year's recipients are exploring topics ranging from electronic-waste management, anthropogenic emissions, and the role of wildfire on landscape formation to climate adaption in East Africa and recent earthquakes in Haiti and the Himalaya.

FY2013 CIRES GSRF Students

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 the ability to communicate are also considered.

Sunil Baidar

Chemistry
Advisor: Rainer Volkamer

Adriana Raudzens Bailey

CIRES Ph.D. Student: Atmospheric and Oceanic Sciences

Advisor: David Noone
Raudzens Bailey is studying the vertical moisture exchange through the convective boundary layer in the atmosphere.

Gaddy Bergmann

CIRES Ph.D. Student: Ecology and Evolutionary Biology

Advisor: Noah Fierer
Bergmann is studying the community of bacteria that inhabits the bison digestive tract and how it varies among different herds across the Great Plains.

Sean Haney

CIRES Ph.D. Student: Atmospheric and Oceanic Sciences
Advisor: Baylor Fox-Kemper
Haney's research focuses on improving global climate models by better accounting for the ocean mixed layer and its interactions with the atmosphere.

Katie McCaffrey

Atmospheric and Oceanic Sciences
Advisors: Baylor Fox-Kemper and Jeffrey Weiss

Ryan Reynolds Neely III

Atmospheric and Oceanic Sciences
Advisors: Brian Toon and Jeffrey Thayer

Brett Palm

CIRES Ph.D. Student: Analytical/Atmospheric Chemistry
Advisor: Jose-Luis Jimenez
Palm's research focuses on the application of a Rapid Secondary Aerosol Formation Measurement Tool for laboratory and field studies.

Joe Rokicki

CIRES Ph.D. Student: Molecular, Cellular, and Developmental Biology
Advisor: Shelley Copley
Rokicki is investigating the *Sphingobium chlorophenolicum* bacterium and the genetic regulation of enzymes that degrade the environmental toxin pentachlorophenol.

Jessica Weinkle

CIRES Ph.D. Student: Environmental Studies
Advisor: Roger Pielke, Jr.
Weinkle's research involves a policy evaluation of Florida's Citizens Property Insurance Corporation with the goal of informing the process of forecasting, negotiating understanding, and democratically governing hurricane risk.

Diversity and Undergraduate Research

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

Significant Opportunities in Atmospheric Research and Science Program (SOARS)

This 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 four-year mentorship and research program for protégés majoring in an atmospheric science or related field. More: http://www.ucar.edu/soars/

FY2013 SOARS Protégés

Ma'Ko'Quah Jones

Research: Statistical analysis of relations between monthly teleconnection indices
CIRES Mentor: Leslie M. Hartten

Ana Ordonez

Research: Energy extraction from ocean currents and waves: mapping the most promising locations
CIRES Mentor: Baylor Fox-Kemper

Undergraduate Research Opportunities Program (UROP)

This program funds 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 research assistantships, stipends and/or expense allowances to students who undertake an investigative or creative project with a faculty member. More: http://enrichment.colorado.edu/urop/

FY2013 UROP Students

Kelsey Bickham

Project: Long-term effects of multiple disturbances on soil properties and regeneration in Colorado subalpine forest
CIRES Sponsor: Carol Wessman

Scott Bucy

Project: Charcoal production across fire severities
CIRES Sponsor: Carol Wessman

Albert Fosmire

Project: Evolution of specialized enzymes from an inefficient generalist progenitor
CIRES Sponsor: Shelley Copley

Sean Kuusin

Project: Charcoal production across fire severities
CIRES Sponsor: Carol Wessman

Alexander Zaczek

Project: The effects of nonnative fish on zooplankton export and downstream food webs in lakes at high elevation
CIRES Sponsor: William M. Lewis Jr.

Research Experiences in Solid Earth Sciences for Students (RESESS)

RESESS at Unavco, in Boulder, Colo., is a summer research internship program aimed at increasing the diversity of students in the geosciences. RESESS was founded with support from SOARS. http://resess.unavco.org/

2012-2013 RESESS Students

Angel Bonano

University of Puerto Rico, Mayaguez
Sponsor: Anne Sheehan

Jenny Nakai

University of Colorado Boulder
CIRES Sponsor: Anne Sheehan

Gina Oliver

California State University, Long Beach
CIRES Sponsor: Will Levandowski

Research Experiences for Undergraduates (REU)

The National Science Foundation funds research opportunities for undergraduate students through its REU program. Through REU, students work in the research programs of a host institution and investigate a specific research project, working closely with faculty and other researchers. Students are granted stipends and often assistance with housing and travel. www.nsf.gov/crssprgm/reu/

2012-2013 CIRES REU Students

Chris Steenbock

Host: Noah Fierer
Project: Steenbock is examining the effects of nutrient additions on soil microbial communities.

Jennifer Harding

Host: Anne Sheehan and Daniel Feucht
Project: Studying the Rio Grande Rift and its subsurface structure through the REU-funded Incorporated Research Institutions for Seismology (IRIS) internship program.

CIRES Communications

CIRES mission goes beyond nurturing and producing world-class research; it also includes a commitment to communicate the Institute's scientific discoveries to the public and decision makers. Through accessible, accurate, and engaging written articles and multimedia products, the CIRES Communications Group helps communicate vital information necessary to ensure a sustainable future environment and protect Earth's resources.

CIRES communicators collaborate closely with NOAA, CU-Boulder, our centers, and international colleagues in academic and government institutions. In FY13 , communications efforts included press releases and media relations, social media posts, *Spheres* magazines, web features, and videos.

CIRES research and scientists are highlighted frequently in the media, receiving coverage in, for example: The New York Times, The Washington Post, BBC, Scientific American, Science, Nature News, National Geographic, CBS, National Public Radio, Science NOW, Science News, New Scientist, Time, MSNBC, and many other international, national and local media outlets.

FY13 press-release highlights

Arctic sea ice breaks lowest extent on record (August 2012)

Each year, the CIRES National Snow and Ice Data Center (NSIDC) provides Arctic Sea Ice News and Analysis to the international and national community. In August 2012, NSIDC analysis recorded that Arctic sea-ice cover melted to its lowest extent in the satellite record, breaking the previous record low in 2007.

Wildfires: The Heat is on (August 2012)

When the Fourmile Canyon fire erupted west of Boulder, Colo., in 2010, it gave CIRES scientists based at NOAA's David Skaggs Research Center the unique opportunity to sample and analyze smoke-laden air. The scientists became the first researchers to directly measure and quantify some unique heat-trapping effects of wildfire smoke particles.

Alaska's iconic Columbia Glacier expected to stop retreating in 2020 (November 2012)

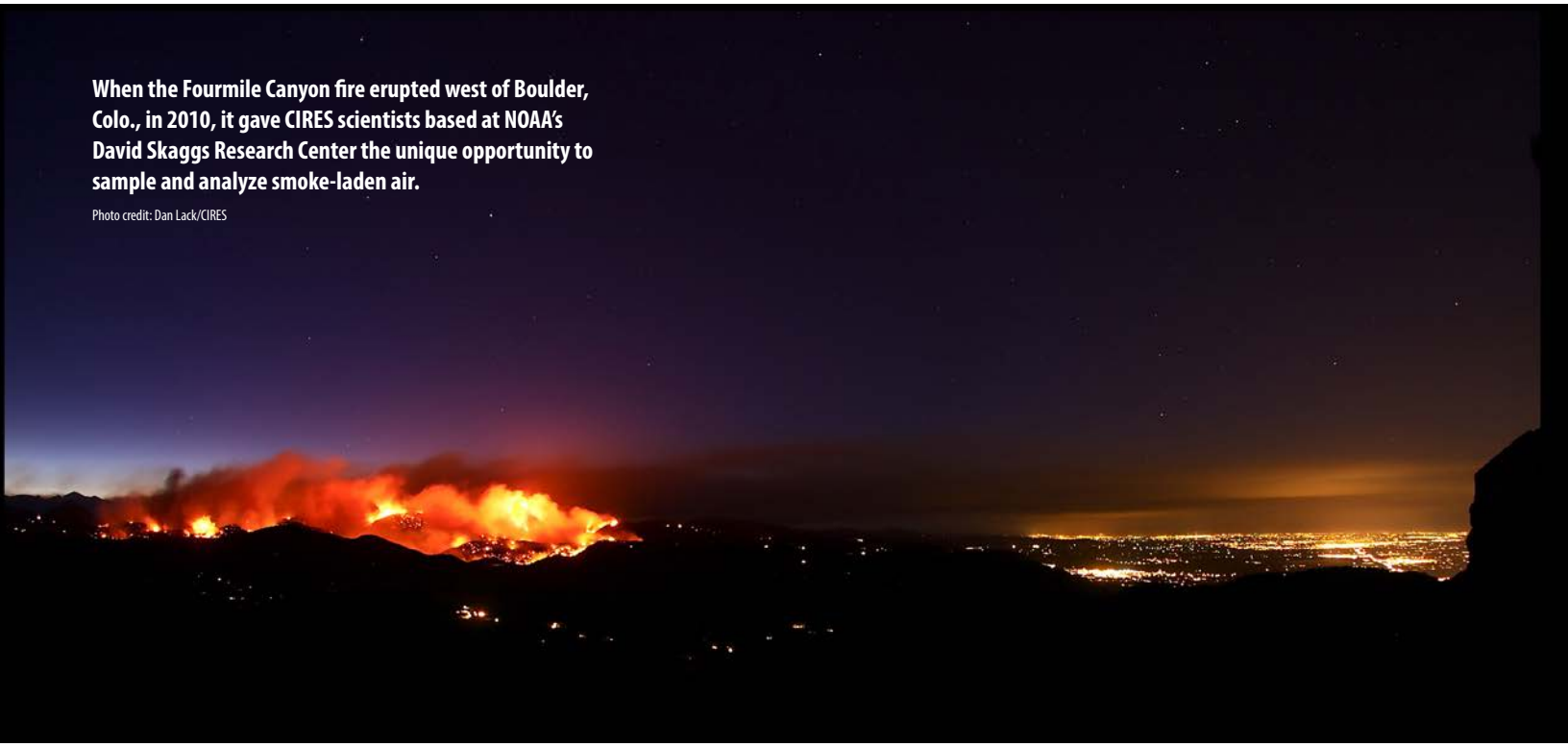
CIRES scientists project that the wild and dramatic cascade of ice into the ocean from Alaska's Columbia Glacier will cease around 2020. The imminent and irreversible finish of the glacier's retreat highlights the difficulties of trying to estimate future rates of sea-level rise as a single glacier's contribution to sea-level rise can "turn on" and "turn off" rapidly and unpredictably.

Oil and gas wells contribute fuel for ozone pollution (January 2013)

Extensive analysis of more than 550 air samples revealed that emissions from oil and natural gas operations north of Denver could be adding to ozone pollution in that region. These operations produce the "starting ingredients" for creating ozone, and average levels of certain ingredients were four to nine times higher than in Houston and Pasadena.

Black carbon is much larger cause of climate change than previously assessed (January 2013)

The first quantitative and comprehensive analysis of atmospheric black carbon, or soot, revealed that it is the second largest man-made contributor to global warming. The study also identified that black carbon's influence on climate has been greatly underestimated. Its impact on warming the



When the Fourmile Canyon fire erupted west of Boulder, Colo., in 2010, it gave CIRES scientists based at NOAA's David Skaggs Research Center the unique opportunity to sample and analyze smoke-laden air.

Photo credit: Dan Lack/CIRES

Thin, low-lying clouds over the central Greenland Ice Sheet last July were "just right" for driving surface temperatures there above the melting point and played a significant role in 2012's record-breaking summer melt.
Photo credit: CIRES

climate could be about twice the value of previous estimates.

Volcanic aerosols, not pollutants, tamped down recent Earth warming (March 2013)
Dozens of volcanoes spewing sulfur dioxide tempered Earth's warming between 2000 and 2010. The emission of sulfur dioxide initiates a mechanism that eventually leads to the reflection of the sun's rays. This finding shifted the focus away from India and China, which, through coal burning, are estimated to have increased their industrial sulfur dioxide emissions by about 60 percent in the last decade.

Origin of life: Essential step in chemistry unraveled (March 2013)
While scientists believe that water is necessary for the emergence of life on a planet, the new finding suggested that the water surface may play a more integral role, providing a site for the formation of the key building blocks for life. The research was particularly timely because of recent findings by NASA's Mars rover that habitable water once existed on the red planet.

Thin, low Arctic clouds played an important role in the massive 2012 Greenland ice melt (April 2013)
Thin, low-lying clouds over the central Greenland Ice Sheet last July were "just right" for driving surface temperatures there above the melting point and played a significant role in 2012's record-breaking summer melt. Understanding the clouds' contributions to Greenland's warming is important because ice melt there contributes to sea-level rise globally.

First independent confirmation of global land warming (April 2013)
A unique and innovative new observational technique that did not use temperature recordings from land stations confirmed that global land warming is real. By using alternative metrics to arrive at the results, the study refuted concerns that artifacts in land-based observing systems have led to an artificial global land-warming trend.

Los Angeles air pollution declining, losing its sting (June 2013)
The cleanup of California's tailpipe emissions over the last few decades has not only reduced ozone pollution in the Los Angeles area, but it has also altered the pollution chemistry in the atmosphere, making the eye-stinging "organic nitrate" component of air pollution plummet. The study revealed the mechanism behind reductions in pollutants and confirmed that California's policies to control emissions have worked as intended.

Spheres magazine

The 45th anniversary edition of *Spheres* covered the breadth and depth of the outstanding research carried out at CIRES. It featured stories from each division of CIRES, each Center, and the Western Water Assessment and Education Outreach programs. The collection of interviews with previous scientific directors, engaging and compelling storytelling and stunning images from air, land, and sea, the 45th edition showcased CIRES past and present—an institute committed to understanding Earth's environment.

Videos, photographs, and social media

CIRES Communications provides web-casting services for Institute seminars, workshops, and meetings; develops short educational and newsy videos; and provides compelling photographs that highlight our science and scientists. The Communications Group also began to develop a social media presence in this fiscal year.

http://www.facebook.com/CIRESnews
http://twitter.com/CIRESnews
http://www.youtube.com/user/ciresvideos
http://www.flickr.com/photos/cires-photos
http://vimeo.com/cires

Project Reports

Projects below are organized by CIRES theme. In the following pages, projects are listed in alphanumeric order, by NOAA organization.

AIR QUALITY IN A CHANGING CLIMATE

CLIMATE FORCING, FEEDBACKS, AND ANALYSIS

EARTH SYSTEM DYNAMICS, VARIABILITY, AND CHANGE

MANAGEMENT AND EXPLOITATION OF GEOPHYSICAL DATA

MANAGEMENT AND EXPLOITATION OF GEOPHYSICAL DATA (CONTINUED)

REGIONAL SCIENCES AND APPLICATIONS

SCIENTIFIC OUTREACH AND EDUCATION

SPACE WEATHER UNDERSTANDING AND PREDICTION

STRATOSPHERIC PROCESSES AND TRENDS

SYSTEMS AND PREDICTION MODELS DEVELOPMENT

Chemical Sciences Division

CSD-01 Intensive Regional Field Studies of Climate–Air Quality Interdependencies

CIRES LEAD: ANDY NEUMAN
NOAA LEAD: DAVID PARRISH
CIRES THEME: AIR QUALITY IN A CHANGING CLIMATE
NOAA THEME: WEATHER-READY NATION

GOALS & OBJECTIVES

This project will characterize the emissions, transport processes, chemical transformations, and loss processes that contribute to regional and local air quality issues and to climate change on regional and global scales.

ACCOMPLISHMENTS

During the past year, our group's accomplishments include publishing findings from the Research at the Nexus of Air Quality and Climate Change field study (CalNex); performing extensive atmospheric sampling during the Energy and Environment–Uintah Basin Winter Ozone Study (UBWOS); and preparing for the Southeast Nexus Experiment (SENEX).

Research vans loaded with instruments to study wintertime ozone formation in the Uintah Basin, Utah. Photo credit: Scott Sandberg

These three intensive regional field studies—CalNex, UBWOS, and SENEX—serve to characterize atmospheric chemistry and emissions that affect air quality and climate. Quantification of emissions improves the ability of models to estimate future climate and air quality. Atmospheric chemical and meteorological processes often dictate the abundance of constituents that control air quality and climate. These field studies provide the scientific understanding of emissions, atmospheric chemistry, and transport to support development of effective mitigation strategies.

The CalNex study enhanced scientific knowledge of issues that affect regional air quality and climate change, and we detailed these results in many peer-reviewed manuscripts published between September 2012 and May 2013. We determined emissions of climate-relevant greenhouse gases from agricultural sources in California (Peischl et al. 2013; Xiang et al. 2013) and anthropogenic sources in the Los Angeles Basin (Brioude et al. 2012; Newman et al. 2013). Additionally, we quantified emissions from the Los Angeles Basin that affect air quality (Borbon et al. 2013; Ryerson et al. 2013). We examined aerosol formation to better constrain radiative forcing from aerosols (LeBlanc et al. 2012; Liu et al. 2012; Zhang et al. 2012; Ensberg et al. 2013). We examined the effects of meteorology and transport upon ozone concentrations in California to better understand the contributions of local and regional emissions to ozone levels (Wagner et al. 2012; Lin et al. 2012; Angevine et al. 2012). We also assessed the consequences and promise of emission controls through studies of long-term trends in trace gas concentrations in the Los Angeles Basin (Warneke et al. 2012; Pollack et al. 2012).

Our team conducted an intensive field campaign in winter 2013 that studied the causes of high wintertime ozone in the Uintah Basin, Utah. Scientists have observed high wintertime ozone levels, which are damaging to human health, in several regions where geologic basins trap emissions associated with oil and gas extraction. The scientific community does not understand the chemistry and meteorology that cause these large ozone values, making effective and efficient mitigation strategies challenging and uncertain. To understand the factors that influence ozone abundance in this region, we used comprehensive measurements of trace gases, aerosols, and meteorological parameters to examine the emission sources, ozone-formation chemistry, unique radical sources, and air-mass transport in the Uintah Basin.

Planning and preparing for the SENEX study included experiment design and instrument development and calibration. Scientists involved with the SENEX study designed it in collaboration with the Southeast Atmosphere Study to facilitate extensive collaborations with other studies in the same region. The Southeast U.S. is a region with significant anthropogenic and biogenic emissions that result in large atmospheric abundances of many climate-forcing agents and air pollutants. But the sources and effects of some of the constituents are poorly known. For example, organic aerosols constitute approximately half the aerosol loading in this region, but researchers don't fully understand their sources and climate effects. Our team developed instruments to measure the gas-phase precursors to organic aerosols, and we installed these instruments on the NOAA WP-3D aircraft in preparation for the study in summer 2013.

Borbon, A, JB Gilman, WC Kuster, N Grand, S Chevaillier, A Colomb, C Dolgorouky, V Gros, M Lopez, R Sarda-Esteve, et al. 2013. Emission ratios of anthropogenic volatile organic compounds in northern mid-latitude megacities: observations versus emission inventories in Los Angeles and Paris. *J. Geophys. Res.* Forthcoming.

Ensberg, JJ, JS Craven, AR Metcalf, JD Allan, WM Angevine, R Bahreini, J Brioude, C Cai, H Coe, JA de Gouw, et al. 2013. Inorganic and black carbon aerosols in the Los Angeles Basin during CalNex. *J. Geophys. Res.* Forthcoming.

Newman, S, S Jeong, ML Fischer, X Xu, CL Haman, B Lefer, S Alvarez, B Rappenglueck, EA Kort, AE Andrews, et al. 2013. Diurnal tracking of anthropogenic CO_2 emissions in the Los Angeles basin megacity during spring 2010. *Atmos. Chem. Phys.* 13.

Peischl, J, TB Ryerson, J Brioude, KC Aikin, AE Andrews, E Atlas, D Blake, BC Daube, JA de Gouw, E Dlugokencky, et al. 2013. Quantifying sources of methane using light alkanes in the Los Angeles basin, California. *J. Geophys. Res Atmos.* 118.

Ryerson, TB, AE Andrews, WM Angevine, TS Bates, CA Brock, B Cairns, RC Cohen, OR Cooper, JA de Gouw, FC Fehsenfeld, et al. 2013. The 2010 California Research at the Nexus of Air Quality

and Climate Change (CalNex) field study. *J. Geophys. Res. Atmos.* 118.

Xiang, B, Miller SM, EA Kort, GW Santoni, BC Daube, R Commane, WM Angevine, TB Ryerson, MK Trainer, AE Andrews, et al. 2013. Nitrous oxide (N_2O) emissions from California based on 2010 CalNex airborne measurements. *J. Geophys. Res. Atmos.* 118:2809–2820.

CSD-02 Chemistry, Emissions, and Transport Modeling Research

CIRES LEAD: STU MCKEEN
NOAA LEAD: MICHAEL TRAINER
CIRES THEME: AIR QUALITY IN A CHANGING CLIMATE
NOAA THEME: CLIMATE ADAPTATION AND MITIGATION

GOALS & OBJECTIVES

This project will use field observations and laboratory studies to provide better representation of atmospheric chemical, physical, and dynamical processes in numerical models, which will improve predictions and projections of climate and air quality.

ACCOMPLISHMENTS

An international team led by CIRES scientist Owen Cooper recently compiled an assessment of long-term (1990–2010) rural ozone trends throughout the United States and also updated free-tropospheric ozone trends above western North America. Ozone observations in the free troposphere show that ozone has increased above western North America at a rate similar to that observed at the surface of East Asia. Ozone at rural surface sites in the United States shows contrasting trends in the western and eastern portions of the country. In the eastern United States, ozone is decreasing in spring and summer for high-ozone episodes, in good agreement with declining emissions.

In the U.S. West, ozone precursor emissions have not decreased as rapidly as in the U.S. East, but emission reductions have been sufficient to greatly reduce ozone values in heavily urbanized areas of California. In contrast, ozone at most rural sites in the West has not responded to decreasing emissions. In fact, during spring, half of the rural western sites show increasing ozone. Model simulations indicate that ozone in the West should have decreased in response to reduced precursor emissions. The lack of a response suggests that rising ozone precursor emissions in East Asia are leading to greater levels of ozone imported into the West, offsetting the potential benefits from domestic reductions of ozone-precursor emissions.

CSD-03 Scientific Assessments for Decision Makers

CIRES LEAD: CHRISTINE ENNIS
NOAA LEAD: A. R. RAVISHANKARA
CIRES THEME: CLIMATE FORCING, FEEDBACKS, AND ANALYSIS
NOAA THEME: CLIMATE ADAPTATION AND MITIGATION

GOALS & OBJECTIVES

This project addresses adaptation and mitigation.

ACCOMPLISHMENTS

During this past year, our team's work on this project laid the foundation for the next *Scientific Assessment of Ozone Depletion* (due out in 2014) for the Montreal Protocol on Substances that Deplete the Ozone Layer. Four team members are serving on the international Scientific Steering Committee for the 2014 report. The cochairs, steering committee, and assessment coordinator worked to determine the overall approach of the report and the chapter structure. They sought the advice of the international scientific community and received it in March and April 2013. Based on the advice and further deliberations, the chairs and steering committee developed the team of chapter lead authors and review editors for the report. The team planned a first meeting to take place in June 2013.

CSD-04 Effects of Emissions on Atmospheric Composition

CIRES LEAD: JOOST DE GOUW
NOAA LEAD: TOM RYERSON
CIRES THEME: CLIMATE FORCING, FEEDBACKS, AND ANALYSIS
NOAA THEME: CLIMATE ADAPTATION AND MITIGATION

GOALS & OBJECTIVES

This project will advance scientific understanding of the effects on air quality, climate, and stratospheric ozone of emissions from both anthropogenic and biogenic sources.

ACCOMPLISHMENTS

During this project period, our team characterized the emissions of hydrocarbons from oil and gas production in the Colorado Front Range. We found that these emissions constitute more than half of the hydrocarbon reactivity in the area, suggesting that they may be important for the formation of photochemical ozone.

From the 2010 CalNex (Research at the Nexus of Air Quality and Climate Change field study) data, we determined the emissions of methane and other small alkanes from the Los Angeles Basin. The analysis showed that the two largest methane sources in the city are emissions of gas from pipelines and/or geologic seeps (47 percent) and emissions from landfills (40 percent).

Gas production on the Colorado Front Range.

Photo credit: David Oonk/CIRES

Using measurements made at the Fire Sciences Laboratory in Missoula, Mont., in 2009, our team determined the emissions of trace gases and fine particles from controlled laboratory burns. The data set amounted to one of the most comprehensive measurements of biomass-burning emissions to date.

Using field measurements made in Fort Collins, Colo., in 2011, we determined emissions of volatile organic compounds (VOCs) associated with the growing of biofuel crops. We found that the VOC emissions from the growing of biofuel crops are of the same order of magnitude as those associated with the use of the biofuel that is produced as a transportation fuel. In a separate study, we found that urban emissions of ethanol have strongly increased over the last decade due to an increased use of E10 fuel, a blend of 10 percent ethanol and gasoline.

We determined emissions of hydrocarbons and nitrogen oxides in the Los Angeles Basin, and long-term trends therein, by using the CalNex data set and comparison with earlier measurements in the area. Our team found that urban emissions of hydrocarbons and nitrogen oxides have strongly decreased during the last several decades.

CSD-05 Laboratory Studies of Fundamental Chemical and Physical Processes

CIRES LEAD: RANAJIT TALUKDAR
NOAA LEAD: JIM BURKHOLDER
CIRES THEME: CLIMATE FORCING, FEEDBACKS, AND ANALYSIS
NOAA THEME: CLIMATE ADAPTATION AND MITIGATION

GOALS & OBJECTIVES

This research will produce fundamental information on photochemical processes, chemical reactions of atmospheric relevance, and chemical and physical processes that contribute to aerosol formation and growth. The information is used to improve climate and air-quality predictions and projections made by numerical models.

ACCOMPLISHMENTS

Our team elucidated lifetimes, ozone-depletion potentials (ODP), and global-warming potentials (GWP) of long-lived greenhouse gases (GHG). The contribution of long-lived GHGs—including NF_3, SF_5CF_3, CHF_3 (known as HFC-23), C_2F_6, c-C_4F_8, n-C_5F_{12}, and n-$C6F_{14}$—to the radiative forcing of Earth has increased during the past several decades. Their long atmospheric lifetimes and GWPs result primarily from stratospheric loss processes via reaction with the electronically excited oxygen $O(^1D)$ and their strong absorption in the infrared "window" region. The improved $O(^1D)$ rate coefficients that we measured will result in longer atmospheric lifetime of GHGs compared to the present evaluation (Baasandorj et al. 2012).

We also calculated atmospheric photolysis rates and global annually averaged lifetimes of NF_3 (a persistent GHG) by using our measured UV absorption cross sections, photolysis quantum yields, and $O(^1D)$ reaction with the Goddard Space Flight Center 2-D model (Papadimitriou et al. 2013). Our new data increased NF_3's calculated global lifetime from 484 years to 585 years and GWP by 6.5 percent for a new value of 19,700 on a 500-year time horizon (Papadimitriou et al. 2013).

Additionally, our team researched society's ongoing switch from halons. Perfluoroketones (PFK)—such as PFMP (perfluoro-2-methyl-3-pentatnone, $C_2F_5C(O)F(CF_3)_2$), a clean fire-extinguishing agent with a GWP of approximately 1 and a photolysis lifetime of approximately two weeks—are replacing hydrofluorocarbons (HFC) and halons. Aqueous-phase processing of PFMP produces the halocarbon HFC 227ea which is long-lived (39 years) and has a high GWP (3,580 on a 100-year time horizon). This consequently increases the effective GWP of PFMP. We determined the Henry's law solubility coefficients and hydrolysis rate coefficients of PFK and other persistent long-lived molecules of atmospheric interest by using a newly developed methodology and apparatus in our laboratory. We will use these values to understand the atmospheric impact of PFMP and other long-lived molecules.

We also made advances in our understanding of halons. We re-evaluated the ozone-depleting substances CF_2Br_2 (known as Halon-1202), CF_2ClBr (Halon-1211), and CF_2BrCF_2Br (Halon-2402) by measuring their UV absorption cross section with a highly sensitive cavity ring down technique. The new, improved values reduced the uncertainties of calculated ODP and GWP (Papanastasiou et al. 2013).

We made progress in the realm of halogen chemistry as well. Nitryl chloride is produced in the atmosphere via the heterogeneous interaction of gas-phase N_2O_5 with chloride-containing salt (in the aerosols). We studied the photochemistry of this molecule relevant to atmospheric conditions by measuring its UV absorption cross sections and quantum yields for the formation of the chloride atom and oxygen atom to evaluate its oxidative capacity (Ghosh et al. 2012).

Other topics we investigated include: heterogeneous processing

of N_2O_5 on HCl-doped H_2SO_4 under stratospheric conditions to produce $ClNO_2$ (Talukdar et al. 2012); UV photolysis of oxalyl chloride, $(COCl)_2$; determination of photodissociation of quantum yield (Ghosh et al. 2012); and degradation of volatile organic compounds (VOC). With the latter, we studied OH-initiated atmospheric degradation of isomers of butanols as a function of temperature, which included the determination of OH rate coefficients and the products of the reaction. The manuscript on the OH reaction is forthcoming in the *Journal of Physical Chemistry A*.

Finally, we initiated three new projects:

1) The medical field uses 1,2-dichlorohexafluoro-butane (1,2-c-$C_4F_6Cl_2$, or R-316c) as a nonimmobilizer amnesiac. Manufacturers have recently been considering this compound as a potential replacement in industrial applications. And the United States is considering using hydrofluoro ether mixtures, such as with methyl-perfluoroheptene-ether ($C_7F_{13}OCH_3$, or MPHE), as a potential replacement for perfluorinated alkane (PFC) and perfluorinated polyether mixtures used as heat transfer fluids. Using our measured rate coefficients for these compounds' reactions with O(1D), and OH, O_3, UV cross sections, photolysis products, and infrared cross sections, we calculated their lifetimes, ODP, and GWP.

2) We set up experiments to study the NO_3 reactions with VOCs by using cavity ring down technique to understand their nighttime processing.

3) To study heterogeneous chemistry of atmospheric interest with an electrospray ion source mass spectrometer (ESI-MS), we designed and modified the front end of a chemical ionization mass spectrometer (CIMS) to adapt an ESI and detect the ions with a quadruple mass filter.

Baasandorj, M, EL Fleming, CH Jackman, and JB Burkholder. 2013. O(^{1}D) kinetic study of key ozone depleting substances and greenhouse gases. *J. Phys. Chem. A.* 117(12):2434-2445.

Papadimitriou, VC, MR McGillen, EL Fleming, CH Jackman, and JB Burkholder. 2013. NF^3: UV absorption spectrum temperature dependence and the atmospheric and climate forcing implications. *Geophys. Res. Lett.* 40(2):440-445.

Papanastasiou, DK, NR Carlon, JA Neuman, EL Fleming, CH Jackman, and JB Burkholder. 2013. Revised UV absorption spectra, ozone depletion potentials, and global warming potentials for the ozone-depleting substances CF_2Br_2, CF_2C_1Br, and CF_2BrCF_2Br. *Geophys. Res. Lett.* 40(2):464-469.

CSD-06 Aerosol Formation, Composition, Properties, and Interactions With Clouds

CIRES LEAD: DAN LACK
NOAA LEAD: DAN MURPHY
CIRES THEME: CLIMATE FORCING, FEEDBACKS, AND ANALYSIS
NOAA THEME: CLIMATE ADAPTATION AND MITIGATION

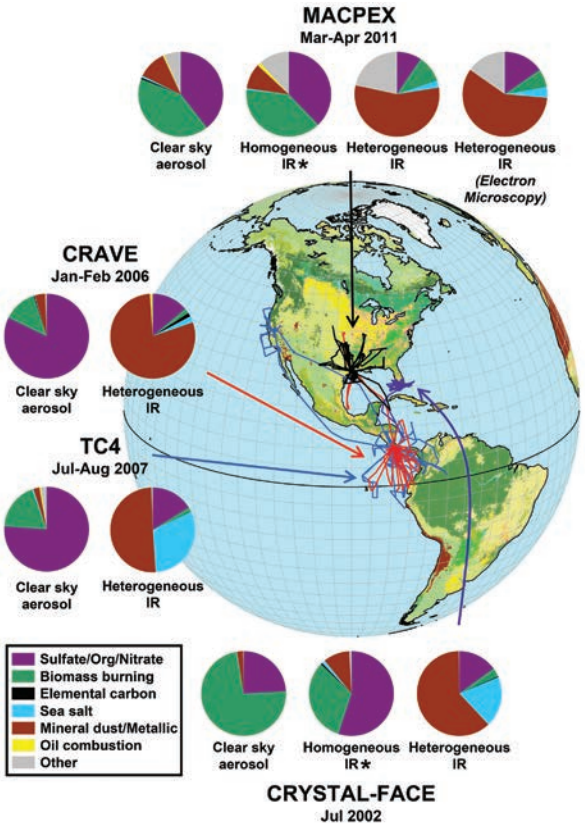
GOALS & OBJECTIVES

This project will investigate the origins, transformations, and fate of aerosols in the atmosphere, including both direct and indirect (interactions with clouds) radiative effects.

ACCOMPLISHMENTS

During the reporting period, our team made advancements in the following areas.

Shipping emissions: In collaboration with Norwegian researchers, we published modeling studies on the impact of current and future



The composition of cirrus ice residuals (captured cloud particles with water removed) compared to nearby clear-sky aerosol particles measured during 36 cloud encounters over four aircraft sampling campaigns. The large majority of encounters show enhancement of mineral dust/metallic particles in cirrus. The ice-formation mechanism, either heterogeneous nucleation or homogeneous freezing, is inferred from the composition measurements (Cziczo et al., *Science* 2013).

shipping emissions on the rapidly changing Arctic environment. This work, in addition to prior studies from our group, provided to the International Maritime Organization's (IMO) policy discussions scientific expertise on the impacts of ship black carbon in the Arctic and global environment.

Forest fires: We also continued to publish work on the chemical and optical relationships of particles emitted from forest fires. The emitted particles can have significant effect on climate, and our measurements have provided initial insights to the contributions of black carbon and brown oils to the climate impacts of forest-fire smoke.

Development of secondary organic aerosol (SOA) models: In collaboration with colleagues from CU-Boulder and by using laboratory-derived reaction parameters, we showed that chemical processes in the aqueous phase can explain a large fraction of SOA formation in Mexico City.

Development of ice microphysics models: Cloud models poorly represent ice nucleation due to unknown key parameters and the complexity of ice nuclei. Analysis of different descriptions of heterogeneous freezing has revealed that researchers need more accurate descriptions since simplification can lead to great biases in predicted ice-particle concentrations.

Cirrus cloud ice nuclei: In collaboration with colleagues from the Massachusetts Institute of Technology and other universities, we have shown through measurements of upper tropospheric ice nuclei that mineral dust and industrial metallic particles exert a disproportionally large influence on cirrus cloud formation in a variety of geographic regions. These observations will help simplify theoretical treatments of global cirrus formation and also suggest a new route whereby human activities may modify the upper tropospheric radiation balance.

Aerosol nucleation and Earth's radiative forcing: We have published a climate model study of aerosol nucleation in the atmosphere. For this purpose, we developed a representation of aerosol nucleation for use in climate models. The results of this study quantify the effect of aerosol nucleation on Earth's radiative forcing and show that aerosol nucleation has a far greater effect on clouds and radiative forcing over oceans than over continents.

Effects of solar activity on climate: We published a climate model study of the effect of the decadal solar cycle on Earth's cloud cover and on Earth's radiative forcing. The effect arises from charged nucleation of aerosol in the atmosphere, which is initiated by the ionization of air molecules by galactic cosmic rays. The Sun's magnetic field modulates the flux of galactic cosmic rays in the course of its decadal activity cycle, and a resulting signal could propagate to cloud properties via the various effects of aerosol particles on clouds. The results show that the decadal solar cycle has a small effect on Earth's cloud cover and radiative forcing. This outcome challenges the arguments of anthropogenic-climate-change critics who invoke a large influence of solar variability as an explanation for the 20th-century warming of the planet.

Aerosol nucleation in open cells: We have published a large-eddy-simulation study that explains the mechanisms leading to aerosol nucleation in marine boundary layer open cells.

CSD-07 Atmospheric Measurements and Impacts of Aerosols, Black Carbon, and Water Vapor

CIRES LEAD: JOSHUA SCHWARZ
NOAA LEAD: DAVID FAHEY
CIRES THEME: CLIMATE FORCING, FEEDBACKS, AND ANALYSIS
NOAA THEME: CLIMATE ADAPTATION AND MITIGATION

GOALS & OBJECTIVES

This project will provide improved measurement capability and data for atmospheric aerosols (including black carbon) and water vapor. Analyses and modeling results will lead to more accurate representation of these critical species in numerical models, which will advance the scientific understanding of their climate impacts.

ACCOMPLISHMENTS

During the past nine months, work on this project has resulted in expanded capabilities to measure aerosols and water vapor in the atmosphere, as well as continued analysis of recently obtained data sets. In March, our team acquired a Wide-Incidence Bioaerosol Sensor (WIBS4) from Droplet Measurement Technology Inc. in Boulder, Colo., and we are evaluating it in the laboratory in preparation for measurements at the Boulder Atmospheric Observatory (BAO). The BAO work stems from a funded CIRES Innovative Research Program proposal that links the WIBS4 measurement with flow-cytometry measurements made by CIRES Fellow Noah Fierer's research group of airborne bacteria.

Work continued on analysis of the Deep Convective Clouds and Chemistry (DC3) data set obtained in summer 2012 with our new humidified-dual single particle soot photometer (HD-SP2). We finalized the data and are preparing a manuscript describing the black carbon aerosol measurements made during DC3. Also in conjunction with this data, the group hosted a collaborator, Sho Ohata, from the University of Tokyo, in preparation for the upcoming Studies of Emissions and Atmospheric Composition, Clouds and Climate Coupling by Regional Surveys (SEAC4RS) mission in summer 2014. He stayed for one month and contributed to improving the quality assessment of the HD-SP2 measurements by improving the design of the humidification system and improving our analysis of the data. We also presented black carbon data from the 2011 Mid-latitude Airborne Cirrus Properties Experiment (MACPEX) campaign in a manuscript describing a technical improvement to the sampling system; this technical improvement allows measurement of interstitial aerosols in cirrus clouds. We submitted the manuscript to *Aerosol Science and Technology*, and it is currently in revision.

We deployed the NOAA unmanned aircraft system (UAS) ozone instrument on the NASA Global Hawk UAS during the second

stage of the Airborne Tropical Tropopause Experiment (ATTREX) in January–March 2013. We measured ozone values in the Pacific tropical tropopause layer (TTL) to provide an indication of the tropospheric or stratospheric nature of the air being sampled.

Our efforts on measurement of water vapor and condensed-phase water in the upper troposphere and lower stratosphere (UT/LS) during the last nine months involved completing construction of a new two-channel, tunable, diode-laser-based instrument and integration and deployment of the instrument on the NASA Global Hawk unmanned aircraft for the second stage of the ATTREX campaign. The instrument performed well during its initial deployment and yielded measurements of both low TTL water-vapor mixing ratios and the ice-water content of high-altitude tropical cirrus clouds. This information is important for understanding the mechanisms leading to dehydration of air transported into the stratosphere.

In April 2013, the water instrument participated in the AquaVIT2 (Aqua Validation and Instrument Tests) water-vapor measurement intercomparison campaign at the AIDA (Aerosol Interaction and Dynamics in the Atmosphere) chamber of the Karlsruhe Institute of Technology in Germany. This intercomparison seeks to address outstanding questions about the ability to make accurate measurements in the driest regions of the UT/LS.

A manuscript describing the measurement of water vapor in the UT/LS through the use of chemical ionization mass spectrometry during the MACPEX campaign is forthcoming. We are also preparing a manuscript analyzing the agreement and potential sources of disagreement between a number of UT/LS hygrometers operating in the MACPEX campaign.

CSD-08 Remote-Sensing Studies of the Atmosphere and Oceans

CIRES LEAD: CHRISTOPH SENFF
NOAA LEAD: ALAN BREWER
CIRES THEME: CLIMATE FORCING, FEEDBACKS, AND ANALYSIS
NOAA THEME: WEATHER-READY NATION

GOALS & OBJECTIVES

This project will investigate atmospheric dynamics, including transport of atmospheric constituents over complex terrain, in coastal and open ocean regions, and from high altitudes to the surface. These studies have particular relevance to air quality, climate, ocean ecosystems, and renewable energy.

ACCOMPLISHMENTS

During the past year, work under this project included studies to investigate the distribution and transport of ozone, quantify greenhouse gas emissions, characterize the wind field at potential offshore-wind-farm sites, and investigate ocean properties.

Our team used lidar backscatter data from the Spaceborne Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations satellite (CALIPSO) to develop a method for identification of plankton layers just beneath the ocean surface. Changes in biological activity near the ocean surface may be coupled to changes in atmospheric aerosol concentrations and, thus, impact climate. Other ocean-ecosystem-related work included a laboratory study to determine if aircraft-based lidar can measure certain ocean properties by using laser light scattered by underwater air bubbles. To characterize the wind field over the ocean at wind-turbine-rotor heights, we used data collected with the High Resolution Doppler Lidar (HRDL) over the Gulf of Maine during the 2004 New England Air Quality Study. This data set will provide crucial information for siting and design of future offshore wind farms.

This spring, our team used the HRDL to quantify greenhouse gas emissions associated with oil and gas exploration. HRDL provided wind profiles throughout the boundary layer as well as a record of boundary-layer height. These data, combined with airborne in situ measurements of greenhouse gas concentrations, allowed the retrieval of greenhouse gas fluxes downwind of a large oil and gas field. We deployed the TOPAZ (Tunable Optical Profiler for Aerosol and oZone) ozone and aerosol lidar at two different field campaigns: the Uintah Basin Winter Ozone Study (UBWOS) and the Las Vegas Ozone Study (LVOS). At UBWOS, the TOPAZ lidar provided unique information about the vertical distribution of ozone, including the height of the polluted layer, during high-ozone events. During the LVOS study, which concludes at the end of June 2013, we are using TOPAZ to assess the influence of stratosphere-to-troposphere transport—as well as transport of ozone from southern California and Asia—on surface ozone concentrations in the Las Vegas area.

CSD-09 Stratospheric Radiative and Chemical Processes That Affect Climate

CIRES LEAD: SEAN DAVIS
NOAA LEAD: KAREN ROSENLOF
CIRES THEME: STRATOSPHERIC PROCESSES AND TRENDS
NOAA THEME: CLIMATE ADAPTATION AND MITIGATION

GOALS & OBJECTIVES

This project seeks to understand the processes in the stratosphere and upper troposphere that affect the radiative balance, transport (horizontal and vertical), and chemistry, especially the in stratospheric ozone layer, in that region of the atmosphere.

ACCOMPLISHMENTS

During the past year, this project advanced understanding of past changes in stratospheric composition and their radiative impacts, as well as understanding of processes that govern variability in stratospheric composition.

Radiative forcing is an important metric for quantifying surface climate impacts because it allows for the direct comparison of im-

pacts due to different climate-forcing agents. Estimates of radiative forcing due to ozone depletion during the past 30 years stem from databases of ozone-concentration measurements. Through a new and improved historical record of ozone concentrations, our study identified stronger ozone depletion. In the study, we calculate a stronger radiative forcing due to past stratospheric ozone depletion than previous studies (Hassler et al. 2012). This study pointed to an increased role for ozone depletion in recent climate change.

Our team also performed preliminary work for understanding the sensitivity of the climate response to stratospheric ozone depletion. We used the aforementioned ozone-concentration database as input for climate model experiments with the National Center for Atmospheric Research Community Earth System Model. Analysis is ongoing, but the initial results indicate that the use of the new database enhances the model-predicted climate change. This initial analysis suggests that previous studies that used climate models forced with ozone data sets containing too little ozone depletion have underestimated climate change due to stratospheric ozone depletion.

In addition to our work improving understanding of past stratospheric composition and radiative changes, several studies increased understanding of processes that govern variability in stratospheric composition. Previous studies have shown that the concentration of stratospheric aerosols has increased during the past decade and that this increase caused a significant radiative forcing and contributed to a slowdown in surface climate warming. The cause of these changes is important for future climate projections, but researchers did not know whether the aerosol changes were due to increased sulfate emissions from Asia or natural variability. Using a state-of-the-art climate model coupled to an aerosol microphysical model, we showed definitively that the increases in aerosols were due to moderate volcanic eruptions, not Asian emissions (Neely et al. 2013).

Several recent studies have also highlighted the radiative importance of changes in stratospheric humidity, which is largely determined by coupled radiative, microphysical, and dynamical processes operating in the 14- to 19-km region of the tropical atmosphere, called the Tropical Tropopause Layer (TTL). We showed the importance of cirrus clouds for accurately simulating TTL temperatures, which largely determine stratospheric humidity (Evan et al. 2013). Another study showed that TTL cirrus cloud occurrence is modulated both "from above" by stratospheric dynamical variability and "from below" due to the El Niño Southern Oscillation (Davis et al. forthcoming). Together, these studies highlight the need for improved model representation of coupled TTL processes in order to predict future changes in stratospheric humidity.

Davis, SM, CK Liang, and KH Rosenlof. Interannual variability of tropical tropopause layer clouds. *Geophys. Res. Lett.* Forthcoming.

Evan, S, KH Rosenlof, J Dudhia, B Hassler, and SM Davis. 2013. The representation of the TTL in a tropical channel version of the WRF model. *J. Geophys. Res. Atmos.* 118:2835–2848.

Neely, RR III, OB Toon, S Solomon, JP Vernier, C Alvarez, and JM English, et al. 2013. Recent anthropogenic increases in SO_2 from Asia have minimal impact on stratospheric aerosol. *Geophys Res Lett.* 40.

Global Interoperability Program

GIP-01 Environmental Software Infrastructure and Interoperability Program

CIRES LEAD: CECELIA DELUCA
NOAA LEAD: ADAM DUNBAR
CIRES THEME: SYSTEMS AND PREDICTION MODELS DEVELOPMENT
NOAA THEME: SCIENCE AND TECHNOLOGY ENTERPRISE

GOALS & OBJECTIVES

This project provides infrastructure software in support of NOAA modeling and data services.

ACCOMPLISHMENTS

During the past year, our team delivered releases of the Earth System Modeling Framework (ESMF), with improvements including 3-D first-order conservative weight generation and nearest-neighbor grid remapping. The National Weather Service, the Navy, the National Center for Atmospheric Research (NCAR), NASA, and other institutions continue to use ESMF as infrastructure in their research and operational climate and weather codes.

We delivered releases of ESMP (the Python interface) to ESMF grid remapping functions. End users widely employed this software and incorporated it into multiple analysis and visualization packages including Ferret, NCL (NCAR Command Language), and UV-CDAT (Ultrascale Visualization Climate Data Analysis Tools).

In collaboration with U.S. operational weather and water prediction centers and their research partners, we prepared a set of conventions and templates, called the NUOPC (National Unified Operational Prediction Capability) Layer, for use with ESMF and for release next year.

We received a new award from NASA to develop an Integrated Development Environment, called Cupid, for ESMF/NUOPC, in collaboration with NASA teams and the Georgia Institute of Technology.

Our team developed and used the Earth System CoG (Community Governance) collaboration environment to support the Dynamical Core Model Intercomparison Project (DCMIP), a two-week summer colloquium focused on comparison of atmospheric dynamical cores. About 150 people used the Web-based environment for collaborative analysis.

We developed and integrated into CoG a metadata collection system to support the DCMIP workshop. We also integrated into CoG for DCMIP a metadata display tool developed by the international Earth System Documentation (ES-DOC) project, which the CIRES team co-leads.

We prepared the OpenClimateGIS software—a tool for subsetting, reformatting, and performing calculations on climate data—for use during a downscaling intercomparison project that will take place summer 2013.

Global Monitoring Division

GMD-01 Collect, Archive, and Analyze Global Surface Radiation Network Data

CIRES LEAD: GARY HODGES
NOAA LEAD: JOSEPH MICHALSKY
CIRES THEME: SYSTEMS AND PREDICTION MODELS DEVELOPMENT
NOAA THEME: CLIMATE ADAPTATION AND MITIGATION

GOALS & OBJECTIVES

Initial project goals include developing a mobile SURFRAD station to complement the network of seven fixed sites.

ACCOMPLISHMENTS

A paper that came out of the described research was published January 30, 2013, in the *Journal of Geophysical Research–Atmospheres*. This paper presents an initial look at four years of spectral measurements used to calculate albedo for the Colorado prairie just east of the Rocky Mountain range foothills. In the paper, project researchers discuss some issues associated with calculating broadband albedo from thermopile sensors, demonstrating that uncorrected instrument issues have led to incorrect conclusions. Normalized Difference Vegetative Index is defined for the spectral instruments in this study and used to demonstrate the dramatic changes that can be monitored with this very sensitive product. We present examples of albedo wavelength and solar-zenith angle dependence for different stages of vegetative growth and senescence. The spectral albedo of fresh snow and its spectral and solar-zenith angle dependence are discussed and contrasted with other studies of these dependencies. We conclude that fresh snow is consistent with a Lambertian reflector over the solar incidence angles measured; this is contrary to most snow albedo results. Even a slope of a degree or two in the viewed surface can explain the asymmetry in the morning and afternoon albedos for snow and vegetation. We describe plans for extending these spectral measurements for albedo to longer wavelengths and to additional sites.

Michalsky, JJ, and GB Hodges. 2013. Field measured spectral albedo–four years of data from the Western U.S. prairie. *J. Geophys. Res. Atmos.*118:813–825.

GMD-02 Analysis of the Causes of Ozone Depletion

CIRES LEAD: IRINA PETROPAVLOVSKIKH
NOAA LEAD: RUSS SCHNELL
CIRES THEME: STRATOSPHERIC PROCESSES AND TRENDS
NOAA THEME: CLIMATE ADAPTATION AND MITIGATION

GOALS & OBJECTIVES

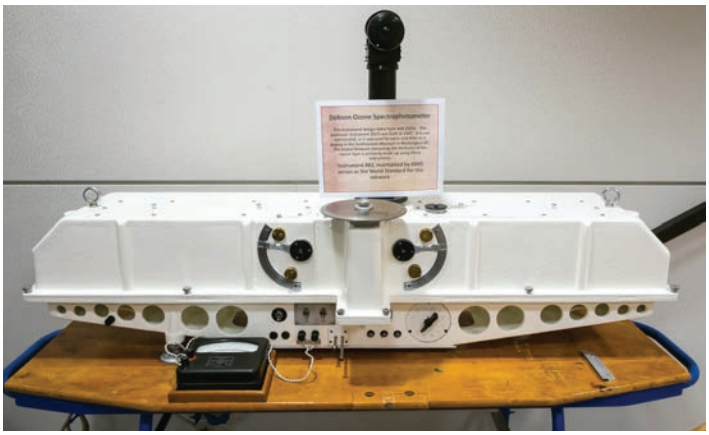
This project addresses long-term changes in the chemistry and dynamics of the stratosphere that affect ozone depletion, and supports national and international adaptation and mitigation policies that are necessary to stabilize ozone in the stratosphere.

ACCOMPLISHMENTS

Since the 1960s, researchers have used Dobson ozone spectrophotometers to measure atmospheric total ozone variability across the continental United States. Almost 50 years of Dobson total ozone column climatology show a distinct seasonal cycle that varies among individual stations. Although all stations commonly detect the long-term ozone changes, the interannual variability is of interest for understanding how local dynamics and transport affect the long-term time series. The long-term changes in patterns of the transport (quasi-biannual oscillations, QBO, at 30 hPa and 50 hPa) can be related to climate changes over the United States. Therefore, continuous monitoring of column ozone is very important for assessment of climate changes on global, regional, and local environment.

In addition to standard evaluation techniques of ozone variability, we used the STL method (a seasonal-trend decomposition procedure based on Locally Weighted Scatterplot Smoothing (LOESS) to address temporal variability and trends in the Dobson data. Furthermore, we apply a statistical modeling approach to the ozone data set to attribute ozone variability to individual driving forces associated with natural causes (e.g., solar cycle) and anthropogenic causes (e.g., effective equivalent stratospheric chlorine, or EESC). All five Dobson records show a clear seasonal cycle with maxima in spring and minima in late fall/early winter (in accordance with the Brewer-Dobson circulation transporting ozone-rich air toward northern mid-latitudes during boreal winter).

In addition, the LOESS-smoothed trend component shows the decline of ozone during recent decades. In particular, the effects of the two major volcanic eruptions of El Chichón (1982) and Mt. Pinatubo (1991) are strongly visible in the trend component. However, next to the volcanic eruptions, we can also derive "fingerprints" of dynamical features, such as the North Atlantic Oscillation and El Niño Southern Oscillation, from the decomposition. The residual component shows a high degree of short- to medium-term variability, which we can attribute to synoptic-scale meteorological variability and climate variability. We also apply statistical extreme-value models for extreme low ozone (ELO) and extreme high ozone (EHO) events and autoregressive moving average models for mean values at mid-latitudes. We find that the trends derived from Dobson time series decrease by half when we remove the ELO and EHO events from analysis.



Dobson ozone spectrophotometer. Photo credit: NOAA

The world-standard Dobson resides in the NOAA Earth System Research Laboratory's Global Monitoring Division (GMD), and scientists use it to calibrate local network and regional standards for traceability of the World Meteorological Organization (WMO) ozone network. The maintenance and calibration of this instrument occurs at the Mauna Lao Observatory station in Hawaii. The Langley plots measurements and analysis occur on a two-year schedule. Between calibrations against the world standard, all station instruments rely on the lamp tests. Our team wrote the software to track the parameters of the standard lamps and schedules for station verification tests. It is important to keep the record free of instrumental interferences. GMD personnel process annual total ozone data from 15 Dobson stations at the end of each calendar year and archive it locally at NOAA and at the World Ozone and Ultraviolet Radiation Data Centre (WOUDC) in Canada.

In 2012, we converted all historical U.S. total ozone data (five stations) to a new processing system, and we verified the conversion against the original archives. We therefore detected and fixed some instrument-related issues, and we are in the process of submitting data to the WOUDC. We also updated the NOAA website for Dobson ozone, and all records are now accessible from http://www.esrl.noaa.gov/gmd/ozwv/dobson/.

Every four years, we exchange the Dobson instrument at the South Pole station with the new instrument. We run a series of intercomparisons at the South Pole station during the exchange to ensure that no instrumental artifacts are in the long-time series. Last polar spring (2012) was unusually warm, so the record low ozone measured at South Pole station was higher than in previous years. The vortex broke and shifted off the South Pole sooner in 2012 than is typical. Thus, the recovery of the spring depletion was faster than in previous years. South Pole personnel will continue to monitor ozone depletion in Antarctica.

We also worked to address the effect of ozone cross sections on ozone profile and column retrievals from the NOAA Dobson and Brewer network. A new data set recently developed by the University of Bremen became available for conducting tests on how ozone retrievals are sensitive to atmospheric-temperature variability. The data set plays an important role in reconciling historical differences among ozone products derived from various ozone-measuring systems, including satellites. The problem becomes more pronounced over the tropics (low temperatures in the vicinity of the tropopause) and at high latitudes (where low sun and large ozone amounts make comparisons very difficult). The WMO advisory group has to decide whether to recommend changes to currently used ozone cross sections.

Our team reprocessed the ozonesonde records at several long-term NOAA stations to correct the instrumental artifacts (change of the sonde types in time series and the pump pressure corrections). We developed new corrections in 2012–2013 by launching several types of ozonesonde instruments attached to the same balloon. The processing occurs in accordance with the WMO directives to homogenize time series of ozonesonde data for trend analysis in the upcoming 2014 WMO Ozone Assessment. Data are available at http://www.esrl.noaa.gov/gmd/ozwv/ozsondes/index.html.

Finally, NOAA and CIRES personnel closely monitored long-term changes in upper troposphere/lower stratosphere water vapor through monthly flights of the balloon-born NOAA frost point hygrometer at three sites: Boulder, Colo.; Hilo, Hawaii; and Lauder, New Zealand. The 33-year Boulder record shows a net increase in stratospheric water vapor of 1 ppmv (27 percent) with implications for both ozone recovery and climate forcing. These high-resolution vertical profiles also provide critical calibration and validation data for satellite-based water vapor sensors. See more information about data at http://www.esrl.noaa.gov/gmd/ozwv/wvap/.

GMD-03 Monitor and Understand the Influences of Aerosol Properties on Climate

CIRES LEAD: ANNE JEFFERSON
NOAA LEAD: JOHN OGREN
CIRES THEME: CLIMATE FORCING, FEEDBACKS, AND ANALYSIS
NOAA THEME: CLIMATE ADAPTATION AND MITIGATION

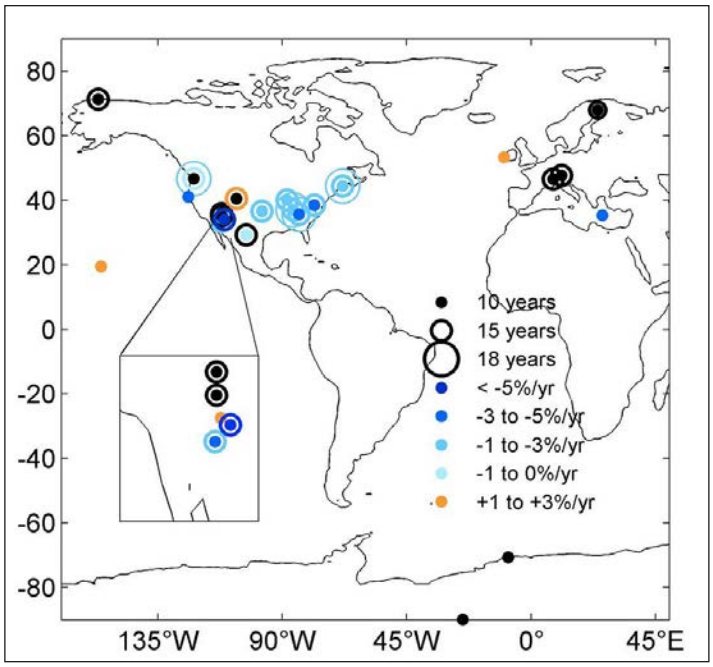
GOALS & OBJECTIVES

This project makes use of aerosol measurements from long-term monitoring sites and shorter-term deployments to analyze trends in aerosol properties, transport, and aerosol radiative forcing.

ACCOMPLISHMENTS

Our team deployed the Aerosol Observing System (AOS) to the Cape Cod National Seashore as part of the Department of Energy's Two-Column Aerosol Project to study aerosol- and cloud-formation behavior and test a regional-scale model. The region's seasonal variation of air masses—including polluted air during the summer and clean, marine air during the winter—offers the opportunity to study and test closure among measurements and model algorithms of varying aerosol and cloud type. During the deployment, the site was in the path of Superstorm Sandy, which necessitated instrument and site infrastructure repairs. Downtime was minimal, and surface instruments were ready for an intensive operation period in January and February 2012, with aircraft measurements over the site.

We devoted a great deal of work to analyzing long-term and seasonal



Trends analysis results for the aerosol light scattering coefficient. Black symbols correspond to stations with no significant trends. Blue and orange symbols correspond to statistically significant negative and positive trends, respectively, the magnitude of the trends (slope) being given by the colors (see legend). Circle sizes are proportional to the length of the data sets; the trends for the whole period, the 10 year (dots), and, if possible, 15 year were calculated. The largest circles denote the trend of the longest analyzed period.

trends across the NOAA and global network of aerosol-monitoring sites. This resulted in five publications, one paper submitted, and another in preparation. The two papers published in *Atmospheric Chemistry and Physics* examine decadal trends in aerosol optical properties and particle concentrations across Europe and North America. The submitted paper looks at seasonal trends in the aerosol properties at a Himalayan site in India. We are working with one of our Appalachian State University colleagues to examine long-term and seasonal trends in aerosol optical properties and radiative forcing at four sites in the United States.

Laboratory and modeling work is in progress to develop and test a radiative transfer model for two common absorption photometers used to measure aerosol absorption at visible wavelengths. Researchers often use these instruments to estimate atmospheric concentrations of black carbon, which is predicted to be the second-largest forcing agent after CO_2. So accurate calibrations and measurements of these instruments are essential to predicting climate change from absorbing aerosol.

GMD-04 Studies of Greenhouse Gas Trends and Distributions

CIRES LEAD: JOHN B. MILLER
NOAA LEAD: PIETER P. TANS
CIRES THEME: CLIMATE FORCING, FEEDBACKS, AND ANALYSIS
NOAA THEME: CLIMATE ADAPTATION AND MITIGATION

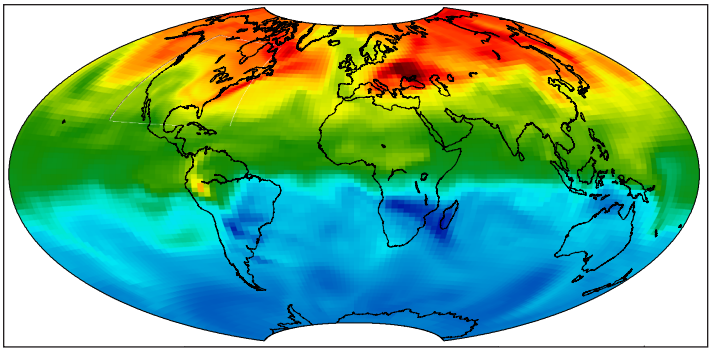
GOALS & OBJECTIVES

This project focuses on the global distribution of the anthropogenically influenced greenhouse gases: both the major ones (CO_2, CH_4, and N_2O) and the large suite of minor ones (CFCs, HFCs, and HCFCs). In addition to providing an accurate and well-documented record of their distributions and trends, the project aims to use these distributions to determine the time-space distributions of sources and sinks of these gases.

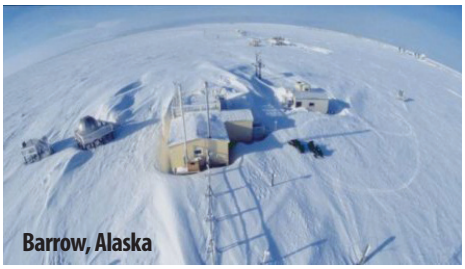
ACCOMPLISHMENTS

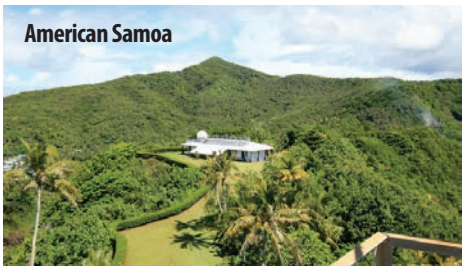
As summarized in NOAA's Annual Greenhouse Gas Index, our team determined changes in global abundances for all major long-lived greenhouse gases for 2012 and calculated their influence on radiative forcing. We will soon post this information to http://www.esrl.noaa.gov/gmd/aggi/.

Additionally, we are currently calculating CarbonTracker CO_2 and CH_4 updates. We will post them for public review in summer 2013. We also recently published GlobalView 2012 data products in a new format called "ObsPack." It is available for public download.



CarbonTracker, shown here in March 2010, depicts the seasonal ups, downs and swirls of carbon dioxide, an important greenhouse gas. Red indicates areas where atmospheric carbon dioxide levels are relatively high; blues indicate relative lows. CIRES researchers support NOAA's CarbonTracker program. Image credit: NOAA





NOAA's baseline atmospheric observatories, where researchers and instruments collect long-term monitoring data on many atmospheric gases and particles, including greenhouse gases and ozone-depleting substances. CIRES researchers support NOAA's long-term global monitoring programs. Photo credits: NOAA

GMD-05 Provide Data and Information Necessary to Understand Behavior of Ozone-Depleting Substances

CIRES LEAD: FRED MOORE
NOAA LEAD: JAMES W. ELKINS
CIRES THEME: STRATOSPHERIC PROCESSES AND TRENDS
NOAA THEME: CLIMATE ADAPTATION AND MITIGATION

GOALS & OBJECTIVES

This project provides both long-term global surface data sets and correlated vertical data sets that are used to quantify emissions, chemistry, and transport of ozone-depleting gases. This information is used to monitor national and international emission policies, and is combined with models to improve our understanding of ozone, climate, and the feedback mechanisms that connect and drive both.

ACCOMPLISHMENTS

The contributions of our group center around two surface networks: a weekly flask program and an hourly in situ program. Long-term surface trend data from these programs feed into the calculations of NOAA's Annual Greenhouse Gas Index (AGGI) and the Ozone-Depleting Gas Index (ODGI). This year, we made improvements in the ODGI to more accurately reflect the stratospheric distribution of ozone-depleting halocarbons and their partitioning into reactive halogens.

Regular low-altitude airborne flask measurements and periodic higher-altitude, mission-oriented data sets complement this surface data set. The three active high-altitude data sets come from the recent High-performance Instrumented Airborne Platform for Environmental Research (HIAPER) Pole-to-Pole Observations (HIPPO) mission, which is funded by the National Science Foundation; the recent NASA-funded Global Hawk Pacific (GloPac) mission; and the continuing NASA Airborne Tropical Tropopause Experiment (ATTREX) mission.

These airborne programs help define the process that connects the surface network measurements to the atmosphere as a whole. By itself each data set addresses specific aspects of atmospheric chemistry, etc. But because these data sets conform to a common in-house standards program, they represent a much more powerful tool when combined and are especially well-suited to 3-D models analysis. Many global and process-oriented studies used this combined data set during the past year. We list some of these studies (many not yet final) below; they investigate trace-gas lifetime and loss estimates; trace-gas source and emissions estimates; and satellite-validation measurements.

Kellmann, S, T von Clarmann, GP Stiller, E Eckert, N Glatthor, M Höpfner, M Kiefer, J Orphal, B Funke, U Grabowski, A Linden, GS Dutton, and JW Elkins. 2012. Global CFC-11 ($CFCl_3$) and CFC-12 (CF_2Cl_2) measurements with the Michelson Interferometer for Passive Atmospheric Sounding (MIPAS): retrieval, climatologies and trends. *Atmos. Chem. Phys. Discuss.* 12:18325-18377.

Rigby, M, RG Prinn, S O'Doherty, SA Montzka, A McCulloch, CM Harth, J Mühle, PK Salameh, RF Weiss, D Young, PG Simmonds, BD Hall, GS Dutton, D Nance, DJ Mondeel, JW Elkins, PB Krummel, LP Steele, and PJ Fraser. 2012. Re-evaluation of the lifetimes of the major CFCs and CH_3CCl_3 using atmospheric trends. *Atmos. Chem. Phys. Discuss.* 12:24469-24499.

Saikawa, E, M Rigby, RG Prinn, SA Montzka, BR Miller, LJM Kuijpers, PJB Fraser, MK Vollmer, T Saito, Y Yokouchi, CM Harth, J Mühle, RF Weiss, PK Salameh, J Kim, S Li, S Park, K-R Kim,

D Young, S O'Doherty, PG Simmonds, A McCulloch, PB Krummel, LP Steele, C Lunder, O Hermansen, M Maione, J Arduini, B Yao, LX Zhou, HJ Wang, JW Elkins, and B Hall. 2012. Global and regional emission estimates for HCFC-22. *Atmos. Chem. Phys.* 12:10033-10050.

Thompson, RL, F Chevallier, AM Crotwell, G Dutton, RL Langenfelds, RG Prinn, RF Weiss, Y Tohjima, T Nakazawa, PB Krummel, LP Steele, P Fraser, K Ishijima, and S Aoki. 2013. Nitrous oxide emissions 1999–2009 from a global atmospheric inversion. *Atmos. Chem. Phys. Discuss.* 13:15697-15747.

Yver, C, H Graven, DD Lucas, P Cameron-Smith, J Muhle, JE Shields, PK Salameh, CM Harth, SA Montzka, ML Fisher, R Weiss, and R Keeling. 2013. Observation-based estimates of HFC-134a emissions from California. *J. Geophys. Res. Atmos.* Submitted.

Global Systems Division

GSD-01 Improve Weather Information Systems

CIRES LEAD: LEON BENJAMIN
NOAA LEAD: GREGORY PRATT
CIRES THEME: SYSTEMS AND PREDICTION MODELS DEVELOPMENT
NOAA THEME: ENGAGEMENT ENTERPRISE

GOALS & OBJECTIVES

This project maintains and improves the advanced weather forecasting system and assures its accessibility for broad national use.

ACCOMPLISHMENTS

During this reporting period, our team worked toward achieving final operating capability (FOC) of the Meteorological Assimilation Data Ingest System (MADIS) at the National Weather Service (NWS). MADIS is a conduit for providing non-NWS meteorological data and quality-control algorithms to NWS operations and for use by the greater meteorological community.

MADIS FOC at NWS should occur fiscal year 2015. MADIS ported its primary processing system from the Central Computing System supercomputer at the National Centers for Environmental Prediction to the new Weather and Climate Operational Supercomputer Systems (WCOSS). MADIS added 2,000 new fixed-surface sites plus mobile sites; added five data providers; increased sites processed per hour by 30,000; added 200 data users; and serviced more than one million data requests a day. MADIS ported its backup processing system to a new architect that uses RAM (random-access memory) disk technology to improve throughput. MADIS upgraded its graphical data displays to leverage relational databases and Google Maps technology to deliver a state-of-the-art user interface that allows users to interactively view, query, plot, filter, and spatially subset MADIS real-time data.

We also worked on the port of FX-Collaborate software to the Advanced Weather Interactive Processing System (AWIPS II). FX-Collaborate is a drawing tool that gives weather forecasters the ability to produce annotated products, such as a cold front line, text explaining various features, and shaded shapes representing warning areas. It is now a Common AWIPS Visualization Environment (CAVE) plug-in that augments the core AWIPS II software. Recent improvements include the addition of the ability to vary the shadow size, color, opacity, and features to allow complex drawings with visually distinct elements. At this stage, the project is complete until we identify additional funding.

In the effort to develop an AWIPS II collaboration prototype as part of the AWIPS II, developers in the Global Systems Division's Information Systems Branch (ISB) completed the prototype collaboration tool that allows internal NWS forecasters at different sites to share weather products, drawings, and other data within the AWIPS II environment. We turned over the code and functionality to Raytheon Technology Services Inc. to integrate into the core AWIPS II software. Raytheon implemented many of the prototype's concepts into its code. ISB developers were able to evaluate the implementation and provide feedback to help guide future versions of the software. The ISB team also demonstrated external-collaboration functions; this will enable forecasters to collaborate with external partners such as emergency managers. This would aid forecaster situational awareness and improve the NWS products disseminated to the public. We successfully demonstrated an end-to-end capability among Environment Canada, NWS Weather Forecast Offices, and ESRL's Global Systems Division (GSD).

With the prototype Hazard Services in AWIPS II, we commenced development for initial operating capability. Hazard Services is an extended project of AWIPS II that will provide a common user interface and process for issuing hazard products. It will streamline NWS watch, warning, and advisory operations, allowing forecasters to focus more on situational awareness and communication with partners. The common interface and process for issuing hazard products will have the potential to increase warning lead times which, in turn, may reduce the loss of life and property.

During the reporting period, the Hazard Services Team transitioned to the implementation of Production Version One (PV1) of Hazard Services for deployment to NWS forecast offices. This involved the creation of a Integrated Product Team (IPT) consisting of software engineers and scientists from ISB in Boulder, Colo., and Raytheon. PV1 began in fall 2012 and continued through spring 2013. During PV1, we designed a solid, extendable foundation for Hazard Services and implemented several major components. These components include the recommender framework, the product-generation framework, the data-access framework, interfaces to legacy applications, two new hydrologic recommenders, and several new product generators. In May, we held another face-to-face meeting, this time at Raytheon in Omaha, Neb. A goal of this meeting was to prepare PV1 Hazard Services for delivery to the test and evaluation sites. It also focused on developing a vision for Production Version

Two (PV2) Hazard Services. By the end of May, developers were fully engaged on PV2 tasks. Work will continue toward Hazard Services IOC in spring 2014.

In addition to software development, we are also emphasizing testing and documentation. The IPT will ensure that Hazard Services is robust and can support the NWS hydrologic warning operations for IOC. During this time, the users will continue to be closely involved, providing feedback at weekly meetings and software demonstrations. We will carefully document this feedback and cull it for future requirements.

GSD-02 Science Education and Outreach

CIRES LEAD: ELIZABETH RUSSELL
NOAA LEAD: WILLIAM BENDEL
CIRES THEME: SCIENTIFIC OUTREACH AND EDUCATION
NOAA THEME: ENGAGEMENT ENTERPRISE

GOALS & OBJECTIVES

This project connects NOAA science to the public and to students and educators in the K-12 system.

ACCOMPLISHMENTS

The Science Education and Outreach Project has had a very busy and successful year thanks to the hard work and dedication of CIRES and collaborators. NOAA's Science On a Sphere (SOS) and NOAA's Data Visualizations and Games (DVG) Group have seen growth and improvement, leading to enhanced scientific environmental literacy and improved understanding, value, and use of weather and water information through services to the public, including the K–12 education community.

From September 1, 2012, through May 31, 2013, we installed 11 new Science On a Sphere exhibits worldwide, including in Canada, Mexico, the Republic of Korea, People's Republic of China, Italy, and the United States. These new, permanent installations make SOS accessible to a broader audience and help to further spread NOAA science around the world. With these new installations, an estimated 32.9 million people see SOS every year. In addition, the traveling SOS exhibit made appearances at three conferences across the United States. The Science On a Sphere® in the NOAA David Skaggs Research Center had 5,000 visitors during this period, including K-12 students, university students, the general public, and many other groups.

During this time, our team made available to users updates to the SOS software, to greatly augment the presenter experience. The updated features include annotation, zooming, and layering. All of these features have the goal of allowing the SOS presenter to interact more with the data shown on SOS, and they explain what are sometimes complex subjects in an understandable way to audiences. These are all features that have come at the request of the SOS Collaborative Users Group.

The SOS Collaborative Users Group Workshop took place November 2012 at the Aquarium of the Pacific in Long Beach, Calif. This proved to be a valuable time for introducing the new SOS software features and planning the path forward for future SOS work. The workshop also highlighted best practices for presenters, creative ways to engage audiences, and educational goals for the SOS Collaborative Users Group. During the workshop, we showcased new SOS data sets, thematic narratives, and productions, inspiring more ideas for future work.

The DVG Group continued work on the TerraViz 4D data visualization engine and the backend NOAA Earth Information Services (NEIS) core. New features include annotations; analytic tools; geolocated data scenes; the introduction of Keyhole Markup Language (KML) support; improved support for Web Map Services; an updated, faceted search screen; map tiling for progressive disclosure; and multiuser collaboration tools. Additionally, the group upgraded TerraViz to work with touchscreen kiosks and the zSpace holographic display.

Science On a Sphere®, in NOAA's David Himes Planet Theater, in Boulder, CO. CIRES staff are integral to the Science On a Sphere® program. Photo credit: NOAA

During this time, the DVG Group worked on developing an educational video game that North Carolina A&T State University and NASA will use for outreach among minority high-school students considering STEM (science, technology, engineering, and mathematics) degrees. DVG was also involved with research in display and interface technologies including touchscreen kiosks, holographic displays, touchless interfaces like the Leap Motion Controller, and mobile technology. DVG was also a government pioneer in the use of cloud computing for data searching and delivery.

Members of DVG were active in the community, including teaching at CU-Boulder and participating

in nearly a dozen industry organizations. During this period, group members presented NEIS and TerraViz to 22 groups and conferences, including to the head of NOAA and at the American Geophysical Union annual fall meeting. Two members of DVG received a Research and Service Initiative Award from the Cooperative Institute for Research in the Atmosphere, and one member received CIRES' Outstanding Performance Award. DVG's research efforts also appeared on the cover of Government Computer News and in various other publications.

GSD-03 Improving Numerical Weather Prediction

CIRES LEAD: CURTIS ALEXANDER
NOAA LEAD: GEORG GRELL
CIRES THEME: SYSTEMS AND PREDICTION MODELS DEVELOPMENT
NOAA THEME: SCIENCE AND TECHNOLOGY ENTERPRISE

GOALS & OBJECTIVES

This project focuses on improvements in numerical weather prediction by use of models through improved model design and implementation and optimal use of new and existing observations.

ACCOMPLISHMENTS

The High-Resolution Rapid Refresh (HRRR) model remains a foundational component of the 2010–2013 Consolidated Storm Prediction for Aviation (CoSPA) forecast system used for convective weather guidance in both tactical and strategic flight planning in the national airspace. The National Weather Service, including the Storm Prediction Center, also extensively uses HRRR for severe-weather prediction.

During development of the Earth System Research Laboratory's 2013 Rapid Refresh (RAP) and HRRR forecast systems, we focused on efforts to 1) improve the depiction of the mesoscale environment through refinements to the RAP data assimilation, 2) introduce 3-km HRRR data assimilation for analysis of storm-scale information, and 3) enhance RAP and HRRR model physics for improved land surface and boundary layer prediction.

Our team updated the RAP data-assimilation system in Gridpoint Statistical Interpolation (GSI) using a hybrid Global Forecast System (GFS) 80-member ensemble Kalman filter and 3-D variational background error covariance estimate. This enhancement permits weather (flow) dependence in the model background error covariance estimate and has shown significant improvement in RAP forecasts with reduced root-mean-square (RMS) values for upper-level temperatures, humidity, and winds. This indicates a superior forecast of the mesoscale environment.

We made additional updates to improve the RAP snow-cover analysis by adding the capability to build and trim surface snow cover based upon a daily Interactive Multisensor Snow and Ice Mapping System analysis.

In the 2013 HRRR, we established 3-km data assimilation to incorporate storm-scale information using GSI that includes sub-hourly 3-km radar data assimilation during a preforecast hour (starting from a one-hour-old ESRL RAP analysis); 3-D variational assimilation of conventional observations; and a 3-km nonvariational cloud and precipitating hydrometeor analysis using radar reflectivity observations to retrieve rain and snow mixing ratios.

We used observed radar reflectivities as a proxy for the HRRR model latent-heating specification that replaces the model microphysics latent heating during four 15-minute periods of a cycled preforecast hour, with an emphasis on forcing observed convective structures from higher-reflectivity regions. We gave special attention to continuity of convective-scale structures originating from an accurate storm-scale analysis (initial condition) during much of the free forecast period (several hours). The 3-km assimilation has led to an improvement in very short-term forecasts (first few forecast hours) of air-mass thunderstorms and other small-scale convective structures in the real-time 2013 HRRR model forecasts.

We made an enhancement to the RAP and HRRR GSI retrieval of rain and snow hydrometeors from radar reflectivity observations. This enhancement results in a reversible diagnostic of model reflectivity in the Weather Research and Forecasting (WRF) model, both matching the observed reflectivity and consistent with the model microphysics scheme used in the RAP and HRRR. This update led to an improved analysis of radar reflectivity, including echo tops, and these initial conditions translated into improved reflectivity and echo-top analysis and forecasts from the RAP and HRRR.

Prior to the 2013 summer season, we updated the underlying WRF model of the HRRR and the parent RAP to include the official version 3.4.1 release. Additionally, we made RAP and HRRR model physics updates to expand the Rapid Update Cycle land surface model from six to nine levels for improved vertical resolution near the land surface and a reduced diurnal bias of surface temperature and humidity forecasts. We increased the surface roughness length to reduce the high bias in forecasted 10-m wind speeds. Finally, we changed the planetary boundary layer scheme from Mellor-Yamada-Janjic to an enhanced version of the Mellor-Yamada-Nakanishi-Niino scheme, for improved boundary layer prediction of temperature, water vapor, and wind.

GSD-04 Improve Regional Air-Quality Prediction

CIRES LEAD: STEVEN PECKHAM
NOAA LEAD: GEORG GRELL
CIRES THEME: AIR QUALITY IN A CHANGING CLIMATE
NOAA THEME: SCIENCE AND TECHNOLOGY ENTERPRISE

GOALS & OBJECTIVES

This project focuses on improving the numerical models that combine atmospheric transport and atmospheric chemistry for the purpose of making air-quality forecasts for regions of interest and at specific locations.

ACCOMPLISHMENTS

Work continued on the development of the Weather Research and Forecasting model coupled with Chemistry (WRF-Chem) and the Flow-following finite-volume Icosahedral atmospheric Model coupled with Chemistry (FIM-Chem). Significant improvements to the WRF-Chem model include the Community Atmosphere Model 5 physics and the Modal Aerosol Module chemistry. The climate-modeling community commonly uses these numerical packages, and the improvements should allow for a closer collaboration with that community. In addition, at several conferences and workshops, our team presented model developments and results from scientific research, and the model-development team members continued international outreach through a WRF-Chem tutorial held in Sao Paulo, Brazil.

During 2012, we used the WRF-Chem model to produce daily real-time forecasts on a high-resolution domain, and we made the forecasts available to the community through Web pages and collaboration applications. The forecasts include the smoke from satellite-observed wildfires (Wildfire Automated Biomass Burning Algorithm, WFABBA, and the Moderate Resolution Imaging Spectroradiometer, MODIS, projects) as well as particles that interact with the regional meteorological forecast via absorption and reflection of downward shortwave radiation. The model generates the initial fine-particle aerosols for the forecast by using previous forecast data along with chemical-data assimilation via the Gridpoint Statistical Interpolation methodology. During the chemical-data-assimilation segment, the model uses observations from more than 380 cities across the lower 48 United States to refine the previous six-hour, three-dimensional weather/particle forecast fields. This is one of the first NOAA models to include chemical data assimilation in real-time forecasts, and so far, it has demonstrated a significant improvement in fine-particulate-matter forecasts.

On May 26, 2012, strong winds transported a narrow plume of fine particle smoke from the Whitewater-Baldy fires in New Mexico northward over Colorado, where the plume mixed down to the surface. Satellite data and observational reports revealed that a hazy, brown cloud of fine particles plagued the Colorado Front Range during the first part of the Memorial Day weekend. Due to the inclusion of wildfire smoke emissions and chemical-data assimilation, the real-time WRF-Chem forecasts produced by CIRES collaborators in the Global Systems Division captured remarkably well the narrow plume of fine particles from the New Mexico fires and its impact on Colorado air quality (http://ruc.noaa.gov/wrf/Hotitem2012.html).

GSD-05 Development of High-Performance Computing Systems

CIRES LEAD: CRAIG TIERNEY
NOAA LEAD: MARK GOVET
CIRES THEME: SYSTEMS AND PREDICTION MODELS DEVELOPMENT
NOAA THEME: SCIENCE AND TECHNOLOGY ENTERPRISE

GOALS & OBJECTIVES

This project will allow environmental applications of advanced computing to assimilate and use new technical developments in the field of high-performance computing.

ACCOMPLISHMENTS

Research related to high-performance computing (HPC) and support technologies continues to progress. Our group has mostly focused on developing software tools that improve the reliability and resiliency of HPC systems; understanding performance characteristics of different HPC systems; and developing future HPC technologies.

During the past year, we have completed a performance study by using NOAA's major applications across all NOAA Research and Development HPC systems. The results of this study have helped NOAA understand the architectural pros and cons of its heterogeneous environment. We presented results of this study at the European Center for Mid-Range Weather Forecasting's Workshop on High Performance Computing in Meteorology. NOAA also has used the results to properly measure how their systems accomplish work.

CIRES has been working with NOAA on research relating to application work-flow management for many years. The tools we've developed have been quite valuable to NOAA and CIRES researchers, allowing them to construct complex and reliable scientific work flows. This past year, we re-engineered the entire system, now named Rocoto, to improve the functionality, reliability, and portability of work-flow management in NOAA.

We continually research and develop new technologies to improve the reliability and user productivity of the NOAA HPC systems. By leveraging partnerships among CIRES, NOAA, and the NOAA HPC-integrator Computer Sciences Corp., we have made several improvements. These include tools to better manage memory usage of HPC applications; improved validation of the hardware health of live systems; and tools to monitor bandwidth and metadata usage on user, node, project, and application levels.

To research methods to effectively use next-generation architectural technologies, we are providing NOAA and CIRES researchers with access to these technologies. We continue to support devel-

New CIRES-developed tools will improve aviation weather forecasts and safety.

Photo credit: iStock

opment by using Nvidia Graphical Processing units. Also, we are working with Intel Corp. and its latest-generation Many Integrated Core coprocessors so NOAA and CIRES scientists can investigate how to design future HPC applications.

GSD-06 Verification Techniques for Evaluation of Aviation Weather Forecasts

CIRES LEAD: MATTHEW WANDISHIN
NOAA LEAD: JENNIFER MAHONEY
CIRES THEME: SYSTEMS AND PREDICTION MODELS DEVELOPMENT
NOAA THEME: WEATHER-READY NATION

GOALS & OBJECTIVES

This project contributes to the prediction of specific weather related threats to aviation, thus potentially enhancing the safety of aviation.

ACCOMPLISHMENTS

Our team's accomplishments since September 2012 include:

- Completing the second version of the Lead-time and Displacement (LTD) assessment of the National Digital Forecast Database (NDFD). The assessment examined the performance of the National Weather Service (NWS) Forecast Office product, along with model forecasts, in the context of aviation terminal and en-route operations.
- Completing a prototype of the Event-based Verification and Evaluation of NWS Gridded Products Tool, which will extend the LTD assessment to provide ongoing, near-real-time forecast performance statistics.
- Completing 75 percent of an evaluation of the high-resolution version of the Current Icing Potential and Forecast Icing Potential products.
- Completing the beta version of the INtegrated Support for Impacted air-Traffic Environments (INSITE) decision-support tool, which is an update to last year's VERIFIED (VERification of Impact-translated Forecasts for IntEgrated Decision-making) tool. The Aviation Weather Center's National Airspace Meteorologists will use the tool as an aid for issuing Aviation Weather Statements.

GSD-07 Testbed Center for Numerical Prediction Development

CIRES LEAD: LIGIA BERNARDET
NOAA LEAD: ZOLTAN TOTH
CIRES THEME: SYSTEMS AND PREDICTION MODELS DEVELOPMENT
NOAA THEME: WEATHER-READY NATION

GOALS & OBJECTIVES

This project is directed toward maintenance and improvement of the hurricane prediction system and is supportive of government agencies and public information systems that provide hurricane warning.

ACCOMPLISHMENTS

Researchers at NOAA operations and in the research and development communities continue to use the Hurricane Weather Research and Forecast model and the Gridpoint Statistical Interpolator codes. To that effect, our group and our collaborators:

- Maintained the community and operational codes, synchronized to prevent divergence.
- Helped community users test and commit their code to the repository.
- Hosted developers committee meetings.
- Supported users by maintaining Web portals with data sets and documentation and staffing a help desk.

Additionally, we conducted tests to evaluate new code developments, which led to operational implementations both at NOAA's National Centers for Environmental Prediction and the Air Force Weather Agency.

Agile developers discuss design options. Photo credit: Dan Wilkinson

National Geophysical Data Center

NGDC-01 Enhancing Data Management Systems and Web-Based Data Access

CIRES LEAD: DAVID NEUFELD
NOAA LEAD: KELLY PRENDERGAST
CIRES THEME: MANAGEMENT AND EXPLOITATION OF GEOPHYSICAL DATA
NOAA THEME: SCIENCE AND TECHNOLOGY ENTERPRISE

GOALS & OBJECTIVES

This project focuses on improved data interoperability and usability through the application and use of common data management standards, enhanced access and use of environmental data through data storage and access, integration of data management systems, and long-term stewardship.

ACCOMPLISHMENTS

CIRES researchers at the National Geophysical Data Center (NGDC) are working collaboratively to enhance data management systems and improve Web-based data access for both the public and other scientists. Toward that end, CIRES and NGDC migrated to an agile software-development process this past year. As a result, the team produced a variety of new and enhanced software systems. The software we developed provides improved data-extraction services, robust metadata tools, online management of undersea feature data, and analyses used to determine new boundaries for the Extended Continental Shelf.

The NGDC Data Extract System (NEXT) provides a general data-access service for data managers through a simple and scalable retrieval architecture. This initial system supports three data sets and is expandable to support additional data sets with further development. The previous approach required the creation of a retrieval system for each data set, which resulted in code duplication and discrepancies in the features available. NEXT accommodates the unique features of each data set without the redundancy of the common data delivery functionality required by all the data sets, including security, system monitoring, and email notification.

The Enterprise Metadata Management Architecture (EMMA) is a system of tools and services to assist metadata management and re-use; standardize documentation through the use of International Standards Organization (ISO) formats; and enable discovery of scientific data. The tools include conversion of metadata from other format—such as Network Common Data Form Markup Language, Federal Geographic Data Committee, Sensor Observation Service, and Web Map Services—into International Standards Organization documentation standards. The system hosts and displays metadata by using Web Accessible Folders with dynamic custom views, and the metadata is discoverable through Esri Geoportal through the use of keyword and geospatial search criteria. EMMA includes a variety of assessment metrics for completeness and correctness of metadata content; provides diagnostic reports; and allows the visualization of these metrics over time. The EMMA team also provides to NOAA (as well as other federal agencies and international collaborators) training in ISO metadata documentation standards and in the usage of the EMMA tools.

The General Bathymetric Chart of the Oceans (GEBCO) Gazetteer is a new Web-based tool that allows public access to undersea feature names. With a secure login, it also allows the International Hydrographic Organization's Data Center for Digital Bathymetry and GEBCO sub-committee members to manage and maintain the database. The tool includes the ability to search for and display results on an interactive map and also includes programmatic access for end-users such as Google and Esri. To enhance the accuracy of the Gazetteer, we undertook a review of undersea feature locations. The review resulted in numerous improvements to the database. The Gazetteer interface is available at: http://ngdc.noaa.gov/gazetteer.

Lastly, in collaboration with NGDC, CIRES researchers developed the Extended Continental Shelf (ECS) Catalog software. This software provides production tools for a multi-agency collaboration aiming to determine and define the extent of the U.S. continental shelf beyond 200 nautical miles. The ECS project team uses this software to assemble a boundary extension submission to the United Nations, tracking data sets, analysis, documentation, and other arguments in support of the official request. Close interaction with the stakeholders provided rapid progress in the design, user interface, and supporting code.

NGDC-02 Enhancing Marine Geophysical Data Stewardship

CIRES LEAD: JENNIFER HENDERSON
NOAA LEAD: SUSAN MCLEAN
CIRES THEME: MANAGEMENT AND EXPLOITATION OF GEOPHYSICAL DATA
NOAA THEME: SCIENCE AND TECHNOLOGY ENTERPRISE

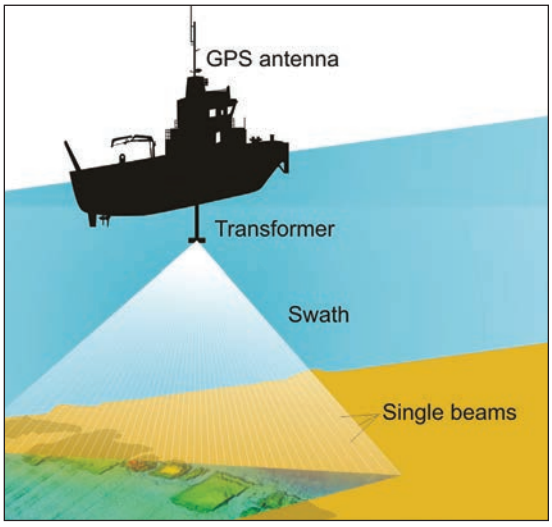
GOALS & OBJECTIVES

This project focuses on application of common management standards for environmental data supporting many NOAA research and operational endeavors. The project will reduce cost of data access through increased use of partnerships and integration of systems that leverage the value of data.

ACCOMPLISHMENTS

Since September 2012, staff with CIRES and the National Geophysical Data Center (NGDC) have added to NGDC's global marine geophysical archives 287 multibeam swath sonar surveys (327,262 nautical miles) and 665 trackline (single-beam bathymetry, magnetics, gravity, subbottom, and seismic reflection) surveys (2,237,667nautical miles) throughout all of the world's oceans. Both national and international organizations contribute to and retrieve marine geophysical data from the interactive databases. By using standard metadata, spatially enabled databases, robotic tape archives, and standards-based Web services, NGDC provides long-term archiving, stewardship, and delivery of data to scientists and the public. 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.

In the past year, CIRES and NGDC staff have continued to focus their efforts on the design and implementation of the ECS database, referred to as the ECS Information Management System (IMS). IMS tracks the provenance of data and products used in an analysis to determine the extents of the U.S. extended continental shelf. NGDC and CIRES staff spent much of 2012 preparing for the NGDC-hosted Mock Gulf of Mexico ECS Regional Analysis Workshop (January 2013). Along with identifying, reviewing, and verifying the procedures, data, and products necessary to complete a U.S submission to the United Nation's Commission on the Limits of the Continental Shelf, the workshop also tested the ECS IMS capabilities to ensure system support for future Regional Analysis Workshops. We also tested the newly developed ECS Web Map Viewer, a map interface created to show the spatial coverage of all ECS-related data and products that have been uploaded into the ECS IMS. This includes geophysical surveys from a variety of federal government and academic sources and products from preliminary analyses conducted by ECS Project scientists.



Multibeam swath sonar survey. Image credit: NOAA

In the effort to improve common metadata standards for data-product level (e.g., bathymetric and gravity grids and various seismic data products) and cruise-level data for both the ECS project and the IOCM program, we have continued to collaborate with scientists and data experts from several U.S federal agencies and academic science data centers. Staff have continued to generate both types of metadata records for all ECS-funded cruises and have made these records available to the public through the NGDC ECS Data Access website (http://www.ngdc.noaa.gov/mgg/ecs/cruises.html).

NGDC-03 Improved Geomagnetic Data Integration and Earth Reference Models

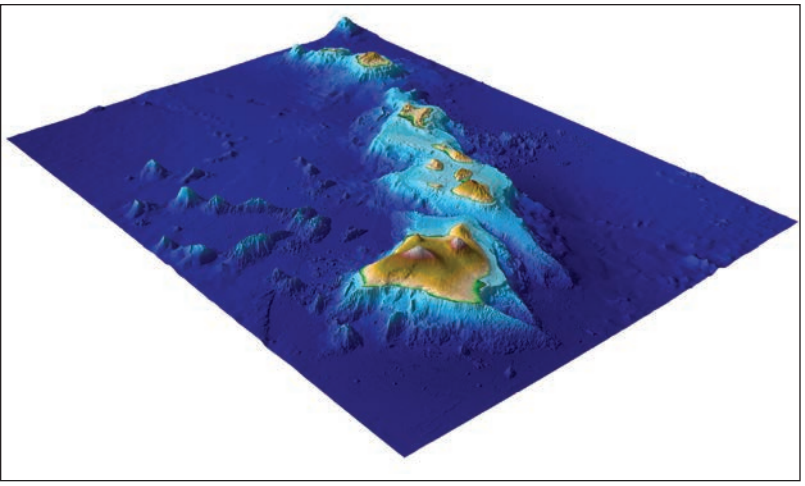
CIRES LEAD: H. STEFAN MAUS
NOAA LEAD: SUSAN MCLEAN
CIRES THEME: MANAGEMENT AND EXPLOITATION OF GEOPHYSICAL DATA
NOAA THEME: SCIENCE AND TECHNOLOGY ENTERPRISE

GOALS & OBJECTIVES

This project will increase the volume and diversity of geomagnetic data that are integrated into improved, higher-resolution geomagnetic reference models of Earth, which are increasingly important for navigation.

ACCOMPLISHMENTS

Our team made advances in real-time modeling of Earth's geomagnetic disturbance field. A significant amount of the geomagnetic field's time variation is due to electric currents in the magnetosphere. Using the National Geophysical Data Center's Pomme geomagnetic model, we implemented a disturbance geomagnetic calculator. Two sets of real-time data streams drive the model. The first is the Disturbance storm-time (Dst) index of the U.S. Geological Survey geomagnetism program, which is derived from its global observatory network. The second is based on solar-wind measurements of NASA's Advanced Composition Explorer (ACE) satellite. The predicted fields compare favorably with measurements at obser-



Digital elevation model of Hawaii. CIRES staff at the National Geophysical Data Center develop digital elevation models, in support of NOAA's Tsunami program.

vatories in the mid-latitudes. The predictions deteriorate at higher latitudes where stronger ionospheric currents, such as the auroral electrojets, dominate the disturbance field. Real-time specification of the geomagnetic field can play an important role in applications such as navigation, surveying, and the prediction of induced voltages in power grids. We implemented the real-time calculator as a cloud computing application at www.geomag.org/models/RTDFC.html. The calculator also allows the computation of historical geomagnetic disturbance fields going back to the year 2000.

NGDC-04 Enhanced Coastal Data Services, Integration, and Modeling

CIRES LEAD: KELLY CARIGNAN
NOAA LEAD: SUSAN MCLEAN
CIRES THEME: MANAGEMENT AND EXPLOITATION OF GEOPHYSICAL DATA
NOAA THEME: SCIENCE AND TECHNOLOGY ENTERPRISE

GOALS & OBJECTIVES

The purpose of this project is to enhance the utility of coastal hazards data through the use of common data management standards, and increase the volume and diversity of data that can be integrated into hazard assessments and coastal elevation models at local, regional, national, and global scales.

ACCOMPLISHMENTS

CIRES staff at the National Geophysical Data Center (NGDC) developed three new digital elevation models (DEMs) and updated two existing DEMs that support NOAA's Tsunami Program. Our work updating existing DEMs with recently collected, high-resolution, lidar-based elevation data improves the models' accuracy, resulting in better forecasts and warnings of coastal hazards. We also archived 85 new lidar surveys at NGDC, thus supporting long-term data-storage needs of many NOAA agencies as well as DEM development.

Our scientific research into DEM development includes: quantifying the DEM uncertainty that various gridding interpolation techniques introduce between sparse bathymetric data; establishing standardized robust procedures for the building of consistent, companion-structured and -unstructured DEMs from common-source elevation data; and developing standardized, robust procedures for building a suite of consistent, routinely updated, nested, and telescoping coastal DEMs of the entire U.S. coastline.

To plan for the impacts of many coastal natural hazards, having water-level data is a crucial element. CIRES staff at NGDC ingest, process, and archive tide gauge data and deep-ocean bottom pressure data from several NOAA agencies. We then make these data available via online tools for researchers and modelers. Recent improvements include developing procedures for data verification and correction of the post-event processing for high-resolution Deep-ocean Assessment and Reporting of Tsunamis (DART) tsunameters; adding to NGDC's database raw and processed high-resolution DART records for 2002–2012, along with real-time records for recent strong tsunamis; ingesting NGDC's 34 coastal, one-minute, raw and processed water-level data covering all tide gauges on U.S. Pacific Islands and Alaska and several important observations on the U.S. West Coast; and updating physical and socioeconomic data in the global historical tsunami database.

Following the devastating 2004 Indian Ocean tsunami, 181 U.S. tide gauges received an instrumental upgrade to enable collection of one-minute, real-time water-level sample data, allowing for the detection of even small amplitude tsunamis. Improvements to data processing have isolated the tsunami waves from records dominated by local tides and coastal effects. Observations show that tsunami-magnitude amplification depends on local features (i.e., bathymetry, estuary vs. open-coast tide gauge). Such findings highlight the importance of ongoing tide gauge water-level analysis and research to support science-based planning and management of coastal communities.

The planning required to collect and disseminate hazard-event data is extensive. Following a damaging or fatal event, NGDC begins to collect and integrate data and information from many people and organizations into the hazards databases. We regularly update the resulting report to incorporate the most recent news and observations. Providing timely access to authoritative data and information ultimately benefits researchers, state officials, the media, and the public.

NGDC-05 Enhanced Stewardship of Space Weather Data

CIRES LEAD: JUSTIN MABIE
NOAA LEAD: WILLIAM DENIG
CIRES THEME: MANAGEMENT AND EXPLOITATION OF GEOPHYSICAL DATA
NOAA THEME: SCIENCE AND TECHNOLOGY ENTERPRISE

GOALS & OBJECTIVES

This project will ensure future availability of NOAA's space weather data.

ACCOMPLISHMENTS

Computer system upgrades have resulted in failure of some legacy data management code. Specifically, the McNish-Lincoln Sunspot Number Forecast model became inoperative. This model is essential for a wide array of applications, including predicting high-frequency radio limitations for Army communications on the battlefields of Afghanistan. Our team reworked this legacy code to function on a modern 64-bit computer, and the forecast continues to serve our customers.

We modernized the master observatory list of the International Association for Geomagnetism and Aeronomy (IAGA). This list had previously served the single purpose of assigning new observatory codes, and we updated it to include a robust selection of metadata fields. We did this at the request of IAGA to support database development efforts at the British Geological Survey. We also modernized the process for developing the National Geophysical Data Center's Solar Indices Bulletin and Geomagnetic Indices Bulletin, and these products are in full production.

Our team collected a library of data from the Vertical Incidence Pulsed Ionospheric Radars (VIPIR) at Wallops, Va., and San Juan, Puerto Rico, and backed it up in a custom tape library. Efforts are underway to migrate these data to the Comprehensive Large Array Data Stewardship System (CLASS). We developed a binary reader to read Raw In-phase and Quadrature (RIQ) data files from the VIPIR instruments in Interactive Data Language (IDL). We made upgrades to the Wallops VIPIR site, and in cooperation with the University of Texas Applied Research Labs, we installed a new ionospheric radar in Austin, Texas. We set up the Wallops VIPIR to record ionospheric disturbances during Superstorm Sandy. This work demonstrated a new and innovative use of the radar capabilities and data. Additionally, we repaired on-site damage caused by the superstorm, and researchers there continued the longstanding climatology with minimal interruption.

NGDC-06 Satellite Anomaly Information Support

CIRES LEAD: JUAN RODRIGUEZ
NOAA LEAD: JANET GREEN
CIRES THEME: SPACE WEATHER UNDERSTANDING AND PREDICTION
NOAA THEME: SCIENCE AND TECHNOLOGY ENTERPRISE

GOALS & OBJECTIVES

Data and research from this project will be used to provide space environmental data and tools to satellite operators and designers.

ACCOMPLISHMENTS

The Satellite Anomaly Information Support project involves the development of products and services for satellite operators and designers. These products and services can include: improved-quality (e.g., reprocessed) environmental data; new tools; detailed post-anomaly environmental assessments; and specification of extreme space environmental conditions.

Prior to 2011, the data from the new particle instruments—the MAGnetospheric Electron Detector (MAGED) and the MAGnetospheric Proton Detector (MAGPD)—on Geostationary Operational Environmental Satellite (GOES) 13, GOES-14, and GOES-15 were not processed into calibrated fluxes. During this period, we completed the initial processing of the complete set of 2006–2010 MAGED and MAGPD data archived at the National Geophysical Data Center (NGDC). Before we can release the data to the general public, our group still needs to make several refinements to the data, the need for some of which we uncovered during the processing effort.

We developed a tool to produce 24-hour averages of omnidirectional differential electron fluxes from 40 keV to 2,500 keV. This tool ingests the one-minute-averaged archived fluxes and produces one-month files in comma-separated-variable format. We ran this tool for specific disturbed periods requested by a customer.

Regarding implementation of the SAIS Web portal itself, we have been writing a Web application based on a similar one written by former CIRES software engineer Peter Elespuru. We created the app by using the most recent version of the framework, while adding support for visualization of data from the GOES Space Environment Monitor DataService Web Application Programming Interface.

In this area of Web services, we also made progress on the Auroral People Empowered Products (PeEP). Using Auroral Oval Variation, Assessment, Tracking, Intensity, and Online Nowcasting (OVATION) Prime with integration of Twitter and Flickr, the Auroral PeEP project aims to develop a Web interface intended for public education on auroras. In addition, this project has opened the possibility of validating OVATION Prime via crowd-sourced auroral observations. We are collaborating on this project with a small but growing team of students from Cornell University. We designed the initial demo version of the website and are currently building and analyzing the Twitter data set. Since mid-March, we have been archiving about

27,000 tweets per day. Accomplishments include creation and management of these databases; an algorithm that determines relevancy of tweets to auroral phenomena; and visualization of the data.

We delivered an oral presentation on PeEP at the American Geophysical Union fall meeting in San Francisco (Codrescu et al. 2012).

We also contributed to a manuscript, led by former CIRES research scientist Paul Loto'aniu, based on our earlier "Tiger Team" assessment of the space environment at the time of the Galaxy 15 anomaly. We submitted this manuscript to the *Space Weather* journal for peer review. In January 2013, the editor of the journal highlighted this paper (not by name) at the American Meteorological Society meeting in Austin, Texas, saying that both he and the reviewers want this paper to serve as the model for future anomaly assessments published in *Space Weather*. The manuscript is currently under revision in response to referee comments.

NGDC-07 Remote Sensing of Anthropogenic Signals

CIRES LEAD: KIMBERLY BAUGH
NOAA LEAD: CHRISTOPHER ELVIDGE
CIRES THEM: MANAGEMENT AND EXPLOITATION OF GEOPHYSICAL DATA
NOAA THEME: SCIENCE AND TECHNOLOGY ENTERPRISE

GOALS & OBJECTIVES

The purpose of this project is to increase capacity for investigation and assessment of changing patterns of global economic activity.

ACCOMPLISHMENTS

NASA/NOAA Earth at Night image. CIRES research is the foundation of this imagery, which provides valuable data for many applications.

During the past year, our group started the transition from using the Defence Meteorological Satellite Program (DMSP) Operational Linescan System (OLS) as our primary satellite-image source for nighttime lights and fire products to using data from the Suomi National Polar-orbiting Partnership (NPP) Visible Infrared Imaging Radiometer Suite (VIIRS). The higher spatial resolution and additional infrared bands have allowed our group to make significant advances in mapping combustion sources and nighttime lights.

We have developed a global nighttime VIIRS combustion-source product called Nightfire. The Nightfire algorithm takes as input the nighttime VIIRS Moderate resolution data (M-bands) along with the VIIRS day-night-band (DNB). The algorithm then makes preliminary estimates of combustion-source location, temperature, radiant heat, and combustion-source size.

Our group also has started to perform an atmospheric correction on the VIIRS data to get more accurate estimates of combustion parameters. We developed the atmospheric correction by using the MODerate resolution atmospheric TRANsmission (MODTRAN) model with input of atmospheric profiles from the NPP Cross-Track Infrared Microwave Sounding Suite data. We packaged the Nightfire products in 24-hour increments, and the products are available online for review: http://www.ngdc.noaa.gov/eog/viirs/download_viirs_fire.html.

In addition to the Nightfire product, our group has completed most of the algorithm development necessary to start producing monthly cloud-free nighttime-lights composites using the VIIRS DNB data. We have developed tools to: run a terrain correction on latitude/longitude values provided with the VIIRS DNB data; reproject the DNB imagery; create cloud-masks using M15 data; and correct the VIIRS cloud-mask provided as a retained intermediate product from the cloud Environmental Data Records production.

We have algorithms to identify areas of stray-light, moonlit areas, and dark-nighttime areas. Using 23 nights from April and October 2012, we made a preliminary nighttime-lights composite that became the base layer to NASA and NOAA's "black marble" press panel at the 2012 American Geophysical Union meeting. These data are available online at http://www.ngdc.noaa.gov/eog/viirs/download_viirs_ntl.html.

NGDC-08 Development of Space Environment Data Algorithms and Products

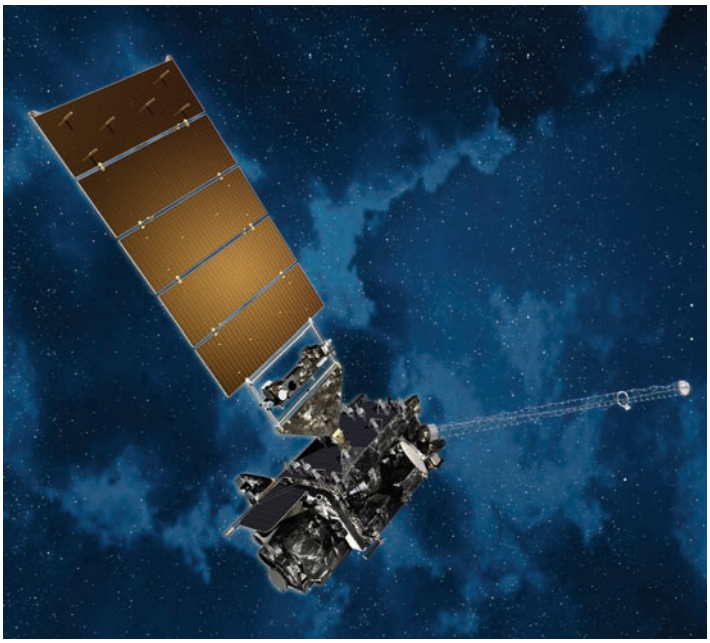
CIRES LEAD: JAMES MANLEY
NOAA LEAD: WILLIAM DENIG
CIRES THEME: MANAGEMENT AND EXPLOITATION OF GEOPHYSICAL DATA
NOAA THEME: SCIENCE AND TECHNOLOGY ENTERPRISE

GOALS & OBJECTIVES

This project will develop the algorithms and products necessary to support use of the Geostationary Operational Environmental Satellite R-Series (GOES-R) satellite data for describing space weather, with particular attention to damaging solar storms.

ACCOMPLISHMENTS

Our group's work on GOES-R is split between two different tasks: calibration/validation and Level 2+ product development for the space weather instruments. To address the ongoing calibration/validation tasks, the team participated in meetings and performed document



GOES-R, an artist's depiction. CIRES researchers support the use of GOES-R satellite data for detecting and forecasting space weather. Image credit: NOAA

review for all instruments under the project's technical oversight. This effort includes ensuring that the Space Environment In-Situ Suite (SEISS) Ground Processing Algorithm is scientifically and algorithmically correct. We provided inputs on recent changes to instrument requirements that potentially could impact the needs of the customer (the National Weather Service). In addition, we performed validation activities on items related to the Space Weather Level 1b products such as the Extreme Ultraviolet and X-ray Irradiance Sensors (EXIS) proxy spectrum and the Solar Ultraviolet Imager (SUVI) Filter Diffraction Analysis.

Specific accomplishments include:

• Successful completion of the GOES-R SUVI sensor Preliminary Design Review for all Phase III algorithms.

• Successful demonstration of prototype algorithms for the SUVI Phase III products, such as solar coronal hole boundaries.

• Improvement of the implementation of the Phase II SUVI Thematic Map. This is necessary for quality proxy data for testing and validation of Phase III products.

• Assessment and evaluation of the calibration of the GOES-NOP-series EUVS sensor.

• Evaluation of the data processing and calibration coefficients and determination of the correct values for developing true solar EUV irradiance measurements. This effort will greatly improve the quality and value of the GOES-R algorithms and data products.

• Development of proxy data sets for testing and evaluating GOES-R algorithms.

• Development of a prototype version of the GOES-R Magnetometer Sudden Impulse Detection Algorithm and completion of a successful Preliminary Design Review for this algorithm.

• Creation of a GOES-R Magnetometer section of the program calibration and validation plan.

• Support of multiple reviews of the instrument and algorithm design for the GOES-R Magnetometer.

• Continued support of the National Geophysical Data Center as a technical advisor in the GOES-R SEISS hardware and Level 1b algorithm development.

• Development of plans for the validation of the algorithm, which create proxy spectra from the GOES-R EXIS. We presented these at the GOES-R Preliminary Design Review.

Papers and presentations associated with the year's activities include participation in the 4th International High Energy Particle Precipitation into the Atmosphere Workshop in Boulder, Colo., October 9-11, 2012. Also, at the American Meteorological Society meeting in Austin, Texas, January 6-10, 2013, we gave the following presentations:

• The GOES-R Sudden Impulse Detection Algorithm (poster); Rowland et al.

• GOES-R solar extreme-ultraviolet irradiance: requirements, observations, and products (poster); Machol et al.

• Development of a proxy data set for the Energetic Heavy Ion Sensor (EHIS) in the GOES-R space environment in-situ suite (poster); Bharath et al.

• Improved space weather monitoring for GOES-R (invited oral); Denig et al.

• Automatic analysis of EUV solar features using solar imagery for the GOES-R SUVI (poster); Darnel et al.

Additionally:

• During Boulder Solar Days in Boulder, Colo., March 19, 2013, CIRES scientist Jonathan Darnel gave an oral presentation, "Using GOES-R data for solar observations."

• At the Space Weather Workshop in Boulder April 16 to April 19, 2013, Juan Rodriguez gave a poster presentation, "Intercalibration of GOES 8-15 solar proton measurements."

• During the Workshop on Inter-Calibration and Degradation of EUV Instruments in Brussels, Belgium, April 15 to April 18, 2013, Janet Machol gave an oral presentation, "Preliminary calibrations of GOES EUVS."

Other papers and presentations below are cited in full in the Appendices:

Hartlet et al. 2012
Machol et al. 2012a
Machol et al. 2012b
Rodriguez et al. 2012
Rowland and Weigel 2012

NGDC-09 Enhanced Ionosonde Data Access and Stewardship

CIRES LEAD: TERRY BULLETT
NOAA LEAD: ROB REDMON
CIRES THEME: MANAGEMENT AND EXPLOITATION OF GEOPHYSICAL DATA
NOAA THEME: SCIENCE AND TECHNOLOGY ENTERPRISE

GOALS & OBJECTIVES

This project will improve the utility of ionosonde data through the application of common data management standards in support of space weather forecasting.

ACCOMPLISHMENTS

The ionosonde data project team obtained several new data sources this period and made advancements on existing instruments. In the area of new sensors, we refurbished a government-surplus ionosonde and installed it in Austin, Texas. This provides better coverage over the United States and regional support for specific data users.

We installed a new generation Volumetric Imaging and Processing of Integrated Radar (VIPIR) instrument on the equator near Kisumu, Kenya, to monitor the ionosphere in this region. Advanced VIPIR research sensors in Virginia and Puerto Rico received software and data-processing upgrades of Dynasonde software, for investigating waves and tides in the ionosphere and also to provide high-resolution routine ionosphere-monitoring data. This greatly increases the real-time utility of data from these sensors.

We adapted commercial-analysis software used to process third-party ionogram data. This allows us to extract ionogram-scaled characteristics from ionogram data produced by an ionosonde in Taiwan. This makes this instrument useful for real-time use in ionospheric modeling and propagation forecasts.

Our team provided technical data to Japan's National Institute of Information and Communications Technology (NICT) regarding the ionosonde equipment we used under this project. These data were key to NICT's instrument-upgrade decisions.

We developed a new design for a receiving loop antenna and tested it for the high-frequency radar systems, expanding the flexibility of this instrumentation.

Finally, we collected data from 65 stations worldwide and distributed them to real-time and scientific users. Archive additions exceeded 900 gigabytes of routine data and 20 terabytes of high-resolution, research-quality data.

NGDC-10 Enhanced CORS Data Access and Stewardship

CIRES LEAD: FRANCINE COLOMA
NOAA LEAD: WILLIAM DENIG
CIRES THEME: MANAGEMENT AND EXPLOITATION OF GEOPHYSICAL DATA
NOAA THEME: SCIENCE AND TECHNOLOGY ENTERPRISE

GOALS & OBJECTIVES

This project will use models to determine causes for variation in space weather, with implications for infrastructure protection.

ACCOMPLISHMENTS

This project supports activities across four of the six NOAA line offices: Oceanic and Atmospheric Research (OAR), National Ocean Service (NOS), National Weather Service (NWS), and National Environmental Satellite, Data and Information Service (NESDIS). CIRES accomplishments are as follows:

- NOS line office (primary mission): In collaboration with the National Geodetic Survey (NGS), CIRES has continuously operated the mission-critical NOAA-NOS parallel NGS Continuously Operating Reference Stations (CORS) facility located at the National Geophyscial Data Center (NGDC) in Boulder, Colo. This remote facility independently ingests, processes, and distributes Global Navigation Satellite Systems data in parallel with the main CORS facility located in Silver Spring, Md. Each CORS facility provides users access to Global Position System (GPS) data, tools, and products and, hence, access to the National Spatial Reference System.
- Project tool completed for NGS (primary mission): CIRES has designed, developed, and demonstrated for NGS the CORS "Internet Collector" data-collection software.
- NESDIS line office: CIRES and collaborators have successfully transitioned all of the NGS CORS data archive holdings held in the NESDIS NGDC tape archive to the Comprehensive Large Array-data Stewardship (CLASS) system. This accomplishment utilized a CIRES-designed software tool called the CLASS pre-ingestor. This accomplishment has improved dissemination and will enable users to order historical CORS data online.
- OAR line office: To enhance resiliency for a weather-ready nation, CIRES and NGDC continue to provide low-latency GPS data as input into the OAR Earth System Research Laboratory's GPS-meteorology model.
- NWS line office: CIRES and NGDC also continue to enhance resiliency for a weather-ready nation by providing low-latency GPS data as input into the NWS Space Weather Prediction Center's United States–Total Electron Content model.

NGDC-11 Enhanced Stewardship of Data on Decadal- to Millennial-Scale Climate Variability

CIRES LEAD: CARRIE MORRILL
NOAA LEAD: DAVID M. ANDERSON
CIRES THEME: MANAGEMENT AND EXPLOITATION OF GEOPHYSICAL DATA
NOAA THEME: CLIMATE ADAPTATION AND MITIGATION

GOALS & OBJECTIVES

Data and research from this project will improve confidence in our understanding of oceanic, atmospheric, and hydrologic components of the climate system.

ACCOMPLISHMENTS

Our collaboration with the Past Global Changes (PAGES) 2k network culminated in our team archiving the most comprehensive global compilation of climate data for the last 2,000 years. This data set consists of regional-temperature reconstructions and the underlying raw time series upon which the reconstructions are based. Data appear in lists and maps and comprise a valuable collection for other researchers. With partner data managers, we established new protocols that have led to more comprehensive metadata and associated data being preserved for each individual proxy record. This is critical to maximize the usefulness of the data to other scientists, since it allows them to reprocess underlying features of the records such as the chronology or proxy calibrations.

We also accumulated and analyzed paleoclimate data and climate model simulations focused on what's known as the "8.2 ka event," a cooling episode 8,200 years ago. Paleoclimate scientists have targeted this event for data collection and data-model comparisons because it is the most recent analogue to the expected future changes in Atlantic Ocean circulation. By comparing model simulations of the event to paleoclimate data, we can test the skill of models being used to make climate projections.

Our compilation of paleoclimate data consists of 262 time series from 114 sites and also documents the global scope of temperature and precipitation changes during the event. In many regions, these climate changes were larger than those of any other abrupt event of the last 11,500 years. To enable model-data comparisons, we requested model simulations of this event from several groups internationally. Our collection of paleoclimate data is now in permanent archives and is available to the public in a structured format. Archiving climate-model output is part of an ongoing project to ingest results from the Paleoclimate Modelling Intercomparison Project. Resulting products appear below.

PAGES 2k Consortium. 2013. Continental-scale temperature variability during the past two millennia. Nature Geosci. 6:339-346. Boulder (CO): National Oceanic and Atmospheric Administration's National Climatic Data Center. Available from: http://hurricane.ncdc.noaa.gov/pls/paleox/f?p=519:1:::::P1_STUDY_ID:14188

Morrill, C, DM Anderson, BA Bauer, R Buckner, EP Gille, WS Gross, M Hartman, and A Shah. 2013. Proxy benchmarks for intercomparison of 8.2 ka simulations. Climate of the Past. 9:423-432. Boulder (CO): National Oceanic and Atmospheric Administration's National Climatic Data Center. Available from: http://hurricane.ncdc.noaa.gov/pls/paleox/f?p=519:1:::::P1_STUDY_ID:14192

NGDC-12 Historical Surface Marine Meteorological Data Stewardship: The International Comprehensive Ocean-Atmosphere Data Set

CIRES LEAD: SCOTT WOODRUFF
NOAA LEAD: JAY LAWRIMORE
CIRES THEME: MANAGEMENT AND EXPLOITATION OF GEOPHYSICAL DATA
NOAA THEME: CLIMATE ADAPTATION AND MITIGATION

GOALS & OBJECTIVES

Data and products from this project will continue to improve confidence in our understanding of oceanic and atmospheric components of the climate system.

ACCOMPLISHMENTS

Work continued towards completing the transition of legacy ICOADS activities and infrastructure from NOAA's Earth System Research Laboratory to the agency's National Climatic Data Center (NCDC). We continued to refine the next version of the International Maritime Meteorological Archive format, which, together with its access software, will enhance ICOADS data stewardship and access, and also serve as a key foundation for the ICOADS Value-Added Database project. Work continues on implementing and documenting the new merged Global Telecommunication System (GTS) product, which (once operational) will provide ICOADS users with enhanced near-real-time monthly updates extending beyond the ending date of the latest delayed-mode update, presently Release 2.5, covering 1662-2007. This new product combines GTS data from NCDC with data from NOAA's National Centers for Environmental Prediction (NCEP). General planning and long-range preparations proceeded toward the next delayed-mode update: Release 3.0. We participated regularly in regular NCDC meetings discussing the future development of sea-surface temperature analyses based on ICOADS.

Woodruff reviewed (as a Core member and past Chairperson of the Expert Team on Marine Climatology of the Joint World Meteorological Organization(WMO)/Intergovernmental Oceanographic Commission Technical Commission for Oceanography and Marine Meteorology [JCOMM] and related task teams) a variety of draft publications and reports, including: a revised chapter for the Guide to Meteorological Instruments and Methods of Observation (WMO No. 8), a white paper on WMO Data Policy for the Global Framework for Climate Services (GFCS), and Recommended Algorithms for the Computation

of Marine Meteorological Variables (forthcoming JCOMM Technical Report 63).

National Snow and Ice Data Center

NSIDC-01 Maintain and Enhance the Sea Ice Index as an Outreach Tool

CIRES LEAD: FLORENCE FETTERER
NOAA LEAD: ERIC KIHN
CIRES THEME: SCIENTIFIC OUTREACH AND EDUCATION
NOAA THEME: ENGAGEMENT ENTERPRISE

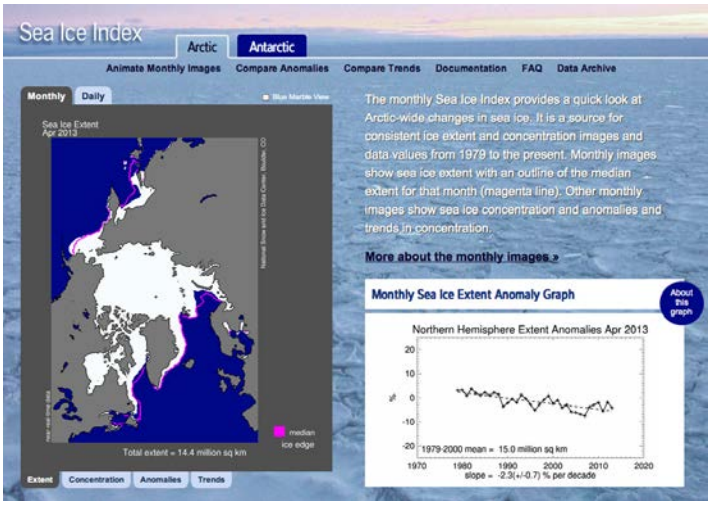
GOALS & OBJECTIVES

The product of this project will attract and engage the interest of students and teachers as well as the general public.

ACCOMPLISHMENTS

Our team added daily data to the Sea Ice Index product archive. This was a major addition. Prior to this, the site deliberately archived only monthly ice extent numbers and images, because the monthly data are more reliable and in keeping with the purpose of the product. However, the Arctic Sea Ice News and Analysis site, with tens to hundreds of thousands of users each month, relies on a Sea Ice Index daily view. We saw it as necessary, then, to archive the daily product and to make easy-to-understand information available on how the daily and monthly products differ.

In associated work during this period, we completed a major update and improvement to the Sea Ice Index site architecture, and we overhauled the product documentation to include an explanation of how we make the products and a complete, clearer description of all Sea Ice Index products. The documentation now includes: flow charts to make data-processing steps easier to follow; explanation on how the median edge position is determined and why it is used; clearer explanation of coverage and resolution; more information on accuracy; a tutorial on how to use the Browse Image Spreadsheet Tool to quickly compare images from past years; and a short section on how the product has evolved from 2002 to 2012.



NSIDC's Sea Ice Index website. Image credit: NSIDC

We also functionally redesigned the Sea Ice Index Web site so it is easier to find and compare earlier years of Sea Ice Index data and to check up on trends and anomalies in sea ice extent. These changes make it easier to understand the information the data holds and find and use Sea Ice Index products.

NSIDC-02 Update and Maintain Educational Resources for the Cryosphere

CIRES LEAD: FLORENCE FETTERER
NOAA LEAD: ERIC KIHN
CIRES THEME: SCIENTIFIC OUTREACH AND EDUCATION
NOAA THEME: ENGAGEMENT ENTERPRISE

GOALS & OBJECTIVES

This project brings unique reference materials to educators and researchers.

ACCOMPLISHMENTS

Our group's outreach, education, and historical-data-publication activities resulted in publication of the Web page titled "All About Arctic Climatology and Meteorology." This page contains information on topics such as arctic climate versus weather; water sky and ice blink phenomena; and highs, lows, and the Arctic Oscillation. We designed the site for educators and high-school students. It consistently ranks in the top 10 of the National Snow and Ice Data Center's (NSIDC) Web pages.

We also published in digital format a data set comprised of historical Greenland snow accumulation data from 1911 to 1981. Geologist Dr. Carl S. Benson, currently professor emeritus at the University of Alaska, Fairbanks, provided scientific field-study notebooks describing his traverses of Greenland from 1952 to 1955. The notebooks contain data on Greenland snow accumulation, snow temperature, stratigraphy, ice-sheet facies, and snow densification. We scanned and published online these notebooks, but other material in NSIDC's analog archive remains at risk. Working toward a solution, staff at the newly named Roger G. Barry Archives and Resource Center (ARC) embarked on a fundraising mission. A new brochure explains the archive's value to the nation and asks for donations.

A Preserve America Initiative Grant assisted the archivist in creating the Web page titled "First 25 Years: The History of the World Data Center for Glaciology and NSIDC in Boulder, Colo." This page offers organized, digitized material documenting NSIDC's beginnings when the U.S. World Data Center (WDC) for Glaciology moved to Boulder, Colo., in 1976. A National Research Council recommendation and an agreement between NOAA and the University of Colorado Boulder resulted in the NSIDC designation in 1982.

NSIDC-03 Update, Improve, and Maintain Polar Region Data Sets

CIRES LEAD: FLORENCE FETTERER
NOAA LEAD: ERIC KIHN
CIRES THEME: MANAGEMENT AND EXPLOITATION OF GEOPHYSICAL DATA
NOAA THEME: SCIENCE AND TECHNOLOGY ENTERPRISE

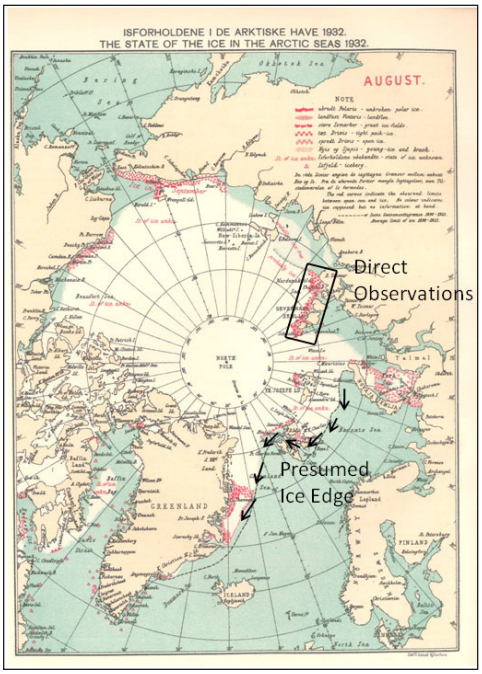
GOALS & OBJECTIVES

This project will ensure availability of data on polar ice and glaciers for research purposes.

ACCOMPLISHMENTS

Our team published six new data collections for this project and updated several others. These data collections come to us from sources as varied as U.S. Navy submarines (Expendable Conductivity, Temperature, and Depth data from the Submarine Arctic Science Program) and the World Glacier Monitoring Service, Zurich, Switzerland. More information is at http://nsidc.org/noaa/news.html.

A CU-Boulder undergraduate student assisted in the publication of Arctic sea-ice charts from the Danish Meteorological Institute, 1893–1956. The publication of the digital version of these charts was an important step in providing supporting material for an imminent sea-ice reanalysis effort.



Arctic sea-ice chart from the Danish Meteorological Institute.

Physical Sciences Division

PSD-01 Relationship of Air Quality to Weather

CIRES LEAD: TIM COLEMAN
NOAA LEAD: ALLEN WHITE
CIRES THEME: AIR QUALITY IN A CHANGING CLIMATE
NOAA THEME: SCIENCE AND TECHNOLOGY ENTERPRISE

GOALS & OBJECTIVES

This project will show how well models can predict air quality under specific weather conditions at locations where air quality typically is poor.

ACCOMPLISHMENTS

Our team collected, processed, and distributed observational data such as sodar reflectivity, surface energy balance fluxes, and 20-meter-tower meteorological data from the Uintah Basin Ozone study in Utah. With this processed data, scientists can compare the data with numerical models to see how well a model simulates state boundary layer.

PSD-02 Diagnosis of Climate Forcing by Ocean Surface Temperatures

CIRES LEAD: PRASHANT SARDESHMUKH
NOAA LEAD: RANDALL DOLE
CIRES THEME: CLIMATE FORCING, FEEDBACKS, AND ANALYSIS
NOAA THEME: CLIMATE ADAPTATION AND MITIGATION

GOALS & OBJECTIVES

This project will show the relationship between regional climate changes around the globe and ocean-surface-temperature changes. Climate changes may be forced to a large extent by both natural and anthropogenic changes in sea-surface temperatures.

ACCOMPLISHMENTS

To deepen our understanding of changes in the mean climate and climate variability during the last 140 years, we recently completed a study using large ensembles of three distinct types of observational and model-simulation data sets of the 1874–2010 period. The first type, the Twentieth Century Reanalysis version 2 (20CRv2) data set, is a 56-member ensemble of global atmospheric reanalyses at six-hourly resolution, produced by an international team led by CIRES and Physical Sciences Division scientists. These reanalyses come from an assimilation of atmospheric-surface-pressure observations in an ensemble Kalman filter-based assimilation system in which nine-hour forecasts serve as background "first guess" fields at each analysis time. The nine-hour forecasts originate from the National Centers for Environmental Predic-

tion (NCEP) Atmospheric General Circulation Model (AGCM), with specified observed sea-surface temperatures (SSTs), sea ice, and radiative forcings.

The second type of data set, which we refer to as the Atmospheric Model Intercomparison Project Twentieth Century (AMIP20C) data set, is a 56-member ensemble of AGCM simulations of the 1874–2010 period; we generate it using the same NCEP AGCM used to produce the 20CRv2 data set and with identical specifications of time-varying SST, sea ice, and radiative forcings.

The third type of data set is a multimodel ensemble of 62 Coupled Model Intercomparison Project phase 5 (CMIP5)–coupled climate-model simulations of the same 1874–2010 period with observed radiative forcings downloaded from the Program for Climate Model Diagnosis and Intercomparison (PCMDI) archive at daily resolution.

These three distinct types of data sets enable us to make cleaner separations of radiatively forced versus internal-natural climate variability than previously possible. We do this by interpreting the long-term variability in the 20CRv2 observational data set as a combination of internal chaotic, SST-forced, and radiatively forced variations; the variability of the ensemble-mean responses in the AMIP20C simulations as a combination of responses to both natural and radiatively forced SST variations; and the variability of the multimodel mean responses in the CMIP5 simulations as responses to the radiative-forcing variations.

The most important new result from this study is that the observed trends in many circulation variables during the second half (1943–2010) of the record are much weaker or nonexistent when calculated over the full record (1874–2010). We anticipated this conclusion in the original paper describing the 20CR project, but the new results put it on a solid footing and are much more comprehensive. The weakness of circulation trends during the full 136-year period has important implications for our understanding of the atmospheric-circulation response to global warming, and it casts doubt on inferences drawn about this response by many published studies that consider only the second half of the record. Consistent with the weak observed long-term circulation trends, we find that the long-term trends in the ensemble-mean AMIP20C and multimodel ensemble-mean CMIP5 simulations are also weak.

PSD-03 Diagnosis of Natural and Anthropogenic Contributions to Climate Variability, Including Changes in Extreme Weather Statistics

CIRES LEAD: PRASHANT SARDESHMUKH
NOAA LEAD: RANDALL DOLE
CIRES THEME: EARTH SYSTEMS DYNAMICS, VARIABILITY, AND CHANGE
NOAA THEME: CLIMATE ADAPTATION AND MITIGATION

GOALS & OBJECTIVES

A clearer separation of natural variations from anthropogenic influences in the climate system over the last 140 years will help explain climate variability better and improve the capacity for climate predictions.

ACCOMPLISHMENTS

Is global warming significantly affecting daily weather extremes? The answer to this trillion-dollar question depends on not just the mean shifts in the probability density functions (PDFs) of daily anomalies, but also on changes in the variance and shape of the PDFs. To assess the change in daily weather variability, we have used a simple measure of "storminess" at every point on the globe: the RMS (root-mean-square) 24-hour difference in sea-level pressure (SLP). We derived maps of the long-term mean stormines from an observational data set (specifically, the Twentieth Century Reanalysis version 2, 20CRv2) and a climate-model-simulation data set (Coupled Model Itercomparison Project phase 5, CMIP5) of the 1874–2010 period. These maps generally agree well with one another. The mean

Hurricane Sandy in 2012. Is global warming affecting weather extremes? CIRES staff work closely with NOAA colleagues to answer this question. Image credit: NASA/NOAA

storminess is about 10 millibars (mb) in the extra-tropical storm-track regions, i.e., the day-to-day variation of SLP in these regions is typically about 10 mb.

We have also produced maps of the change in the mean storminess from the first half of the record (1874–1942) to the second half (1940–2010). These changes are about 1 percent of the long-term mean storminess in the CMIP5 simulations and somewhat larger (3 percent to 5 percent) in the 20CRv2 data set, but these larger values are not statistically significant. The maps of the long-term change in storminess in the 20CRv2 and CMIP5 data sets are also not mutually consistent except in the mid-latitudes of the southern hemisphere, where we see a small but statistically significant enhancement of storminess.

This evidence of generally weak statistically significant changes in the mean SLP and daily SLP variability does not necessarily imply similar weak changes in the statistics of extreme daily SLP anomalies. This is because the PDFs of daily SLP variability are not Gaussian and are, therefore, determined by more than their first two statistical moments (mean and variance). The third and fourth moments (skewness and kurtosis) also come into play. To address this issue, we have used the first four moments to fit so-called SGS (Stochastically Generated Skewed) PDFs to the histograms of daily anomalies; we then used the fitted PDFs to draw inferences about changes in tail probabilities. We have initially focused on the PDFs of daily indices of four prominent modes of SLP variability: the North Atlantic Oscillation (NAO), the North Pacific Oscillation (NPO), the tropical Pacific Walker Circulation (PWC), and the Annular Antarctic Oscillation (AAO). We have fitted SGS distributions to the histograms of these indices in both the first and second halves of our 136-year record and assessed the statistical significance of any apparent changes in the PDFs through extensive Monte Carlo integrations with a "weather generator" model whose parameters are consistent with those of the fitted SGS distributions.

Applying this rigorous significance-testing procedure to changes in the statistics of the four circulation indices, we find no significant change in the mean of the NAO and NPO, and a small but significant positive shift in the mean of PWC and AAO from the first to the second half of the 136-year record. For the PDF as a whole, we find no significant changes in the PDFs of the NAO and NPO. The small positive mean shifts of the PWC and AAO PDFs are associated with increased probabilities of large positive values and reduced probabilities of large negative values. But these changes are much smaller and statistically insignificant for extreme positive values, beyond about 2.5 standard deviations. This result again highlights the importance of not drawing conclusions about the statistics of extremes from shifts of the mean.

PSD-04 An Experimental Approach to Climate Data and Web Services

CIRES LEAD: CATHERINE SMITH
NOAA LEAD: RANDALL DOLE
CIRES THEME: SCIENTIFIC OUTREACH AND EDUCATION
NOAA THEME: CLIMATE ADAPTATION AND MITIGATION

GOALS & OBJECTIVES

This project addresses regional use of climate information.

ACCOMPLISHMENTS

Using a Linear Inverse Model, our team is creating experimental forecasts of annually averaged global surface temperatures. We are making the forecasts available at http://www.esrl.noaa.gov/psd/forecasts/decadal/.

We also made available a wind-forecast project designed to enhance forecasts for wind-energy production. It is located at: http://www.esrl.noaa.gov/psd/psd3/wfip/. This Web page provides vertical cross sections of instrument data at various locations as well as cross sections made using the High-Resolution Rapid Refresh model.

Additionally, our team implemented a Web page for producing trajectory plots from various reanalysis data sets.

CIRES personnel have partnered with National Climate Predictions and Projections to provide Regional Climate Information on monthly to centennial timescales. Specifically, the partnership, which includes the North Central Climate Science Center is working to produce downscaled forecasts to connect climate science and understanding to ecosystem modeling.

Team members in the Physical Sciences Division produced and distributed a South American precipitation data set and made the data set available for interactive plotting. See http://www.esrl.noaa.gov/psd/data/gridded/data.southamerica.html.

We added and refined a set of Web pages for comparing and plotting reanalysis and other data sets. These are located at http://www.esrl.noaa.gov/psd/data/writ/. They include a mapping page, a trajectory page, and a time-series extraction page.

We also added several new data sets including those of Japanese air temperature, the Climate Research Unit 4, and the Global Historical Climate Network Climate Anomaly Monitoring System gridded air temperature data set. These are helpful for monitoring climate change, among other uses.

We upgraded the Thematic Real-time Environmental Distributed Data Services Data Server and added time-series aggregation of files split by time.

We are updating the teleconnection forecast time series (for Pacific North America, East Pacific, and the North Atlantic Oscillation) in real time and making available the ascii values as well.

We put the reforecast2 experimental forecast product online at: http://www.esrl.noaa.gov/psd/forecasts/reforecast2/. The reforecast project uses an ensemble of 11 forecasts to make probabilistic products.

PSD-05 Prediction of Extreme Regional Precipitation and Flooding

CIRES LEAD: DAVID KINGSMILL
NOAA LEAD: MARTY RALPH
CIRES THEME: REGIONAL SCIENCES AND APPLICATIONS
NOAA THEME: CLIMATE ADAPTATION AND MITIGATION

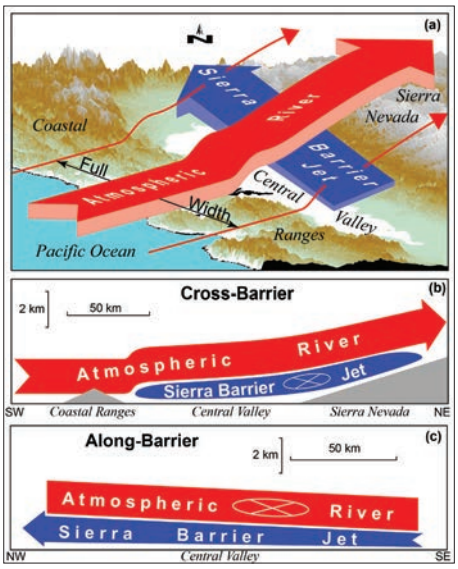
GOALS & OBJECTIVES

This project specifically addresses regional climate predictions.

ACCOMPLISHMENTS

Our group completed a study that characterized kinematic and thermodynamic structures of Sierra barrier jets (SBJs), atmospheric rivers (ARs), and their interaction from February14 -16, 2011, when a winter storm made landfall in northern California. Our team used a suite of scanning and profiling Doppler radars, rawinsondes, and Global Positioning System (GPS) receivers to document these structures across the Central Valley and up the western Sierra slope to the crest along an approximately 200-kilometer segment of the Sierra.

The winter storm occurred in two episodes, each having an AR that made landfall. Low-level winds in the SBJ observed during Episode 1 were southeasterly and embedded in a stably stratified air mass. Southwesterly winds associated with the AR overlaid the SBJ along an interface that sloped upward from southwest to northeast with a southwestern extent at the western edge of the Central Valley. In contrast, low-level winds in the SBJ observed during Episode 2 were more southerly and embedded in a less-stable air mass. Southwesterly winds associated with the AR overlying the SBJ tilted upward from southwest to northeast with a steeper slope, but did not extend as far southwest.



Schematic illustrations from (a) three-dimensional, (b) cross-barrier two-dimensional, and (c) along-barrier two-dimensional perspectives that depict the kinematic structure of Sierra barrier jets and atmospheric rivers observed during this study.

Another accomplishment relates to the cloud radar onboard the CloudSat satellite. We applied simultaneous retrievals of rain rate and ice-water path to observations of ARs over the northeastern Pacific Ocean during three consecutive cool-season periods (2006–2007, 2007–2008, and 2008–2009). Since the CloudSat measurements allow direct partitioning of rain types (i.e., no-brightband rain vs. brightband rain), we derived statistics for rain occurrences, the extent of AR rain bands, and rain rates for different rain types as a function of AR strengths, temperatures, and locations. We showed that overall brightband rain rates exceed those of non-brightband by a factor of 2 to 2.5. We also derived statistics between rain rates and amount of ice phase in the vertical atmospheric column for brightband rains with ice-phase presence aloft. We aimed for these statistics to provide observational context for verification of AR models over the ocean.

Other accomplishments focused on Web displays of hydrometeorological data for use by researchers and weather forecasters in assessing and monitoring extreme precipitation events along the U.S. West Coast. In addition to maintenance of previously developed products, we developed new products to allow users the ability to filter site data and image products based on various criteria such as site ID, instrument categories, data formats, agency type, data types, and site status. Also, we developed a new real-time display that overlays real-time and historical scanning radar data.

PSD-06 Diagnosis and Prediction of Subseasonal Climate Variations

CIRES LEAD: PRASHANT SARDESHMUKH
NOAA LEAD: RANDALL DOLE
CIRES THEME: EARTH SYSTEMS DYNAMICS, VARIABILITY, AND CHANGE
NOAA THEME: SCIENCE AND TECHNOLOGY ENTERPRISE

GOALS & OBJECTIVES

This project attempts an improvement in basic knowledge through a novel combination of models that could extend weather prediction beyond two weeks.

ACCOMPLISHMENTS

A new paradigm of convectively coupled equatorial waves (CCEW) has become popular in tropical meteorology during the last 15 years. This represents a modification of the Matsuno-Gill paradigm of tropical waves as eigenmodes of tropical disturbances on a background state of rest. The modification is apparently due to coupled interactions between deep atmospheric convection and the circulation dynamics that are ignored in the Matsuno-Gill theory. The modified CCEW paradigm has led to a conceptual framework in which most researchers currently perform and interpret observational, diagnostic, and predictability studies of subseasonal tropical variations (which have significant global impacts). But even after hundreds of studies, the glove doesn't quite fit. It still is not clear, for instance, to what extent deep convective variability on subseasonal scales drives the circulation variability; is organized by the circulation variability; or is, indeed, strongly coupled to the circulation variability as claimed.

To address this fundamental issue, we are conducting a study of

internal tropical atmospheric variability through a Linear Inverse Modeling (LIM) approach. This involves estimating the appropriate dynamical linear evolution operator for tropical disturbances through the zero-lag and time-lag covariances of the circulation and humidity fields. We are using 30 years of European Reanalysis (ERA)–Interim data for this purpose. The LIM procedure yields both the effective dynamical evolution operator for tropical anomalies and the statistical structure of the effectively stochastic forcing of those anomalies. Preliminary results from this analysis are already revealing. They show that the wavelike eigenmodes of the linear evolution operator are not mutually orthogonal, as they are in the Matsuno-Gill or the CCEW paradigm, and this non-orthogonality is important in influencing the growth and decay of observed tropical anomalies. They also show that not all of the important predictable dynamics are associated with wavelike modes, as the CCEW paradigm implicitly assumes. Coupling of the circulation and humidity does, however, affect the evolution of some modes, though not in a manner anticipated in the CCEW paradigm.

PSD-07 Sensor and Technique Development

CIRES LEAD: ANDREY GRACHEV
NOAA LEAD: CHRIS FAIRALL
CIRES THEME: EARTH SYSTEMS DYNAMICS, VARIABILITY, AND CHANGE
NOAA THEME: SCIENCE AND TECHNOLOGY ENTERPRISE

GOALS & OBJECTIVES

Technology development such as described in this project is the basis for increased sophistication of measurement, which in turn supports improved modeling and prediction.

ACCOMPLISHMENTS

Our team completed a report on a July 2012 cruise aboard the NOAA ship Hi'ilakai, and we submitted it to the NOAA Climate Observations Division. The group did the first eddy correlation measurements of carbon monoxide (CO) fluxes over the ocean. This involved working with an instrument manufacturer to use a modified version of the fast CO sensor suitable for seagoing deployment (Blomquist et al. 2012).

We also conducted a series of laboratory humidity sensitivity tests on three commercially available fast carbon dioxide (CO_2) sensors. We continued the tests with a deployment of two sensors on the *research vessel Revelle* during the Dynamics of the Madden-Julian Oscillation (DYNAMO) cruise. This study has shown the surprising sensitivity of eddy covariance CO_2 fluxes to a small error in the humidity crosstalk coefficients. Our results suggest a factor-of-five improvement in eddy covariance CO_2 flux measurements (Blomquist et al. 2013).

The group completed theoretical and computational simulations for a new technology for a sonic anemometer. This involves applying acoustic tomography processing to improve the spatial/temporal response. We are working to get NOAA to offer a Small Business Innovation Research (SBIR) grant to attract a commercial vendor (Vecherin et al. 2013).

Research vessel Revelle. Photo courtesy of Andrey Grachev/CIRES

We repackaged the Physical Sciences Division's W-band cloud radar to allow installation on a NOAA WP-3D research aircraft. We completed one trial fitting in Tampa, Fla., in April 2013. Modifications are underway, and we will install and test the radar on a WP-3D in July 2013.

Blomquist, BW, L Bariteau, JW Edson, CW Fairall, JE Hare, WR McGillis, BJ Huebert, SD Miller, and ES Saltzman. 2013. Advances in ship-based air-sea CO_2 flux measurement by eddy covariance. *J. Geophys. Res.* Submitted.

Vecherin, SN, VE Ostashev, CW Fairall, DK Wilson, and L Bariteau. 2013. Sonic anemometer as a small acoustic tomography array. *Bound.-Layer Meteorol.* Submitted.

PSD-08 Cloud, Aerosol, and Water Vapor Observations and Research

CIRES LEAD: MATTHEW SHUPE
NOAA LEAD: TANEIL UTTAL
CIRES THEME: EARTH SYSTEMS DYNAMICS, VARIABILITY, AND CHANGE
NOAA THEME: SCIENCE AND TECHNOLOGY ENTERPRISE

GOALS & OBJECTIVES

This project provides state-of-the-art measurements of climate-related variables over a broad geographic area.

ACCOMPLISHMENTS

A preeminent theme of CIRES cloud observational work relates to

Arctic mixed-phase stratiform clouds. In collaboration with colleagues, we recently used multiyear satellite observations to demonstrate that liquid-containing clouds occur frequently across the Arctic. In 2008, CIRES researchers took part in the Arctic Summer Cloud Ocean Study (ASCOS), an observational campaign from an icebreaker stationed near the North Pole. Using multisensor observations from this experiment, we conducted a detailed study of low-level, stratiform, mixed-phase clouds to examine the atmospheric mixing processes associated with these clouds (Shupe et al. 2013a). Following on this theme, a collaborative analysis has led to a multiyear characterization of cloud microphysical and radiative properties at the Eureka station in northern Canada (Cox et al. 2013) and an evaluation of the effect of aerosols on these clouds (Hildner et al. 2013). Many of the cloud microphysical and dynamical properties data sets associated with these studies are now in the data archive of the Department of Energy's Atmospheric Radiation Measurement Program.

A number of research activities recently have emerged from the Integrated Characterization of Energy, Clouds, Atmospheric state, and Precipitation at Summit (ICECAPS) project, which is an observational activity at Summit Station atop the Greenland Ice Sheet (GIS). ICECAPS observations include cloud radar, lidar, microwave and infrared radiometers, precipitation sensor, and twice-daily radiosondings. The project had two recent, high-profile cover stories. The first was an overview of the project appearing in the *Bulletin of the American Meteorological Society* (Shupe et al. 2013b). The second, in *Nature*, offered an explanation of the important role clouds played in the extreme GIS melt event of July 2012 (Bennartz et al. 2013). Additional ICECAPS papers have examined the low-level atmospheric stability (Miller et al. 2013) and documented a new cloud lidar for looking at ice-crystal orientation (Neely et al. 2013).

CIRES researchers participated in the Storm Peak Cloud Properties Validation Experiment (StormVex) in 2010–2011 near Steamboat Springs, Colo. This experiment targeted mixed-phase cloud processes in a mountainous environment and their impact on precipitation development. The experiment led to two recent papers. These papers examine the potential of using scanning, ground-based radar to characterize snow/ice crystal habit (Matrosov et al. 2012) and to correct for radar-reflectivity biases due to oriented ice crystals (Marchand et al. 2013).

CIRES researchers have coordinated with NOAA personnel to evaluate the utility of an array of dropsonde measurements made from a large, unmanned aircraft system over the central Arctic. We used these atmospheric profile measurements to examine processes related to the Polar Vortex, low-level boundary layer structure, and also to evaluate model reanalysis products (manuscript in preparation).

We use a number of modeling tools to examine Arctic cloud, aerosol, and atmosphere properties. A high-resolution, large eddy simulation model formed the basis for a sensitivity study that considered the relative importance of moisture sources from above and below a mixed-phase cloud layer (Solomon et al. 2013). This study found that as long as a moisture reservoir was present either above or below, the cloud could be sustained for a day or more, but the cloud would collapse without these reservoirs. Additionally, we used high-resolution models to improve our understanding of aerosol effects on the lifetime and properties of liquid water in these mixed-phase clouds (de Boer et al. 2013a).

Finally, we used a variety of measurements to evaluate how reanalyses and global climate models simulate the Arctic atmosphere and clouds (manuscripts in preparation) and to illustrate the struggles faced by climate models in simulating aerosol-cloud interactions (de Boer et al. 2013b).

Cox, CJ, DD Turner, PM Rowe, MD Shupe, and VP Walden. 2013. Cloud microphysical properties retrieved from downwelling infrared radiance measurements made at Eureka, Nunavut, Canada (2006–2009). *J. Appl. Meteor. Clim.* Under review.

de Boer, G, T Hashino, GJ Tripoli, and EW Eloranta. 2013a. A numerical study of aerosol influence on mixed- phase stratiform clouds through modulation of the liquid phase. *Atmos. Chem. Phys.* 13:1733-1749.

de Boer, G, S Menon, SE Bauer, T Toto, and A Vogelmann. 2013b. Evaluation of aerosol-cloud interactions in the GISS ModelE using ASR observations. *J. Geophys. Res.* Accepted.

Hildner, R, GJ Tripoli, EW Eloranta, and G de Boer. 2013. Obser-

The Mobile Science Facility at Summit, Greenland,houses the National Science Foundation–sponsored Integrated Characterization of Energy, Clouds, Atmospheric state, and Precipitation at Summit (ICECAPS) Project.

Photo credit: Mattew Shupe

vational evidence for anthropogenic effects on Arctic boundary layer clouds over Eureka, Nunavut. *J. Appl. Meteor. Clim.* Under review.

Marchand, R, GG Mace, AG Hallar, IB McCubbin, SY Matrosov, and MD Shupe. 2013. Enhanced radar backscattering due to oriented ice particles at 95-GHz during StormVex. *J. Atmos. Oceanic Technol.* Under review.

Miller, NB, DD Turner, R Bennartz, MD Shupe, MS Kulie, MP Cadeddu, and VP Walden. 2013. Surface-based inversions above central Greenland. *J. Geophys. Res.* 118:495-506.

Neely III, RR, M Hayman, R Stillwell, JP Thayer, RM Hardesty, M O'Neill, MD Shupe, and C Alvarez. 2013. Polarization LIDAR at Summit, Greenland for the detection of cloud phase and particle orientation. *J. Atmos. Ocean. Technol.* Forthcoming.

Shupe, MD, POG Persson, IM Brooks, M Tjernström, J Sedlar, T Mauritsen, S Sjogren, and C Leck. 2013a. Cloud and boundary layer interactions over the Arctic sea-ice in late summer. *Atmos. Chem. Phys. Diss.* 13:13191-13244.

Shupe, MD, DD Turner, VP Walden, R Bennartz, M Cadeddu, B Castellani, C Cox, D Hudak, M Kulie, N Miller, RR Neely III, W Neff, and P Rowe. 2013b. High and dry: New observations of tropospheric and cloud properties above the Greenland Ice Sheet. *Bull. Amer. Meteor. Soc.* 94:169-186.

Solomon, A, MD Shupe, POG Persson, H Morrison, T Yamaguchi, G Feingold, PM Caldwell, and G de Boer. 2013. The sensitivity of springtime Arctic mixed-phase stratocumulus clouds to surface layer and cloud-top inversion layer moisture sources. *J. Atmos. Sci.* Under review.

PSD-09 Air-Sea Interaction

CIRES LEAD: ANDREY GRACHEV
NOAA LEAD: JIAN-WEN BAO
CIRES THEME: EARTH SYSTEMS DYNAMICS, VARIABILITY, AND CHANGE
NOAA THEME: SCIENCE AND TECHNOLOGY ENTERPRISE

GOALS & OBJECTIVES

This project provides measurements of climate-related variables at the state of the art over a broad geographic area.

ACCOMPLISHMENTS

During the reporting period, our team did not conduct any field deployments, but we reported in several publications research results from previous studies (Angevine et al. 2012; De Szoeke et al. 2012; Helmig et al. 2012; and McBride et al. 2012). Publications in 2013 include Rodriguez-Alvarez et al.

Our group created a data and science synthesis Web page for the Variability of the American Monsoon Systems Ocean-Cloud-Atmosphere-Land study. See http://people.oregonstate.edu/~deszoeks/synthesis.html. Several publications on this have appeared (most recent is De Szoek et al. 2012). We submitted a review paper that is now in revision (Mechoso et al. 2013). Another 2013 publication in submission is Ghate et al.

Our work on sea-spray effects on hurricanes has continued in model studies during investigations into physical parameterizations on hurricane structure (Bao et al. 2012; and Gopalakrishnan et al. 2013). We released the latest version of the hurricane flux parameterization in January 2013 (ftp://ftp1.esrl.noaa.gov/users/cfairall/onr_droplet/parameterization/version11_kb/).

We made the results from the Gas Exchange III field program publically available as the Coupled Ocean–Atmosphere Response Experiment gas flux algorithm version 3.1: ftp://ftp1.esrl.noaa.gov/users/cfairall/bulkalg/gasflux/COAREG31_vectorized. We have extended this work to carbon monoxide (Blomquist et al. 2012).

Ghate, VP, BA Albrecht, MA Miller, A Brewer, and CW Fairall. 2013. Turbulence and radiation in stratocumulus topped marine boundary layer: a case study from VOCALS-Rex. *J. Geophys. Res.* Submitted.

Gopalakrishnan, G, F Marks, JA Zhang, X Zhang, JW Bao, and V Tallapragada. 2013. A study of the impacts of vertical diffusion on the structure and intensity of the tropical cyclones using the high-resolution HWRF system. *J. Atmos. Sci. 70:524–541.*

Mechoso, CR, R Wood, R Weller, CS Bretherton, AD Clarke, H Coe, CW Fairall, JT Farrar, G Feingold, R Garreaud, C Grados, JC McWilliams, SP de Szoeke, SE Yuter, and P Zuidema. 2013. Ocean-cloud-atmosphere-land interactions in the southeastern Pacific: the VOCALS Program. *Bull. Am. Meteorol. Soc.* Forthcoming.

Rodriguez-Alvarez, N, DM Akos, VU Zavorotny, JA Smith, A Camps, and CW Fairall. 2013. Airborne GNSS-R wind retrievals using Delay-Doppler maps. IEEE Trans. *Geosci. Remote Sens.* 51:626-41.

PSD-10 Physical Processes Controlling the Arctic Surface Energy Budget

CIRES LEAD: OLA PERSSON
NOAA LEAD: JANET INTRIERI
CIRES THEME: EARTH SYSTEMS DYNAMICS, VARIABILITY, AND CHANGE
NOAA THEME: SCIENCE AND TECHNOLOGY ENTERPRISE

GOALS & OBJECTIVES

This project provides analysis and modeling of climate-related processes with a focus on those affecting the mass balance of Arctic sea ice and Arctic soil temperatures.

ACCOMPLISHMENTS

During our team's research to understand the Arctic surface energy budget, we focused on the interactions among: long-range atmospheric transport, cloud formation/microphysics, surface energy budget, impacts on sea-ice internal structure during the Arctic winter, and boundary-layer coupling processes. These studies included modeling efforts using either a highly nested version of the Weather Research and Forecasting model or a pure Large-scale Eddy Simula-

tion (LES) model.

One analysis focus was on processes during a 12-day period in early January during the Surface Heat Budget of the Arctic Ocean (SHEBA) program, with key results showing that long-range transport of mid-level heat/moisture through the Fram Strait led to supercooled clouds over the Beaufort Sea, producing large increases in longwave radiation, significant surface warming, and thermal waves penetrating the sea ice. Mesoscale modeling and examination of reanalysis output showed that both had difficulties producing the supercooled liquid water in these clouds necessary for the energy transfer to the surface.

During the Arctic Summer Cloud Ocean Study (ASCOS), we conducted another observational study of Arctic stratocumulus clouds over the Central Arctic pack ice. It showed that overturning in these clouds is, at times, coupled with surface eddies and, at other times, uncoupled. Because aerosols occurred in greater concentrations within the cloud mixed layer and only increased near the surface when coupling occurred, the study suggests that the aerosol source in the near-surface environment over sea ice is primarily from long-distance advective processes and vertical coupling within the boundary layer. Furthermore, it suggests that a primary source for cloud condensation nuclei (CCN) in Arctic mixed-phase clouds, which are key for the surface energy budget and documented in another study, is through long-range transport rather than from local sources. The paper resulting from this study did not address, however, to what extent the coupling impacts the surface energy budget.

Finally, an LES modeling study showed the importance of a moisture inversion above Arctic stratocumulus clouds for maintaining these clouds. These results are topics of various conference presentations and manuscripts that we've either submitted or are preparing. In collaboration with international colleagues under the National Science Foundation (NSF) Cloud-Atmospheric boundary layer-Surface project and the Department of Energy Cloud project, we are conducting studies of boundary layer turbulent structures and cloud-surface coupling, using data from the indirect and Semi-Direct Aerosol Campaign (ISDAC) and ASCOS field programs. A number of collaborative papers are at various stages, with the aim of including them in the ASCOS special issue.

Our team completed some work on the NSF Study of Environmental Arctic CHange grant by processing data from Eureka and comparing surface energy budgets at Alert and Eureka. Though only 2.5 degrees latitude separate these sites and they are on the same Canadian Arctic island, the soil active layer in summer persists for 91 to 95 days in Eureka and only 50 to 55 days in Alert. Differences in the winter snowfall and evolution appear to be the key factors producing this difference in the summer soil.

In addition, we completed and published a detailed study on the applicability of local similarity theory for surface energy fluxes in the very stable Arctic environment. We also began (but did not complete) further work to provide better quality-assessment of the radiation data at Eureka. We gave a presentation on this topic at the First Tiksi Science Meeting in St. Petersburg, Russia.

During 2012, our team spent a significant amount of time organizing and advancing the concept of an interdisciplinary observatory drifting in the Arctic Ocean (Multidisciplinary drifting Observatory for the Study of Arctic Climate, MOSAiC) to launch within the next five years in collaboration with international colleagues. A key component of MOSAiC would be to better understand the temporal and spatial variability of the surface energy budget over the Arctic Ocean. We also held a science-plan writing workshop in Germany in May 2013. We then made presentations on this concept at a variety of venues throughout the year, including a white paper submitted to the Arctic Observing Summit.

PSD-11 Distributions of Raindrop Size

CIRES LEAD: CHRISTOPHER WILLIAMS
NOAA LEAD: ROB CIFELLI
CIRES THEME: EARTH SYSTEMS DYNAMICS, VARIABILITY, AND CHANGE
NOAA THEME: SCIENCE AND TECHNOLOGY ENTERPRISE

GOALS & OBJECTIVES

This project provides basic scientific information on raindrop size, which will support improved accuracy in estimation of rainfall based on cloud characteristics.

ACCOMPLISHMENTS

During the past year, our team described and published a dual-frequency retrieval technique that uses 50- and 920-Mhz radar spectra to estimate the vertical air motion in precipitating clouds (Williams 2012). The dual-frequency retrieval technique uses a 50-MHz radar to observe both the vertical air motion and precipitation motion, while a 920-MHz radar observes just the precipitation motion. By analyzing the Doppler velocity spectra, we use the 920-MHz radar precipitation signal to mask-out the precipitation signal in the 50-MHz radar spectra, leaving just the vertical air motion signal.

We applied the dual-frequency air motion retrieval technique to two data sets. The first data set included five rain events during the Mid-latitude Continental Convective Cloud Experiment (MC3E), from April to May, 2011. And the second data set included two wet seasons of 50-Mhz and 920-MHz radar spectra from Darwin, Australia (seasons 2005–2006 and 2006–2007). After estimating the vertical air motions, we estimated the raindrop size distribution (DSD) in the vertical rain column. The MC3E air motion and DSD estimates are now in the Department of Energy's Atmospheric Radiation Measurement (ARM) public archive. Researchers at the Centre for Australian Weather and Climate Research in Melbourne, Australia, are evaluating the Darwin air motion estimates before they become open to the public.

We used the dual-frequency vertical air motion estimates from Darwin to check the veracity of vertical air motions estimated using the dual-Doppler technique and two scanning radars. After comparing the vertical air motions near the profiler site, we processed more than 1,000 radar volumes to construct statistical profiles of vertical

air motion in the Darwin area during the Tropical Warm Pool-International Cloud Experiment, January 2006. Details of this study appear in Collis et al. (2013).

During the MC3E field campaign, four vertically pointing radars operated next to each other. Two of the four radars are well-calibrated (specifically, the 35-GHz Ka-band ARM zenith radarm KAZR, and the 2.8-GHz S-band radar), and we used them to check the calibration of the other two radars (the 915-MHz and 449-MHz radars). We determined that the 915-MHz profiler data need extra signal-processing steps to calibrate the profiler data. Details appear in Tridon et al. (2013).

Collis, S, A Protat, PT May, and CR Williams. 2013. Statistics of storm updraft velocities from TWP-ICE including verification with profiling measurements. *J. Appl. Meteor. Climatol.* Forthcoming.

Tridon, F, A Battaglia, P Kollias, E Luke, and CR Williams. 2013. Signal post-processing and reflectivity calibration of the Atmospheric Radiation Measurement program 915 MHz wind profilers. *J. Atmos. Oceanic Technol.* Forthcoming.

PSD-12 Analysis of the Causes of Extreme Weather Events

CIRES LEAD: JUDITH PERLWITZ
NOAA LEAD: RANDALL DOLE
CIRES THEME: SYSTEMS AND PREDICTION MODELS DEVELOPMENT
NOAA THEME: WEATHER-READY NATION

GOALS & OBJECTIVES

This project will promote more accurate forecasting of extreme events.

ACCOMPLISHMENTS

Our team published a paper on the causes of the 2011 Texas heatwave. We also submitted a paper on the causes of the record warmth in the central and eastern United States during March 2012, when daily temperature anomalies at many locations exceeded 20 degrees Celsius. In the paper, we examine how physical factors spanning climate and weather contributed to that record warmth.

Over this region, March temperatures have warmed by approximately 1 degree Celsius since 1901. This long-term regional warming is an order of magnitude smaller than temperature anomalies observed during the event, indicating that most of the extreme warmth must be explained by other factors. Several lines of evidence strongly implicate natural variations as the primary cause for the extreme event. The 2012 temperature anomalies had a close analogue in an exceptionally warm March that occurred in the United States more than 100 years earlier. This provides observational evidence that natural variability alone could produce an extreme event similar to March 2012.

Coupled model forecasts and simulations forced by observed sea-surface temperatures (SSTs) show that forcing from anomalous SSTs increased the probability of extreme warm temperatures in March 2012 above that anticipated from the long-term warming trend. In addition, forcing associated with a strong Madden-Julian Oscillation further increased the probability for extreme U.S. warmth and provided important additional predictive information on the timing and spatial pattern of temperature anomalies. The results indicate that the superposition of a strong natural variation similar to March 1910 on long-term warming of the magnitude observed would be sufficient to account for the record warm March 2012 U.S. temperatures.

We conclude that the extreme warmth over the central and eastern United States in March 2012 resulted primarily from natural climate and weather variability, a substantial fraction of which was predictable.

Hoerling, M, et al. 2013. Anatomy of an extreme event. *J. Climate.* 26:2811–2832.

PSD-13 Effects of the Tropical Ocean on Weather and Climate

CIRES LEAD: LESLIE HARTTEN
NOAA LEAD: CÉCILE PENLAND
CIRES THEME: EARTH SYSTEMS DYNAMICS, VARIABILITY, AND CHANGE
NOAA THEME: CLIMATE ADAPTATION AND MITIGATION

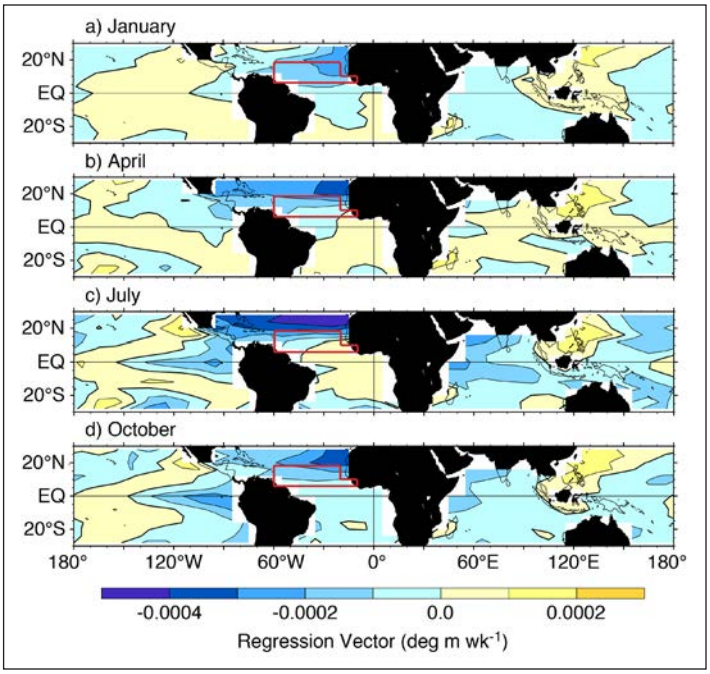
GOALS & OBJECTIVES

This project will help build a basis for forecasting climate variability associated with the temperature and moisture conditions in and over the tropical oceans, which have effects on climate in large portions of the United States and Central America as well as around the globe.

ACCOMPLISHMENTS

Our team's accomplishments fall into two distinct subtopics. One involves using observations from field programs and employing novel techniques to study lower-tropospheric processes in the East Pacific. The other involves using global gridded data sets to investigate the contribution of short-term variability centered above the North Atlantic to longer-term variability in the tropical Atlantic.

Stratocumulus (Sc) clouds occur frequently over the cold waters of the southeastern Pacific Ocean. Data collected during two Pan American Climate Study research cruises in the tropical East Pacific offer many opportunities to study various structural aspects of this Sc-topped marine boundary layer (MBL). The focus during the past year has been on understanding gaps in detectable wind-profiler reflectivities during boreal fall cruises in 2000 and 2004. After rigorously quality-controlling the data, we found many instances with



Seasonal maps of the regression of rapidly varying sea-surface-temperature (SST) forcing onto the North Atlantic Oscillation (NAO), with larger values showing where SST forcing can be parameterized by the NAO index. The north tropical Atlantic region is outlined in red.

no measureable atmospheric signals through a depth of up to several hundred meters, often for an hour or more.

We used rain gauge data from the fall 2004 cruise to calibrate the profiler, which allowed us to convert signal-to-noise ratio to both equivalent reflectivity, Z_e, and the structure-function parameter of the index of refraction, Cn2. Profiles of minimum detectable Z_e indicate this 915-megahertz profiler was not detecting cloud particles. Considering the gaps in terms of Cn2 profiles allows us to understand them as indications of reduced "top-down" buoyancy processes and/or reduced turbulent intensity. Previous researchers have demonstrated both of these are associated with decoupling of the Sc-topped MBL. The absence of valid profiler reflectivity in this setting may, therefore, be used as a proxy for decoupled conditions. In November 2012, we submitted a manuscript describing these results to the *Journal of Applied Meteorology and Climatology* for its 2012 Special Collection on International Symposium for the Advancement of Boundary-Layer Remote Sensing 2012 presentations (Hartten et al. 2013). Reviewers requested various revisions, which we returned in March 2013, and one reviewer requested additional observational verification of decoupled MBL conditions, which we've nearly completed.

The North Atlantic Oscillation (NAO) is a rapidly decorrelating system that strongly affects the climate of the Atlantic and the surrounding continents. Although the NAO itself is basically unpredictable on seasonal timescales, our research during the past year shows that NAO forcing has a significant impact on north tropical Atlantic (NTA) SSTs evolving on those timescales. Annually varying maps of the rapidly varying nonlinearities associated with the NAO regression vector are shown in the figure; the NTA region is outlined in red.

The largest sensitivity to the NAO index is in the North Atlantic, especially during boreal summer. The high sensitivity during July is especially notable because both NAO variability and the correlation between NAO and stochastic forcing in the NTA region are weakest June through August. Even though this sensitivity occurs north of our NTA region, the linear deterministic dynamics spatially redistribute the forcing over time. In the north tropical and subtropical Atlantic, our analysis indicates that the NAO has a strong effect on surface winds, whose weakening during the negative phase of the NAO and strengthening during the positive phase directly affect NTA SSTs. Results employing linear inverse modeling imply that quantitative knowledge of the NAO index and of its convolution with deterministic SST dynamics would nearly double forecast skill of north tropical Atlantic sea-surface tmperature (SST) at lead times greater than nine months. These results could constitute a goal for General Circulation Models (GCMs) and could help either validate coupled GCMs or identify processes incompletely captured in them. A manuscript presenting this work (Penland et al. 2013) is nearly ready for submission.

Hartten, LM, and PE Johnston. 2013. Stratocumulus-topped marine boundary layer processes revealed by the absence of profiler reflectivity. *J. Appl. Meteor. Clim.* In revision.

Penland, C, and LM Hartten. 2013. Stochastic forcing of north tropical Atlantic sea-surface temperatures by the North Atlantic Oscillation. *Geophys. Res. Lett.* In preparation.

PSD-14 Forecasts for Wind Energy

CIRES LEAD: LAURA BIANCO
NOAA LEAD: JAMES WILCZAK
CIRES THEME: SYSTEMS AND PREDICTION MODELS DEVELOPMENT
NOAA THEME: SCIENCE AND TECHNOLOGY ENTERPRISE

GOALS & OBJECTIVES

This project will quantify improvements made to numerical weather prediction models by assimilating in new observations and by developing and implementing new model physical parameterization schemes.

ACCOMPLISHMENTS

The U.S. Department of Energy sponsored a joint research project with NOAA and private industry to improve wind-energy forecasts, the Wind Forecast Improvement Project (WFIP). The key elements of this program have been:

1) From August 2011 to September 2012, one-year deployment of extensive meteorological observing systems (10 915-mHz and two 449-mHz wind-profiling radars, 12 sodars, several instrumented tall towers, and approximately 400 nacelle anemometers) in two regions with significant wind-energy production;

2) Assimilation of these observations into the research version of

Photo credit: David Oonk/CIRES

the hourly updated NOAA Rapid Refresh (RAP) model and the High-Resolution Rapid Refresh (HRRR) model run nationwide at 13-km (RAP) and 3-km (HRRR) resolution;

3) Evaluation of the benefits of these improved wind forecasts on electrical utility operations, including financial savings (more efficient use of wind turbines), especially for ramp-events in the zero- to six-hour forecast timeframe.

In the framework of WFIP, we were prepared to extensively quality-control the data, and we worked on a combination of well-accredited algorithms and newly developed ones to remove any contamination from the data before assimilating them into the models.

During the course of the campaign, we continuously performed statistical analyses to prove that we were, indeed, improving the forecast. On the other side, since we were continuously updating or modifying the models during the length of the campaign, this "on the road" analysis is only preliminary, not final.

Once we reached the end of the campaign, we decided to focus our attention on two weeks for each season and rerun the models (fixed versions of them now) for data-denial experiments (with and without extra observational data-set assimilation) on these weeks only, to produce a consistent statistical study. We started by choosing two weeks in winter (one in December 2011 and one in January 2012) and then compared the forecasts of the model outputs with the tall towers observations.

Improvements were certainly noticeable, particularly up to forecast hour six, so the first real outcome of the WFIP campaign showed very encouraging results. We have presented results relative to the winter weeks at various conferences and meetings as well as at monthly meetings with the other parties involved in the campaign.

We moved on with the selection of the summer period (we selected two weeks in June 2012), and we reran the models with and without assimilating the extra data to see the impact the forecast would experience. The summer experiment showed a positive impact from assimilating extra data as well, and we moved on to choosing the two spring weeks (in April 2012). In May 2013, we obtained the run of the model without the extra data-set assimilation, and we are waiting to obtain the output from the run with extra data assimilation in order to start analyzing the results for the spring season.

Another very important study started inside the WFIP framework is the development of a "Ramp Tool" to identify ramp events in a series of data and compare observed events with modeled ones. The definition of a ramp is still very unclear, and it can change from operator to operator. We experimented with different methods to automatically identify different types of ramps in a time series of data. We then developed a method to match events in different time series (observed and modeled ones) that we want to compare, and we finally developed a metric to rate the skill of a model in identifying ramp events.

PSD-15 An Assessment of Skill and Reliability of Regional Climate Predictions

CIRES LEAD: KATHY PEGION
NOAA LEAD: ROBERT WEBB
CIRES THEME: EARTH SYSTEMS DYNAMICS, VARIABILITY, AND CHANGE
NOAA THEME: CLIMATE ADAPTATION AND MITIGATION

GOALS & OBJECTIVES

This project will provide decision makers with a better understanding of the skill and reliability of regional climate information.

ACCOMPLISHMENTS

Using state-of-the-art models for deterministic skill measures, our team assessed the current seasonal forecast skill of temperature and precipitation for forecasts initialized in late summer 2012 and valid in spring 2013. Specifically, we have focused on six-month lead forecasts with August initial conditions. These forecasts are valid March through May.

We performed the assessment using the current National Centers for Environmental Prediction (NCEP) operational seasonal forecast model, the Climate Forecast System version 2 (CFSv2), and the suite of experimental seasonal forecasts from the National Multi-Model Ensemble (NMME) project of which CFSv2 is a contributor. At the time we performed the analysis, NMME consisted of eight models of varying ensemble size and forecast length and three variables: sea-surface temperature, 2-meter temperatures, and precipitation. Six of these models make forecasts long enough to be useful for this analysis. Results indicate that in the Missouri River Basin, neither the individual model ensemble means nor the NMME ensemble mean have useful correlation skill (defined as a correlation greater than 0.3) at these long lead times. These results are not surprising since there is no signal from the El Niño Southern Oscillation (ENSO) in this region to provide long-lead skill and since summer is a time of weak tropical forcing.

Further assessment of skill in the Missouri River Basin indicates that for forecasts initialized in August, even at short lead times (two weeks to one month), the skill of temperature and precipitation is generally less than correlations of 0.3.

We also analyzed the current limits of predictability over the Missouri River Basin for temperature and precipitation using the NCEP/CFSv2 model and compared that skill with the skill of perfect model forecasts. We again focused on forecasts initialized in August and valid March through May. Perfect model skill is an estimate of the upper limit of predictability, but we know it to be an overestimate since models are much better at predicting themselves than nature.

The result of this analysis indicates that even for perfect model forecasts, there is only minimum skill (correlations less than 0.3) over most of the MRB, though correlations are between 0.3 and 0.4 in eastern North and South Dakota for temperature. This further emphasizes the fact that there is little potential for skill of temperature and precipitation forecasts initialized in summer at these long lead-times.

Our team also met with partners and decision makers to present these preliminary results and understand the variables and timescales of management concerns and needs. Specifically, we traveled with NOAA partners to Omaha, Neb., to meet with the U.S. Army Corps of Engineers (USACE) from April 27-28, 2013. At this meeting, we presented preliminary results and engaged with the USACE management and decision makers to understand their needs; what aspects of our analysis are useful to them; and what specific analyses would be beneficial to meet their needs. Our goals for the coming year resulted from that meeting. We learned several things critical to the direction of this project, including:

- USACE is primarily interested in precipitation forecasts for the MRB. Other variables are not critical to their specific operations, though snowpack may, at times, be important.
- Skill in the upper vs. lower Missouri River Basin is important because of the location of their controls.
- Even if skill is low at long lead times, they would like to know at what lead times there is skill for spring and summer.
- The public and political arenas often expect them to have more skill during El Niño/La Niña times, so they would like clear documentation of the skill for these times.
- May is a key month for their operations.

Predictability is not particularly useful information to them.

PSD-16 Understanding and Explaining the Role of Extremes in Missouri Basin Flooding

CIRES LEAD: XIAOWEI QUAN
NOAA LEAD: ROBERT WEBB
CIRES THEME: EARTH SYSTEMS DYNAMICS, VARIABILITY, AND CHANGE
NOAA THEME: CLIMATE ADAPTATION AND MITIGATION

GOALS & OBJECTIVES

This project will support NOAA's Mission Goals "To understand and predict changes in climate, weather, oceans, and coasts" and "To share that knowledge and information with others" by providing the credible science that other agencies, state, and local decisions makers, and the private sector require.

ACCOMPLISHMENTS

Our team conducted several ensemble climate model simulations including:

1) Multi-hundred year "control" runs of the two Atmospheric General Circulation Models (AGCM), forced with 1979–2010 climatological annual cycle of sea-surface temperatures and sea ice;

2) 20-member Atmospheric Model Intercomparison Project–type simulations of two AGCMs—the Community Atmosphere Model 4 and the European Centre Hamburg 5—forced with observed 1979–2012 SSTs and sea-ice evolution;

3) A 500-year fully coupled run of the Community Climate System Model 4 (CCSM4), forced with preindustrial radiative forcing; and

4) A 1,000-year fully coupled run of CCSM4, forced with present-day radiative forcing.

PSD-17 Understanding How Tropical SSTs Influence Atmospheric Variability

CIRES LEAD: TAO ZHANG
NOAA LEAD: MARTIN HOERLING
CIRES THEME: EARTH SYSTEMS DYNAMICS, VARIABILITY, AND CHANGE
NOAA THEME: CLIMATE ADAPTATION AND MITIGATION

GOALS & OBJECTIVES

This project will promote more accurate prediction of North American climate variability beyond a simple linear response to ENSO forcing.

ACCOMPLISHMENTS

Our team completed 50-member Atmospheric Model Intercomparison Project (AMIP) runs and 30-member, empirical-orthogonal-function (EOF) sea-surface-temperature (SST) runs of the Global Forecast System version 2 (GFSv2) model that covered the period 1979 to 2012. We presented the results from the simulations at the U.S. Climate Variability and Predictability Research Program ENSO Diversity Workshop in Boulder, Colo.

Preliminary results show that there are two dominant flavors of El Niño and two distinguishable teleconnections associated with the El Niño flavors. El Niño/La Niña SST asymmetry can yield two distinguishable teleconnections. Amplitude variability of leading SST EOF also yields two distinguishable teleconnections.

We also have submitted a paper on the causes of the March 2012 record warmth of the central and eastern United States (Dole et al. 2012)

Finally, we are preparing another draft for *Geophysical Research Letters*. The lead author is Chris Funk, and the title will be "Predicting and attributing recent East African spring droughts with dynamical-statistical climate model ensembles."

Dole, R, et al. 2012. The making of an extreme event: Putting the pieces together. *Bull. Amer. Met. Soc.* Submitted.

PSD-18 Linking Changes in Climate to Water Resources Management Outcomes

CIRES LEAD: JON EISCHEID
NOAA LEAD: MARTIN HOERLING
CIRES THEME: EARTH SYSTEMS DYNAMICS, VARIABILITY, AND CHANGE
NOAA THEME: CLIMATE ADAPTATION AND MITIGATION

GOALS & OBJECTIVES

This work is to explain to decision makers what climate variables are potentially responsible for different water-resource-management outcomes.

ACCOMPLISHMENTS

Progress in this project relies on information that has not yet been provided by the U.S. Army Corps of Engineers. CIRES will report on progress in the next annual report to NOAA.

Space Weather Prediction Center

SWPC-01 Space Weather Information Technology and Data Systems

CIRES LEAD: DAVID STONE
NOAA LEAD: STEVEN HILL
CIRES THEME: SPACE WEATHER UNDERSTANDING AND PREDICTION
NOAA THEME: SCIENCE AND TECHNOLOGY ENTERPRISE

GOALS & OBJECTIVES

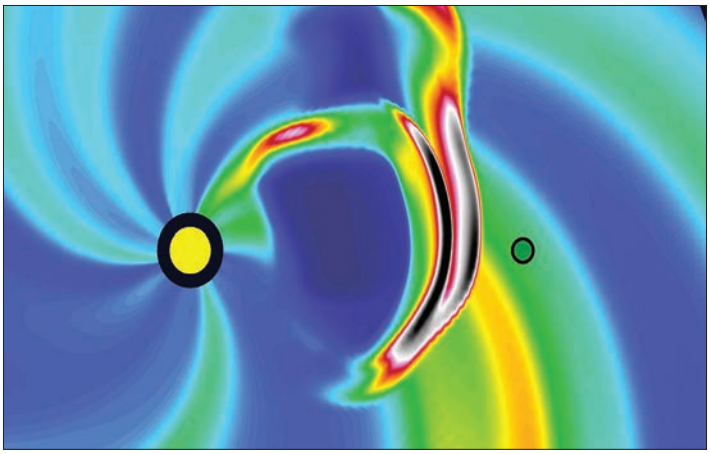
This project will determine the necessary research data systems and infrastructure required to successfully implement the empirical and physical scientific models of the space weather environment.

ACCOMPLISHMENTS

Our team transitioned the Wang-Sheeley-Arge (WSA)–Enlil model into operations. For this work, federal team members received the NOAA Silver Medal of Achievement. We also lead the development of a new, advanced version of the WSA-Enlil model that allows for continuous updating of the ambient solar wind.

Our team provided project leadership for several important efforts: porting of software implemented on Red Hat Enterprise Linux (RHEL) 4.x servers to RHEL 5.x and virtualizing critical hardware systems as the Space Weather Prediction Center (SPWC) prepares for Continuity of Operations.

Our group successfully led the Development and Transition Section to an Agile development methodology, which better integrated change management and provided greater planning visibility for project efforts. A group member served as scrum master, product owner, and project manager for a team of five federal employees tasked with the design, implementation, and rehosting of SWPC's public website. This individual helped the organization establish a Web-content development team, collected the team's editing requirements, developed a customized Content Management System workflow (using Drupal), and trained the team on its use.



A space weather forecast model, showing trajectories of three successive coronal mass ejections - big blasts of plasma from the Sun. CIRES scientists supported NOAA's transition of the Wang-Sheeley-Arge (WSA)-Enlil model into operations, and federal members of the team won the 2012 NOAA Silver Medal of Achievement for the work.

We prototyped the Solar Ultraviolet Imager (SUVI) thematic-maps software product by using data from NASA's Solar Dynamics Observatory Atmospheric Imaging Assembly instrument. We developed the software to implement the Space Environmental Anomalies Expert System model, creating three different graphical plots to help diagnose geosynchronous vehicle anomalies caused by space weather.

Our team resolved many residual issues from the migration of the Advanced Composition Explorer (ACE) processing software to a modern Linux system. This code migration was particularly challenging because an outside contractor only partially completed it, and this project team had to finish it.

Further, our project team led the database design and implementation for three major SWPC software projects. The quality of the data models and schemas we developed resulted in increased software-team productivity and decreased maintenance.

Lastly, this project team continued to provide operational support for the following critical systems:

- ACE processor,
- Geostationary Environmental Satellite processor and preprocessor,
- WSA-Enlil,
- Air Force and Institute for Science and Engineering Simulation Message Decoder processor,
- Polar Orbiting Environmental Satellite processor, and
- Microsoft SQL Server Space Weather Data Store.

SWPC-02 Enhancement of Prediction Capacity for Solar Disturbances in the Geospace Environment

CIRES LEAD: ALYSHA REINARD
NOAA LEAD: VIC PIZZO
CIRES THEME: SPACE WEATHER UNDERSTANDING AND PREDICTION
NOAA THEME: WEATHER-READY NATION

GOALS & OBJECTIVES

This project will advance preparedness for solar storms affecting communication, transportation, and other U.S. infrastructure.

ACCOMPLISHMENTS

Our team has begun to produce daily plots of the normalized helicity gradient variance (NHGV) over the disk. NHGV provides a measure of the potential for flaring. The figure shows an example in which we saw high values of NHGV about one day before an X10 flare occurred.

SWPC-03 Analysis of the Role of the Upper Atmosphere in Space Weather Phenomena

CIRES LEAD: TIM FULLER-ROWELL
NOAA LEAD: RODNEY VIERECK
CIRES THEME: SPACE WEATHER UNDERSTANDING AND PREDICTION
NOAA THEME: SCIENCE AND TECHNOLOGY ENTERPRISE

GOALS & OBJECTIVES

This project will use models to determine causes for variation in space weather, with implications for infrastructure protection.

ACCOMPLISHMENTS

Simulations with the Global Ionosphere Plasmasphere model driven by winds from the Whole Atmosphere Model (WAM) show significant longitudinal and day-to-day variations in the ionospheric parameters. Under fixed solar and geomagnetic activity levels, we estimate the contributions of lower-atmosphere tides to the longitudinal and day-to-day variability in the upper atmosphere. We find larger relative variability in the nighttime than in the daytime, which is consistent with observations. The perturbations from the lower atmosphere contribute about half of the observed variability in the ionospheric F2 peak plasma density under moderate solar activity and geomagnetic quiet conditions. Simulations also suggest that the wave-4 and wave-3 longitudinal variations in the equatorial vertical drifts during September are dominated by the diurnal (D), eastward-propagating (E), nonmigrating tides with zonal wave numbers 3 (DE3) and 2 (DE2), respectively. (Fang et al. 2013)

We used WAM fields at high temporal resolution (three-minutes) to drive the Retterer ionospheric irregularity model. We presented first results from this new multiscale model of the formation and evolution of equatorial plasma bubbles and the turbulence associated with them. We created the model by using the winds and electric fields from a consistent combination of a whole-atmosphere and global-scale ionosphere/electrodynamic model to drive a mesoscale model of plasma irregularity formation. With the realistic structure and variability inherent in the winds driven by forcing from lower altitudes, there is no need to force the irregularity model with artificial density perturbations. The resulting ionospheric disturbances provide the seed for the development of plasma instabilities, removing the need for the assumptions needed to specify an artificial seed.

We investigated the development of plasma-density irregularities in the simulation starting at Universal Time (UT) 1, in a simulation grid centered around longitude 330°. The strongest irregularities are initially confined to the bottom-side of the F layer; a linearization of the continuity equation suggests that the magnitude of the irregularities should be a minimum where the vertical derivative of the density is zero, at the F peak. The strength of the irregularities in this layer waxes and wanes according to the variation of the height of the layer and the resulting changes in the strength of the collision frequency, which modulates the ion mobility, affecting (among other quantities) the strength of the Rayleigh-Taylor growth rate. At around UT 2.5, low-density plumes begin to form. Their rising through the ionosphere is marked by the area of strong irregularities that passes the F-layer peak and continues up to high altitude after that time. The area gradually falls as the plumes experience downward plasma drift at later times.

Fang, TW, R Akmaev, T Fuller-Rowell, F Wu, N Maruyama, and G Millward. 2013. Day-to-day and longitudinal variations in the ionosphere driven by lower atmosphere tidal forcing. *Geophys. Res. Lett.* 40.

Retterer, J, TW Fang, TJ Fuller-Rowell, and F Wu. 2013. seeding of ionospheric irregularities by whole atmosphere model dynamical fields. *J. Geophys. Res.* Submitted.

Appendices

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Publications by the Numbers

CIRES scientists and faculty published at least 528 peer-reviewed papers during calendar year 2012. Below, we tabulate publications by first author affiliation. CIRES scientists and faculty published many addtional non-refereed publications in 2012, many of them listed in the pages that follow. These citations represent a subset of all CIRES publications; our tracking process misses some. Moreover, 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

	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
CIRES Lead Author	177	165	188	141	130	110	158	137	238	186
NOAA Lead Author	31	56	20	81	73	99	79	63	41	30
Other Lead Author	183	134	145	289	264	385	342	312	293	312
Total	**391**	**355**	**353**	**511**	**467**	**594**	**579**	**512**	**572**	**528**

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Journal Articles

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More 2012 Honors and Awards (continued from page 12)

CIRES Outstanding Performance Awards

CIRES Science and Engineering Awards

Christopher Clack, for his work on optimization code supporting a renewable energy project to determine ideal location of wind and solar plants for maximum electrical supply at minimum cost.

Allen Jordan and Emrys Hall, who created and refined powerful software tools for scientists who routinely launch balloons carrying instruments to measure atmospheric composition.

Julien Lynge, for working with scientists to make data easy to find, access, visualize, and understand.

CIRES Service Awards

Walt Meier, for outstanding and exemplary service and outreach activities that promote CIRES science and help educate the public on climate change and its impact on the cryosphere.

Eric Gordon, Jeff Lukas, and Tim Bardsley, for developing the Western Water Assessment Intermountain West Climate Summary (IWCS) dashboard, an exceedingly useful tool for scientists, decision makers, and the public to access a large number of climate-related products at a single website.

CIRES Director's Awards

Ted DeMaria, for extraordinary knowledge in equipment inventory, property management, export controls, and other compliance issues critical to CIRES' smooth functioning.

Yvonne Garcia, for 20 years of exemplary service as Executive Assistant to CIRES Directors.

Lisa Ho, for programming and database work that supports a wide number of critical CIRES functions.

Nancy Lathrop, for broad expertise in human resources and support of graduate students.

Federal Awards

CIRES honors its researchers who work on teams winning key federal awards. This year, CIRES researchers contributed to work earning NOAA Bronze and Silver awards; and NOAA Research Group team of the Year:

Ratina Dodani, Curt de Koning, Leslie Mayer, and George Millward, CIRES staff working in NOAA's Space Weather Prediction Center, won a CIRES Silver Award, for implementing the first space-weather numerical prediction model, the Wang-Sheeley-Arge (WSA)–Enlil model, on the National Centers for Environmental Prediction supercomputer.

Geoff Dutton, Emrys Hall, Eric Hintsa, Dale Hurst, Allen Jordan, Fred Moore, Sam Oltmans, Eric Ray, Troy Thornberry, and Laurel Watts —who work at ESRL—won a CIRES Bronze Award for the successful demonstration of the Global Hawk Unmanned Aircraft Systems for NOAA's Climate Goal.

Curtis Alexander, Patrick Hofmann, Ming Hu, Eric James, Bill Moninger, Joe Olsen, Steven Peckham, Tanya Smirnova, and Xue Wei were members of the Stan Benjamin group, honored as NOAA Research Group of the Year, 2012, for developing, integrating, and transitioning into operations the next generation of NOAA's hourly North American forecast system. Benjamin is a CIRES Fellow.

Other Awards

Below are many of the other awards earned by CIRES scientists and staff in 2012. These are self-reported and represent only a subset of the actual awards received.

Group awards

The 2012 CO-LABS Governor's Impact Award for high-impact research went to a team of 34 CIRES and NOAA scientists in recognition of their "Rapid-Response Atmospheric Science to Assess the Deepwater Horizon oil spill crisis." CIRES winners included: **Kenneth Aikin, Ravan Ahmadov, Wayne Angevine, Roya Bahreini, Jerome Brioude, Joost de Gouw, Barbara Ervens, Fred Fehsenfeld, Gregory Frost, John Holloway, Daniel Lack, Stuart McKeen, J. Andrew Neuman, John Nowak, Jeffrey Peischl, Anne Perring, Ilana Pollack, Joshua Schwarz, Harald Stark, Carsten Warneke, and Laurel Watts**.

Emrys Hall, Gerhard Hubler, Dale Hurst, and Troy Thornberry received the NASA Group Achievement Award "for outstanding accomplishments by the successful Mid-latitude Airborne Cirrus Properties Experiment to better understand the role of cirrus clouds in climate models."

David Gallaher, Mark Serreze, and Ronald Weaver, with the Green Data Center at the National Snow and Ice Data Center, along with collaborators, received the Green Enterprise IT Award, for Facility Retrofit, from the Uptime Institute. The NSIDC Green Data Center team also won the 2012 Campus Sustainability Award from the University of Colorado Boulder.

The Science On a Sphere® web team, including, **Mike Beire, Shilpi Gupta, Irfan Nadiadi, and Elizabeth Russell**, received the Global Systems Division Web Award for the complete makeover of the Science On a Sphere® website.

Joseph Barsugli, on behalf of the Western Water Assessment, received the Partners in Conservation award from the Department of the Interior.

Individual awards

Susan Buhr
Ten-Year Service Award, from the Consortium for Ocean leadership

Noah Fierer
BFA Award for Excellence in Research, Scholarly, and Creative Work, 2012–2013, from the Boulder Faculty Assembly, CU Boulder

Birgit Hassler
Travel Grant Award International Ozone Comission, to attend the 2012 Quadrennial Ozone Symposium to be held August 23–31 in Toronto, Canada

Wentao Huang
Antarctica Service Medal, United States Department of Defense

More 2012 Honors and Awards

José-Luis Jimenez
Eighth most-cited scientist worldwide in the Geosciences (according to Essential Science Indicators from Thomson ISI)

Shelley Knuth
Antarctic Service Medal, United States Armed Forces, for 30-plus days of service in Antarctica

Daniel Lack
Keynote speaker at the United Nations International Maritime Organization meeting, Clean Shipping Coalition

Elliot Lim
Arctic Service Medal, United States Coast Guard

William Moninger
First place in the NOAA "70 Seconds of Science" communications contest

Steven Nerem
Serving as a Lead Author for the Intergovernmental Panel on Climate Change 5th Assessment Report, Sea Level Change chapter

David Noone
Presidential Early Career Award for Scientists and Engineers (PECASE)

Roger Pielke Jr.
2012 Public Service Award, Geological Society of America
2012 Fellow, Geological Society of America
Doctorate honorus causa (Honorary Doctorate), Linköping University, Sweden

Peter Pulsifer
Indigenous Partnership of Excellence Award, International Polar Year 2012 Conference

Balaji Rajagopalan
Co-author of chapter 15, "State of the Resources," of the World Water Development Report, 4th edition, UNESCO
Co-author for the "Climate Extremes" chapter of the National Climate Assessment Southwestern United States

David Reynolds
Special Recognition Award, California Extreme Symposium, for 40 years improving weather forecasting and operational hydrology

Elizabeth Russell
CIRES Cash Award, for work to make the Science On a Sphere® installation at the Fagatele Bay National Marine Sanctuary in American Samoa a success

Gregory Tucker
Ralph Alger Bagnold Medal, European Geosciences Union
BFA Award for Excellence in Teaching, 2012–2013, from the Boulder Faculty Assembly, CU-Boulder

Veronica Vaida
Elected fellow, American Academy of Arts and Sciences

Rainer Volkamer
National Science Foundation CAREER award recipient
Distinguished Lecture Series Speaker at The Center for Global Change Science, University of Toronto, Canada

Rebecca Washenfelder
Presidential Early Career Award for Scientists and Engineers (PECASE)

Betsy Weatherhead
2013 Elizabeth D. Gee Memorial Lectureship Award from the CU-Boulder, for efforts to advance women in academia

Klaus Wolter
Keynote Speaker for the sixth time in a row for the "Weather and Climate Impacts" session at American Meteorological Society annual meeting

More FY2013 Events (continued from page 13)

Analytical Chemistry Seminars

- **Jose-Luis Jimenez** Organic aerosol sources and processing in the atmosphere: recent results and upcoming projects (9/12)
- **Alison Craven** The importance of dissolved organic matter to the binding of copper and the release of trace elements from coal ash (9/12)
- **Katherine Primm** Formation of gold nanoparticles and nanorods analyzed by SEIRA (10/12)
- **Melissa Ugelow** Tailoring porous silicon for analyte response (10/12)
- **Yong Liu** Investigating O_3-initiated heterogeneous oxidation of linoleic acid using ATR-IR flow reactor (10/12)
- **Christopher Kampf** Effective Henry's law constant measurements for glyoxal in model aerosols containing sulfate (10/12)
- **Christoph Knote** 3D model simulations of glyoxal-SOA formation over California (10/12)
- **Theodore Konstantinos** Koenig separation of water spin isomers by absorption (11/12)
- **Siyan Wang** SOA formation from volatile OVOC (11/12)
- **Callie Cole** Laboratory astrochemistry: kinetics studies and instrument modifications (12/12)
- **Roy (Lee) Mauldin** The X Files: oxidation via Criegee radicals—from reactions to global impacts (1/13)
- **Dick Bedell and Jean Bedell** India from an elephant's back (2/13)
- **Neil M. Donahue** Old aerosols never die, they just get oxidized (2/13)
- **Brian Majestic** Using iron isotopes as a tool to identify sources of atmospheric iron: an analysis of desert, urban, and oceanic environments (2/13)
- **Waleed Abdalati** From the terrestrial to the celestial: my perspectives and experiences as NASA Chief Scientist (2/13)
- **Megan L. Melamed** Overview of the International Global Atmospheric Chemistry (IGAC) Project (3/13)
- **Ivan Ortega** Maximizing the information of ground-based remote-sensing measurements: trace gases and aerosol properties (3/13)
- **LaToya Jones-Braun** Investigating and improving the freeze-thaw stability of vaccines with aluminum-containing adjuvants: case studies with model HBsAg vaccines (4/13)
- **Brett Palm** Real-time organic aerosol formation and oxidative aging using a flow reactor in a ponderosa pine forest (4/13)
- **John Orlando and Frank Flocke** An overview of the OASIS 2009 campaign, with focus on halogen, OVOC, and reactive nitrogen chemistry (4/13)
- **Mercedes Gonzalez-Juarrero** How can we improve therapy for tuberculosis? (5/13)

CIRES Graduate Student Association (CGSA) Monthly Lunch Meeting

- **Heidi Yoon and Milos Markovic** On the post-doc experience (11/12)
- **Valentine Roche** Career Services presentation (12/12)
- **Raea Lessard and Tommy Detmer** "Sound Bytes" communication workshop (2/13)
- **Lorine Giangola** (3/13)
- **Adriana Raudzens Bailey** (3/13)
- **Ulyana Horodyskyj** (4/13)
- **Mark Zoback** (4/13)

CGSA Student Seminar Series— Evaluated by Lorine Giangola, Graduate Teacher Program

- **Alice DuVivier** (10/12)
- **Ryan Thalman** (10/12)
- **Jesse Nusbaumer** (11/12)
- **Catalin Negrea** (11/12)
- **Dave Mencin** (2/13)
- **Francis Rengers** (2/13)
- **Will Levandowski** (3/13)
- **Ulyana Horodyskyj** (3/13)

Cryospheric and Polar Processes Seminar

- **Matthew L. Druckenmiller** The transforming Arctic Ocean: Implications for bowhead whales and offshore oil and gas development (9/12)
- **Tyler Erickson** Google Earth Engine, a distributed geospatial processing platform (3/13)

CSTPR Noontime Seminar

- **Samuel Tang** Usable science? The UK Climate Projections 2009 and decision support for adaptation planning (9/12)
- **Franziska Hollender** The contrarian discourse in the blogosphere—what are blogs good for anyway? (9/12)
- **Mark Serreze** Communicating climate change: lessons learned at the National Snow and Ice Data Center (10/12)
- **Roger Pielke Jr.** The mythology of the Green Revolution (10/12)
- **Deserai Anderson Crow** Mass media in the policy process: drafting a comprehensive approach to policy influence (11/12)
- **Max Boykoff and Beth Osnes** Going inside the greenhouse: exploring creative climate communications in the classroom (11/12)
- **Tom Yulsman** State of the media, and implications for climate change coverage (12/12)
- **William Alley and Rosemarie Alley** Too hot to touch: the problem of high-level nuclear waste (1/13)
- **Morgan Bazilian** International efforts in the area of energy and development (2/13)
- **Noah Molotch** Ecohydrological vulnerability to changes in climate and land use in the Rocky Mountains (3/13)
- **Barbara Farhar** The human dimensions of plug-in hybrid electric vehicles in Boulder (3/13)
- **Benjamin Hale** Geoengineering and moral jurisdiction (4/13)
- **Shawn Olson** Power politics: the political ecology of wind energy opposition in Wyoming (4/13)

Hydrology & Water Resources Seminar

- **Erin Towler** Incorporating climate forecasts into aquatic management using a risk-based framework (1/13)
- **Peter Hamlington** The non-normality of nature: intermittency in turbulent flows (1/13)
- **Andrew Slater** Pixels, inputs and parameters: assessing uncertainty in snow modeling (2/13)
- **Dmitri Kavetski** Battling hydrological monsters: distinguishing between data uncertainty, structural errors, and numerical artifacts in rainfall-runoff modeling (2/13)

More CIRES FY2013 Events

- **Sachin Pandey** Effect of soluble microbial products on pyrite oxidation by ferric iron at pH < 2 (2/13)
- **Mari Jones** Exploring multi-annual regimes in total and extreme Argentinian precipitation using hidden Markov models (3/13)
- **Franco Biondi** Tree-ring extension of precipitation in eastern Nevada and its implications for drought analysis (4/13)
- **Adriana Bailey** Stable isotope constraints on the vertical exchange of moisture in the convective boundary layer (4/13)
- **Reed M. Maxwell** Toward a complete description of the hydrologic cycle: large scale simulations with parallel, integrated models (4/13)
- **David Wagner** Probabilistic source characterization in water distribution systems with transient flows (5/13)

Miscellaneous

- **C. Gladwin Joseph** Community-based conservation in globalizing India (8/12)
- **CGSA Academic Year Kick-Off Reception** (9/12)
- **CIRES 45th Anniversary Celebration** (9/28)
- **James Meldrum** WWA webinar: water, energy, and climate change—freshwater use by power plants (11/12)
- **CIRES Innovative Research Program** (11/12)
- **Roger Pielke Jr., Gabrielle Petron, and Carsten Warneke** CIRES Energy and Environment Initiative workshop (11/12)
- **Lori Bruhwiler, Britt Stephens, and Pieter Tans with Betsy Weatherhead (moderator)** Greenhouse gases, climate change, and the future (1/13)
- **Max Boykoff, Susan Buhr, Jorge Figueroa, Kelly Mahoney, Ken Nowak, and Ben Webster** Think outside the lab: six exciting alternative careers in science (3/13)
- **James Balog** The art of chasing ice: a conversation with James Balog (4/13)
- **CIRES Rendezvous** (5/13)

Personnel Demographics

CIRES Personnel Breakdown 2012–2013*

Category	Total CIRES Personnel	NOAA-supported CIRES Personnel	Highest Degree Earned by NOAA-supported Personnel B.S.	M.S.	Ph.D.
Faculty	17	0			
Research Scientist	197	112	0	0	112
Visiting Scientist	38	6	0	0	6
Postdoctoral Researcher	29	6	0	0	6
Associate Scientist	252	144	60	75	9
Administrative	32	28	22	5	1
Total > 50% NOAA support		**296**	**82**	**80**	**134**
Undergraduate Students	83	42	0	0	0
Graduate Students	131	14	13	1	0
Received < 50% NOAA Support		**78**	**17**	**22**	**39**
Total CIRES personnel	**779**				

* Includes CIRES employees receiving NOAA funding anytime between July 2012 and June 2013

CIRES Personnel in NOAA Boulder Laboratories[1]

NOAA Organization	Total CIRES Personnel
OAR, ESRL[2]	**253**
ESRL Director's Office	11
Chemical Sciences Division	72
Global Monitoring Division	47
Global Systems Division	38
Physical Sciences Division	85
NESDIS, NGDC[3]	**49**
NWS, SWPC[4]	**29**
Total NOAA	**331**
Obtained NOAA Employment in Last Year	1

[1] Counted on May 1, 2013
[2] NOAA Office of Oceanic and Atmospheric Research, Earth System Research Laboratory
[3] NOAA Environmental Satellite, Data, and Information Service, National Geophysical Data Center
[4] NOAA National Weather Service, Space Weather Prediction Center

Appendices

Active NOAA Cooperative Agreements

Record number	Description	Time frame
NA12OAR4320137	New Cooperative Agreement	September 2012–August 2017
NA10OAR4320142	Current Cooperative Agreement	June 2010–September 2013
NA08OAR4320914	This record number references two shadow awards still active under the old Cooperative Agreement (NA17RJ1229, 2001–2011)	
	Roger Pielke Sr. and Lixin Lu: Downscaling Global Climate Forecast System seasonal predictions for hydrological applications using the Regional Atmospheric Modeling System (RAMS)	May 2008–April 2011
	Walter Meier: A product development team for snow and ice data records	June 2009–May 2012

Abbreviations and Acronyms

20CR	Twentieth Century Reanalysis
AAO	Annular Antarctic Oscillation
ACE	Advanced Composition Explorer
ADV	Acoustic Doppler Velocimeter
AGCM	Atmospheric General Circulation Model
AGGI	Annual Greenhouse Gas Index
AIDA	Aerosol Interaction and Dynamics in the Atmosphere
AMIP20C	Atmospheric Model Intercomparison Project Twentieth Century
AOS	Aerosol Observing System
ARC	Archives and Resources Center
AR	Atmospheric river
AS	Ammonium sulfate
ASCOS	Arctic Summer Cloud Ocean Study
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
ATTREX	Airborne Tropical Tropopause Experiment
AWIPS	Advanced Weather Interactive Processing System
BAO	Boulder Atmospheric Observatory
BBCES	Broadband cavity enhanced spectroscopy
BVSD	Boulder Valley School District
CALIPSO	Spaceborne Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations
CalNex	Research at the Nexus of Air Quality and Climate Change
CAN-BD	Carbon dioxide Assisted Nebulization with a Bubble-Dryer
CAVE	Common AWIPS Visualization Environment
CCEW	Convectively coupled equatorial waves
CCN	Cloud condensation nuclei
CEDAR	Coupling, Energetic, and Dynamics of Atmospheric Regions
CESAM	Experimental Multiphasic Atmospheric Simulation Chamber
CFSv2	Climate Forecast System version 2

CHARIS	Contribution to High Asia Runoff from Ice and Snow
CIMS	Chemical Ionization Mass Spectrometer
CIRES	Cooperative Institute for Research in Environmental Sciences
CISC	Cooperative Institute for Climate and Satellites
CLASS	Comprehensive Large Array Data Stewardship System
CLEAN	Climate Literacy and Energy Awareness Network
CME	Coronal mass ejection
CMIP	Coupled Model Intercomparison Project
CoG	Community Governance
CoRA	Colorado Research Associates
CORS	Continuously Operating Reference Stations
COS	Carbonyl sulfide
CoSPA	Consolidated Storm Prediction for Aviation
CSD	Chemical Sciences Division
CSTPR	Center for Science and Technology Policy Research
CU-Boulder	University of Colorado Boulder
DART	Deep-ocean Assessment and Reporting of Tsunamis
DC3	Deep Convective Clouds and Chemistry
DCMIP	Dynamical Core Model Intercomparison Project
DEM	Digital elevation model
DMSP	Defense Meteorological Satellite Program
DNB	Day/Night Band
DOD	Department of Defense
DOE	Department of Energy
DSD	Raindrop size distribution
Dst	Disturbance storm-time
DVG	Data Visualizations and Games
DYNAMO	Dynamics of the Madden-Julian Oscillation
ECS	Extended Continental Shelf
EESC	Effective Equivalent Stratospheric Chlorine
EHO	Extreme high ozone
EIA	Energy Information Administration
ELO	Extreme low ozone
EMMA	Enterprise Metadata Management Architecture
ENSO	El Niño Southern Oscillation
EO	Education and Outreach
ERA	European Reanalysis
ES-DOC	Earth System Documentation
ESI-MS	Electrospray Ion Source Mass Spectrometer
ESMF	Earth System Modeling Framework
ESOC	Earth Science and Observation Center
ESRL	Earth System Research Laboratory
EXIS	Extreme Ultraviolet and X-ray Irradiance Sensors
FA	Fulvic acid
Fe	Iron
FIM-Chem	Flow-Following Finite-Volume Icosahedral Atmospheric Model Coupled with Chemistry
FOC	Final Operating Capability
F*p*	Particle-phase fraction
FY	Fiscal year
GCM	General Circulation Model
GEBCO	General Bathymetric Chart of the Oceans
GFS	Global Forecast System
GHG	Greenhouse gas

GIS	Greenland Ice Sheet
GloPac	Global Hawk Pacific
GMD	Global Monitoring Division
GOES	Geostationary Operational Environmental Satellite
GOES-R	Geostationary Operational Environmental Satellite R-Series
GPS	Global Position System
GRACE	Gravity Recovery and Climate Experiment
GSD	Global Systems Division
GSI	Gridpoint Statistical Interpolation
GSRF	Graduate Student Research Fellowship
GTS	Global Telecommunication System
GWP	Global-warming potential
HD-SP2	Humidified-dual Single Particle Soot Photometer
HIAPER	High-performance Instrumental Airborne Platform for Environmental Research
HIPPO	HIAPER Instrumental Pole-to-Pole Observations
HPC	High-Performance Computing
HRDL	High-Resolution Doppler Lidar
HRRR	High-Resolution Rapid Refresh
IAGA	International Association for Geomagnetism and Aeronomy
ICECAPS	Integrated Characterization of Energy, Clouds, Atmospheric state, and Precipitation at Summit
ICEE	Inspiring Climate Education Excellence
ICESat-2	Ice Cloud and land Elevation Satellite-2
ICOADS	International Comprehensive Ocean-Atmosphere Data Set
ICR	Indirect Cost Recovery
IDL	Interactive Data Language
IMO	International Maritime Organization
INSITE	Integrated Support for Impacted Air-Traffic Environments
INSTAAR	Institute of Arctic and Alpine Research
IPT	Integrated Product Team
IRIS	Incorporated Research Institutions for Seismology
IRP	Innovative Research Program
ISB	Information Systems Branch
ISDAC	Indirect and Semi-Direct Aerosol Campaign
ISO	International Standards Organization
IWCS	Intermountain West Climate Summary
JPL	Jet Propulsion Laboratory
K_H	Henry's law coefficient
KML	Keyhole Markup Language
LAB	Lithosphere-asthenosphere boundary
LES	Large-scale Eddy Simulation
LIM	Linear Inverse Modeling
LOESS	Locally Weighted Scatterplot Smoothing
LS	Lower stratosphere
LSA	Land-surface-atmosphere
LTD	Lead-Time and Displacement
LVOS	Las Vegas Ozone Study
Ma	Mega-annum
MACPEX	Mid-latitude Airborne Cirrus Properties Experiment
MADIS	Meteorological Assimilation Data Ingest System
MAGED	Magnetospheric Electron Detector
MAGPD	Magnetospheric Proton Detector
MBL	Marine boundary layer
MPB	Mountain pine beetle

Mmax	Maximum magnitude
MMI	Multimetric index
MODIS	Moderate Resolution Imaging Spectroradiometer
MODTRAN	Moderate Resolution Atmospheric Transmission
MOSAiC	Multidisciplinary Drifting Observatory for the Study of Arctic Climate
Na	Sodium
NAO	North Atlantic Oscillation
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
NCEP	National Centers for Environmental Prediction
NCL	NCAR Command Language
NDFD	National Digital Forecast Database
NEIS	NOAA Earth Information Services
NESDIS	National Environmental Satellite, Data and Information Service
NEXT	NGDC Data Extract System
NGDC	National Geophysical Data Center
NGS	National Geodetic Survey
NGSP	Next Generation Strategic Plan
NHGV	Normalized Helicity Gradient Variance
NICT	National Institute of Information and Communications Technology
NMME	National Multi-Model Ensemble
NOAA	National Oceanic and Atmospheric Administration
NOS	National Ocean Service
NPO	North Pacific Oscillation
NPP	National Polar-Orbiting Partnership
NSF	National Science Foundation
NSIDC	National Snow and Ice Data Center
NTA	North Tropical Atlantic
NUOPC	National Unified Operational Prediction Capability
NWS	National Weather Service
OA	Organic aerosol
OAR	Oceanic and Atmospheric Research
ODGI	Ozone-Depleting Gas Index
ODP	Ozone-depletion potentials
OLR	Outgoing longwave radiation
OLS	Operational Linescan System
OVATION	Oval Variation, Assessment, Tracking, Intensity, and Online Nowcasting
PAGES	Past Global Changes
PCAST	President's Council of Advisors on Science and Technology
PCMDI	Program for Climate Model Diagnosis and Intercomparison
PCP	Pentachlorophenol
PDF	Probability density function
PECASE	Presidential Early Career Award for Scientists and Engineers
PeEP	Auroral People Empowered Products
PDF	Probability density function
PSD	Physical Sciences Division
PV1	Production Version One
PV2	Production Version Two
PWC	Pacific Walker Circulation
QBO	Quasi-biannual oscillations
RAM	Random-access memory
RAP	Rapid Refresh
RESESS	Research Experiences in Solid Earth Sciences for Students

REU	Research Experiences for Undergraduates
RFP	Request for proposal
RH	Relative humidity
RHEL	Red Hat Enterprise Linux
RISA	Regional Integrated Sciences and Assessments
RMS	Root-mean-square
SGS	Stochastically generated skewed
SOARS	Significant Opportunities in Atmospheric Research and Science Program
SBIR	Small Business Innovation Research
SBJ	Sierra Barrier Jet
SEAC4RS	Studies of Emissions and Atmospheric Composition, Clouds and Climate Coupling by Regional Surveys
SEISS	Space Environment In-Situ Suite
SENEX	Southeast Nexus Experiment
SHEBA	Surface Heat Budget of the Arctic Ocean
SOA	Secondary organic aerosol
SOS	Science On a Sphere®
SST	Sea-surface temperature
STL	Seasonal-Trend Decomposition Procedure
StormVex	Storm Peak Cloud Properties Validation Experiment
SUMO	Small unmanned meteorological observer
SUVI	Solar Ultraviolet Imager
SWPC	Space Weather Prediction Center
TCBQ	Tetrachlorobenzoquinone
TCHQ	Tetrachlorohydroquinone
TES	Total Emission Spectrometer
TLS	Terrestrial Laser Scanning
TOPAZ	Tunable Optical Profiler for Aerosol and oZone
TTL	Tropical tropopause layer
UAS	Unmanned aircraft system
UAV	Unmanned aerial vehicle
UBWOS	Uintah Basin Winter Ozone Study
UCAR	University Corporation for Atmospheric Research
UPEC	Université Paris–Est Créteil Val de Marne
UROP	Undergraduate Research Opportunities Program
USACE	U.S. Army Corps of Engineers
USAID	U.S. Agency for International Development
UT	Upper troposphere
UV-CDAT	Ultrascale Visualization Climate Data Analysis Tools
VERIFIED	Verification of Impact-translated Forecasts for Integrated Decision-making
VIIRS	Visible Infrared Imaging Radiometer Suite
VIPIR	Vertical Incidence Pulsed Ionospheric Radar
VOC	Volatile organic compound
WCOSS	Weather and Climate Operational Supercomputer Systems
WDC	World Data Center
WFIP	Wind Forecast Improvement Project
WIBS4	Wide-Incidence Bioaerosol Sensor
WMO	World Meteorological Organization
WOUDC	World Ozone and Ultraviolet Radiation Data Centre
WRF	Weather Research and Forecasting
WRF-Chem	Weather Research and Forecasting Model Coupled with Chemistry
WWA	Western Water Assessment

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