The background of the entire page is a high-angle, wide-area aerial photograph of Earth taken from space. The image shows a vast landscape with a prominent mountain range running diagonally from the bottom left towards the center. The terrain is a mix of green, brown, and grey, indicating different land uses and geological features. The curvature of the Earth is visible at the top of the frame, with a thin blue atmosphere layer separating the dark space from the planet's surface.

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



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**Cover photo: Boulder, Colorado, and the Continental Divide from 87,000 feet,
captured by a camera attached to an ozonesonde balloon.**

Photo credit: Patrick Cullis/CIRES

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executive summary & research highlights

From the Director

Fiscal year 2014 was my first year as director, taking over the reins from Dr. William Lewis Jr., who ushered CIRES through a time of critical transition. Thanks to his hard work and that of the outstanding administrative staff at CIRES, I stepped into the position with our new Cooperative Agreement successfully secured, and with the knowledge that CIRES was strong, healthy, and well-positioned for continued success. The key to that success has been, and continues to be, the commitment and talent of everyone at CIRES, from our world-renowned scientists to our efficient and committed administrative staff to our students, who will carry the promise and contributions of CIRES well into the future. We continue to make outstanding contributions to society through our support of NOAA's mission, the execution of our educational mission, and our effective communications. Moreover, we continue to leverage the NOAA investment, roughly doubling it with support from a range of sources, adding greater depth and breadth to our impressive research portfolio. During CU-Boulder's fiscal year (July 2013 to June 2014), CIRES researchers had 224 extramural proposals awarded for more than \$82 million, which is about 20 percent of

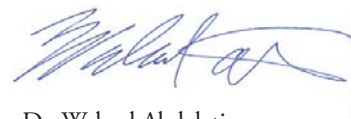
the university's total.

CIRES is a recognized world leader in many facets of environmental research, and this year has seen some substantial recognition of that leadership. One of our scientists, Dr. Peter Molnar, was awarded the very prestigious Crafoord Prize from the Royal Swedish Academy. Another, Dr. José-Luis Jiménez, was awarded the Ascent Award by the American Geophysical Union, and was recognized this year as the fifth most cited scientist worldwide over the last 10 years, according to Thompson Reuters, in both the geosciences and engineering. Thompson Reuters lists three other CIRES Fellows (Drs. Noah Fierer, Mark Serreze, and Rainer Volkamer) and a former Fellow (Russ Monson) among the most cited researchers in their fields.

The future continues to look bright at CIRES, as we look to build on our achievements. The University of Colorado has invested substantially in state-of-the-art chemistry facilities in Dr. Jiménez' laboratory, providing capabilities that exist in only a few other places in the world. The movement of the Western Water Assessment (WWA) to the main campus and the appointment of Dr. Lisa Dilling, CIRES Fellow and Environmental Studies Assistant Professor, as director will strengthen the ties of WWA to the university, and continue to build a bridge between CIRES research and the broader community. Finally, we will continue to develop our Energy and Environment Initiative, working with and complementing the work of the Renewable and Sustainable Energy Institute (RASEI) to apply our capabilities in environmental research to some of society's biggest challenges.

We look forward to building on the successes of the past and rising to the challenges of the future, to advance science, serve society, and develop the next generation of scientists and environmental leaders.

In my inaugural year as CIRES director, the achievements and dedication of our scientists, staff, and students have continually reinforced in my mind what a great institution CIRES is. We look forward to building on the successes of the past and rising to the challenges of the future, to advance science, serve society, and develop the next generation of scientists and environmental leaders.



Dr. Waleed Abdalati



Photo credit: David Oonk/CIRES

CIRES: Science in Service to Society

CIRRES—the Cooperative Institute for Research in Environmental Sciences—is a partnership of NOAA and the University of Colorado Boulder. We are an international leader in research that addresses the pressing challenges facing our planet and people. Many of these challenges are priorities for NOAA: adapting to and mitigating climate change, for example, and conducting research that supports a weather-ready nation. Since its inception more than 45 years ago as NOAA's first cooperative institute, CIRES has been helping NOAA meet these and other strategic goals, by hiring and supporting some of the best and brightest Earth scientists and students.

Our researchers use both 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. A key part of our work—reflected in

our mission statement (page 6)—is to share our findings with others.

Dr. Waleed Abdalati served as CIRES director for most of the reporting period of this annual report (June 1, 2013, to May 31, 2014), taking the reins July 1, 2013. Interim director Dr. William Lewis Jr. continues to serve as associate director of CIRES, and under the leadership of both, CIRES continued its tradition of excellence in research and training.

In the Project Reports section of this report (page 78), we report accomplishments in full, organized by CIRES' nine themes. Here, we highlight a few of the past year's activities and successes as they align with NOAA's priorities: the overarching goals and enterprise objectives outlined in NOAA's Next Generation Strategic Plan.

Climate Adaptation and Mitigation Goal

CIRES researchers:

- conducted and published collaborative research show-

ing that every degree Fahrenheit of warming in Salt Lake City could mean a 1.8 to 6.5 percent drop in the annual flow of streams that provide water to the city. This research received a great deal of national attention in the media and the White House Office of Science and Technology Policy.

- worked with NOAA colleagues to continually monitor the concentrations of carbon dioxide and other long-lived greenhouse gases in Earth's atmosphere. In 2013, the combined warming effects of these gases was up by 34 percent above 1990 values. This work earned a team of NOAA and CIRES scientists, led by NOAA's Dr. Pieter Tans, a Governor's Award for High-Impact Research in Colorado (Awards, page 69).
- published collaborative research quantifying the atmospheric impacts of oil and gas exploration, production, and use in several regions of the United States (in Utah, Colorado, and Texas) and across the country as a whole.



Photo credit: Zhibin Yu/CIRES

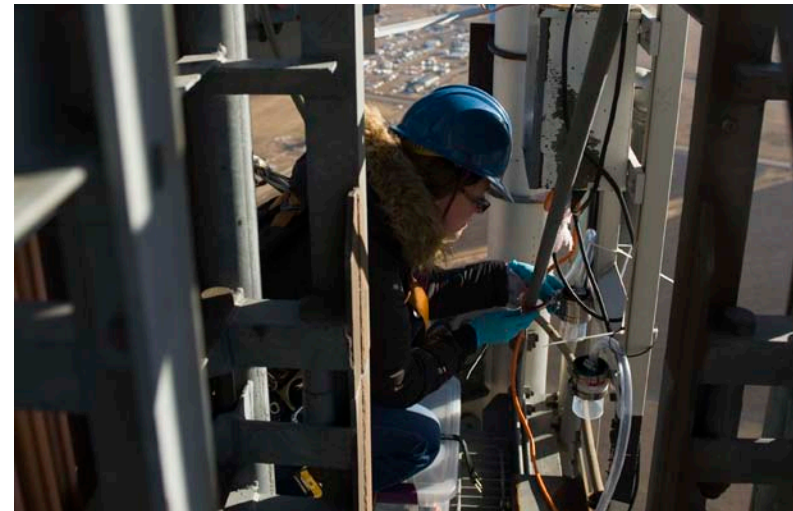


Photo credit: Chris Gray/CIRES

- developed several experimental tools to make climate data more accessible, including the Climate Change Web Portal, to help users assess data on climate extremes. Some of this work earned CIRES scientist Cathy Smith a “special award” from the American Meteorological Society in 2014 (Awards, page 70).
- studied the movement and transformations of natural and anthropogenic emissions in the U.S. Southeast, to gain insight into air quality, haziness, and climate change as part of a multi-agency focus on the region during the summer of 2013. One CIRES scientist involved in this effort, José-Luis Jiménez, won an American Geophysical Union Ascent award in 2013, and he is one of the world’s most highly cited researchers in geosciences and engineering (Awards, page 70).
- published work showing that surface meltwater draining through cracks in an ice sheet can warm the sheet from the inside, softening the ice and causing it to flow faster.

Weather-Ready Nation Goal

CIRES scientists:

- showed that better observations of wind speed and other meteorological parameters can improve wind forecasts for wind-energy producers.
- worked with colleagues to study and publish work evaluating the roles of weather patterns and climate change and variability on extreme weather events such as surface-wide melting on the Greenland Ice Sheet in 2012.
- investigated and published on the causes for surface water stress in every watershed in the contiguous United States.
- in collaboration with the Federal Aviation Administration, made significant improvements in the analysis of weather forecasts for aviation, including icing and turbulence.
- innovated use of a sophisticated lidar system to characterize the distribution and transport of ozone and greenhouse-gas emissions during air quality- and climate-related missions in Utah, Nevada, Texas, and Indiana.

Engagement Enterprise

CIRES researchers:

- worked with NOAA and other colleagues on the Science On a Sphere® (SOS) team to achieve the 100th SOS installation, suspending the 6-foot-diameter sphere from the ceiling in NOAA’s Silver Spring, Maryland headquarters. The SOS team also held its first annual teachers workshop, showing how it can be used to support state and national curricula.
- worked with colleagues on Colorado’s Water Conservation Board to prepare a report on the current and projected future state of climate change in Colorado.
- made available to the science community and the public new data sets that provide estimates of Arctic sea ice extent and concentration from 1901 to 1956. These were created from a collection of historic, hand-drawn sea ice charts from the Danish Meteorological Institute.
- worked with others on the Meteorological Assimilation Data Ingest System (MADIS) team to add more than 200 new data users and service more than 1 million data requests a day. MADIS—which collects, integrates, quality controls, and distributes weather



Photo credit: David Mencin/CIRES



Photo credit: Allen Pope/CIRES

observations from NOAA and non-NOAA organizations—is already widely available, and is scheduled to go operational at NOAA’s National Centers for Environmental Prediction (NCEP) in 2015.

Science and Technology Enterprise

CIRES scientists:

- completed the transition of a weather model, the once-experimental Rapid Refresh (RAP), into operations at NCEP on February 25, 2014. This model accurately simulated the 2012 derecho event that hit the Washington, D.C. area. Now available in weather forecast offices around the country, the model improves forecasts for severe events such as storms, floods, tornadoes, aircraft-relevant turbulence, and more.
- worked collaboratively with colleagues in the NOAA National Geophysical Data Center to improve public and scientific access to large data sets. New software, developed within the Agile framework, improves data extraction and analysis. It has also allowed for better management of undersea data critical to determining new boundaries for the U.S. Extended Continental Shelf.

- developed new ways to calibrate and process magnetic field data from the Defense Meteorological Satellite Program satellites. These data will be used in the planned 2015 release of an updated World Magnetic Model (WMM). That model is critical not only for navigation (WMM is on most mobile phone GPS systems), but it will also help inform research into Earth’s core processes.
- continued to work closely with colleagues on tools to improve the reliability, resilience, and usability of NOAA’s high-performance computing systems.

Informally, CIRES researchers also support two other NOAA goals: Resilient Coastal Communities and Economies, and Healthy Oceans. CIRES researchers in NOAA’s Boulder groups develop and deploy instruments to identify and study phytoplankton blooms in coastal areas. They develop and make accessible detailed digital elevation maps, under the auspices of the NOAA Science and Technology Enterprise. But these detailed maps also help tsunami modelers and emergency planners who want to know likely flooding patterns associated with storm surges. NOAA fisheries managers now use CIRES-developed climate-mod-

eling assessment tools.

In institute news, CIRES maintained a strong financial posture, with expenditures of about \$66 million. The institute’s financial health is supported by diverse 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.

During June 2013 to May 2014, CIRES was comprised of 43 Fellows, 207 research scientists, 276 associate scientists, 32 visiting scientists, 37 postdoctoral researchers, and 111 graduate students—many of them supported by NOAA (Demographics, page 134). Those researchers and graduate students published more than 600 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.

July 1, 2013, following election by the Council of Fellows, Waleed Abdalati became the director of CIRES. Dr. Abdalati is a professor in the CU-Boulder Geography Department, has been a CIRES Fellow since 2008, and served as NASA’s chief scientist in 2011 and 2012.

In the CIRES biennial photo contest, researchers share their photos from across the globe. In this executive summary, we show photos from (left to right, starting on page 3): Arrival Heights, Antarctica; NOAA tall tower near Erie, Colorado; a hydrothermal site in Yellowstone National Park, Wyoming; the Juneau Icefield, Alaska (last two images).



Photo credit: Allen Pope/CIRES

this is CIRES

our mission: CIRES is dedicated to fundamental and interdisciplinary research targeted at all aspects of Earth system science and to communicating these findings to the global scientific community, to decision-makers, and to the public.

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's mission by facilitating research that crosscuts traditional scientific fields. By bringing scientists from CU-Boulder departments and NOAA groups together into a network of CIRES divisions, centers, and programs, CIRES researchers can explore all aspects of the Earth system. These partnerships foster innovation, rapid-response capabilities, and an interdisciplinary approach to complex environmental challenges. The work of the CIRES enterprise strengthens the scientific foundation upon which NOAA's environmental intelligence services depend, and allows coordinated studies on a scale that could not be

addressed by university research units or NOAA alone.

Collaborative Structure

CIRES scientists and staff are affiliated with:

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

NOAA Earth System Research Laboratory (ESRL)

- Chemical Sciences Division
- Global Monitoring Division
- Global Systems Division
- NOAA Environmental Software Infrastructure and Interoperability group
- Physical Sciences Division

NOAA Centers

- National Geophysical Data Center
- Space Weather Prediction Center

CIRES Structure

The CIRES research enterprise is organized into six divisions, each guided by one Fellow; every CIRES scientist falls into one division. Our four centers and two key programs foster cross-fertilization of ideas and enable rapid response to emerging challenges. Other programs are institute-wide or serve the whole institute.

Divisions

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

Centers & Programs

- Center for Limnology (page 48)
- Center for Science and Technology Policy Research (page 50)
- Earth Science and Observation Center (page 52)
- National Snow and Ice Data Center (page 54)
- Western Water Assessment (page 56)
- Education and Outreach (page 58)

Other Programs

- Visiting Fellows (page 60)
- Innovative Research Program (page 64)
- Graduate Student Research Fellowships (page 65)
- Diversity and Undergraduate programs (page 66)
- Awards (page 68)
- Events (page 71)
- Communications (page 74)



Photo credit: CU-Boulder



Photo credit: David Oonk/CIRES



Photo credit: Will von Dauster/NOAA

governance, management, and organization

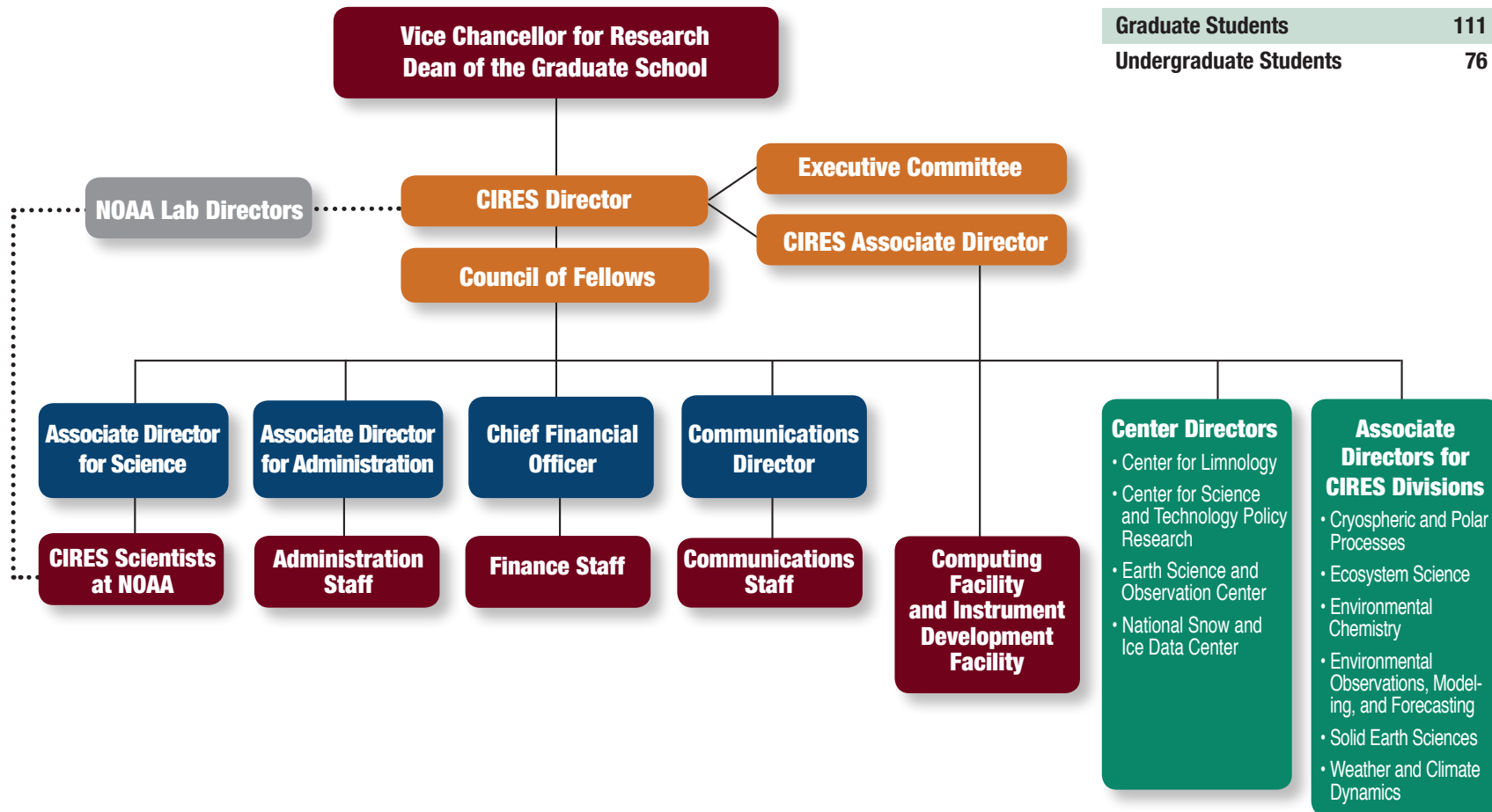
CIRES is governed and managed through its Council of Fellows and Executive Committee, with guidance by the CIRES Members' Council. The CIRES Centers—the Center for Limnology, the Center for Science and Technology Policy Research, the Earth Science and Observation

Center, and the National Snow and Ice Data Center—and our other programs link NOAA to 11 university departments. Coordination among all these entities is facilitated through the CIRES administration. During the University of Colorado Boulder's FY14, Waleed Abdalati led CIRES as director.

The CIRES Team FY2014

Faculty Lines	18
Research Scientists	207
Associate Scientists	276
Visiting Scientists	32
Postdoctoral Researchers	37
Administrative Staff	33
Graduate Students	111
Undergraduate Students	76

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:

- provide leadership at all levels in environmental science,
- maintain an active scientific research and education program,
- support the CIRES infrastructure through indirect cost recovery and in-kind contributions,
- participate in CIRES management, and
- 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 26, October 17, November 21, and December 19 of 2013; and January 23, February 20, March 20, April 24, and May 22 of 2014.

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, four 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 three CIRES career tracks: 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. The Council of Fellows considers new Fellow nominations 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

CIRES is committed to enhancing diversity by extending its community and knowledge across the full spectrum of cultures and backgrounds. The Diversity Committee works with CIRES’ Education and Outreach program, the Communications group, and scientists and staff to identify programs, mentorships, and other opportunities for CIRES to foster diversity and enrich our professional community (pages 66-67 highlight some diversity projects).

Members’ Council

The CIRES Members’ Council, created in 1997, serves as an information and policy conduit between institute members and CIRES leadership. 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, 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 science symposium, 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.

Other CIRES Committees

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

Council of Fellows (June 1, 2013, to May 31, 2014)

Waleed Abdalati CIRES Director; 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

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 and Acting Director, 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

Timothy Fuller-Rowell CIRES Senior Research Scientist, NOAA Space Weather Prediction Center

R. 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

Jen Kay Assistant Professor, Atmospheric and Ocean Studies

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

Peter Molnar Professor of Geological Sciences

Steve Montzka Research Chemist, NOAA ESRL 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, Director of the Center for Science and Technology Policy Research

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

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

Paul Ziemann Professor, Chemistry and Biochemistry

Finance

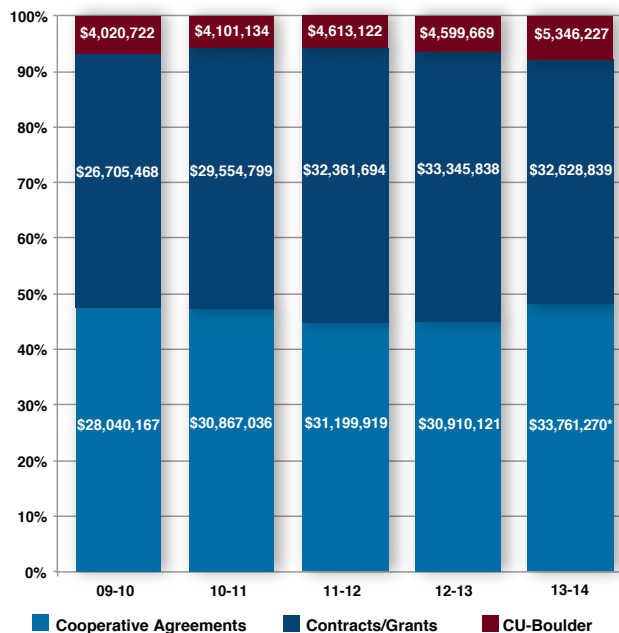
CIREs continued to grow during the university fiscal year of July 1, 2013, to June 30, 2014, with total expenditures of more than \$66 million, not including the university portion (chart 1). The university's monetary contribution to CIREs primarily covers faculty salaries, and it fluctuates from year to year due to changes in our rostered university faculty appointments.

CIREs researchers continue to enjoy success in obtaining external research awards (45 percent of total expenses). To the right of chart 1, we provide a breakdown of contracts and grants by funding agency.

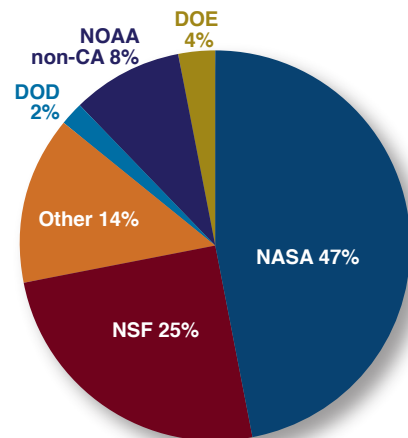
Agreement expenditures by task for the reporting period (June 1, 2013 to May 31, 2014) are shown in chart 2. As of May 31, 2014, NOAA provided \$40,708,924 for the preceding 12 months of our Cooperative Agreement NA12OAR4320137. Task I funding is for CIREs administration and internal scientific programs, 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, Colorado. Task III funds support individual university investigators who conduct stand-alone projects, under the umbrella of our Cooperative Agreement, at NOAA's request.

To the right of chart 2, we provide a breakdown of Task I expenditures from June 1, 2013, to May 31, 2014. 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 from June 1, 2013, to May 31, 2014, 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.

**1. CIREs expenditures by funding source
June 2013 to May 2014**



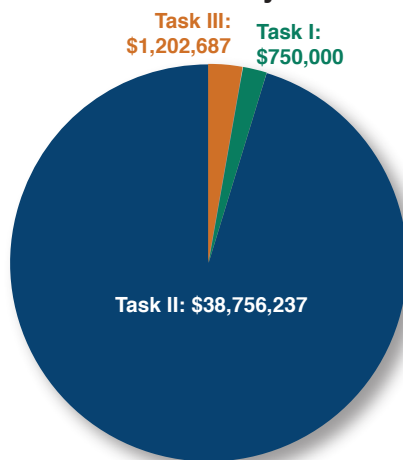
Funding breakdown by source**



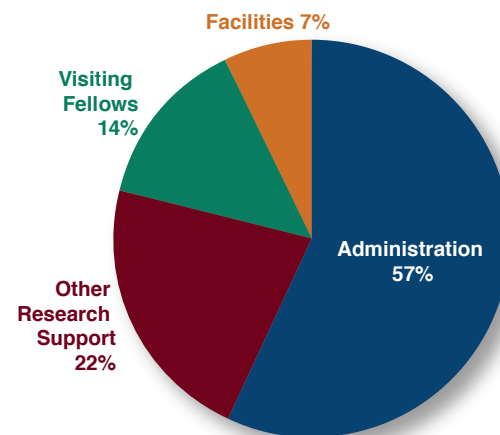
* Please note that NOAA expenditures this year (the light blue bar) include funds from both our current and old cooperative agreements, NA12OAR4320137 and NA10OAR4320142.

**Please note that this pie chart depicts funding, not expenditures.

**2. Agreement expenditures by Task
June 2013 to May 2014**



Breakdown of Task I expenditures





The Colorado River as it flows through the Grand Canyon.
Photo credit: Dan McGrath/CIRES

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 78).



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
Roger Bilham
Maxwell Boykoff
John Cassano
Xinzhao Chu
Shelley Copley
Lisa Dilling
Lang Farmer
Noah Fierer

José-Luis Jiménez
Craig Jones
Jennifer Kay
William M. Lewis Jr.
Peter Molnar
R. Steven Nerem
David Noone
Roger Pielke Jr.
Balaji Rajagopalan

Mark Serreze
Anne Sheehan
Robert Sievers
Margaret Tolbert
Greg Tucker
Veronica Vaida
Rainer Volkamer
Carol Wessman
Paul Ziemann

CIRES Scientists

Richard Armstrong
Thomas Chase
Joost de Gouw
Fred Fehsenfeld

Timothy Fuller-Rowell
R. Michael Hardesty
Judith Perlwitz
Prashant Sardeshmukh

Un-installing a time-lapse camera at the top of the Ngozumpa Glacier, Nepal, September 2013.

Photo credit: Dan Zietlow/CIRES



Waleed Abdalati

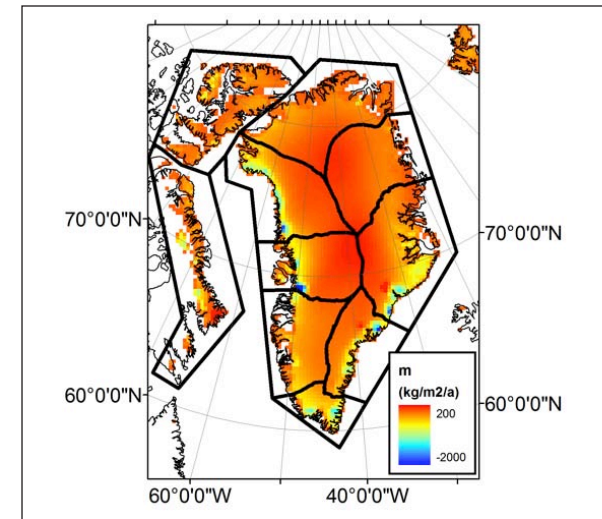
Using satellites and in situ measurements to study polar ice

My group works with space-based, airborne, and in situ observations to study changes in Earth's glaciers and ice sheets, with a focus 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 can reduce 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. We have produced the first-ever detailed and validated maps of supraglacial lake volumes from high-resolution imagery across a large region in Greenland, producing a critical tool for understanding the ice sheet's hydrology and its contributions to sea level rise.

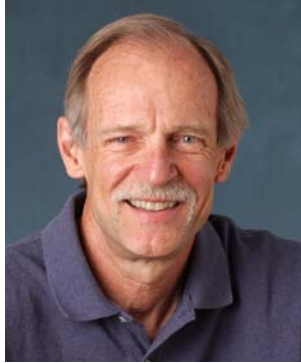
The second research area has focused on understanding the nature of compaction of the near-surface firn (snow) on the Greenland ice sheet to improve the interpretation of satellite and aircraft altimetry observations of ice-sheet-thickness changes. Compaction measurements from stations we installed on the ice sheet surface in 2013 have shown that local melt in summer 2013 released large amounts of latent heat into the firn over

several months following the end of the melt season, increasing annual compaction rates by 8 percent. This seemingly small change during this year of modest melt has a very large impact on converting elevation changes to mass changes, and our ability to quantify it represents a significant step forward in addressing the largest uncertainty component of altimetry-derived sea level contributions from Greenland.

Finally, we combine data from NASA's Gravity Recovery and Climate Experiment (GRACE), Ice Cloud and land Elevation Satellite (ICESat), and other missions to assess the spatial distribution of mass loss from the Greenland Ice Sheet, its peripheral glaciers and ice caps, and the Canadian ice caps with unprecedented detail at 26-kilometer spatial resolution (figure). 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.



Ice mass balance across the Canadian Arctic and Greenland at 26-km² resolution during the period September 2003 to October 2009, inferred from a combination of space-based gravimetry, altimetry, and optical measurements. Figure credit: W. Colgan/CIRES



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 it is generally accepted that a significant component of the High Asian water resources results from the melting of glacier ice and seasonal snow, the actual water volume available from these two individual sources across this region remains generally unknown. Previous studies have simply combined the contributions of seasonal snow and glacier ice to estimate downstream water resources, although the former is resupplied each year, in varying amounts, and the latter is, for all practical purposes, a finite resource. Realistic estimates of the future availability and vulnerability of the water resources in this region are not possible until we achieve a better understanding of the individual contributions of seasonal snow and glacier ice to the current hydrologic regime.

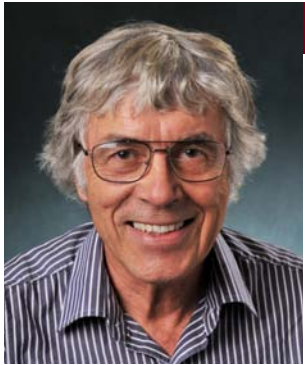
To accomplish the primary research objectives, my group used a suite of satellite remote-sensing, reanalysis, and ground-based data (provided by Asian project

partners), along with gridded maps of snow and glacier area/elevation, as input to spatially distributed temperature-index and energy-balance melt models. See <http://nsidc.org/charis/> for details.

The improved understanding of High Asian water resources is a cross-boundary exercise, and the CHARIS project facilitates international collaboration through formal agreements between the University of Colorado Boulder and key research institutions located in Bhutan, Nepal, India, Pakistan, Afghanistan, Kazakhstan, Kyrgyzstan, and Tajikistan. The CHARIS project includes a strong capacity-building component in support of our international partners, with training courses occurring on the topics of mountain hydrology, glacier mass balance, glacier and snow-cover mapping, and isotopic and geochemical tracers, as well as training in the use and application of satellite remote-sensing data and hydrologic models. Training courses took place in Kazakhstan and Nepal during 2013 and are planned for 2014 in India.



Visit to the newest partner institution, Sherubtse College, Kanglung, Bhutan, of the Contribution to High Asia Runoff from Ice and Snow (CHARIS) project, November 2013. Kneeling, left to right: Sonam Wangmo, Alana Wallace, Pema Lhendrup, and Betsy Armstrong. Standing, from left to right: Richard Armstrong, Ramakanta Barman, Tshering Wangdi, Sonam Chogyel, Pankaj Thapa, Dharmendra Chaudhur, and Konrad Steffen. Photo credit: Sherubtse College



Roger Bilham

CIRES prepares to monitor slip in the forthcoming Bay Area earthquake

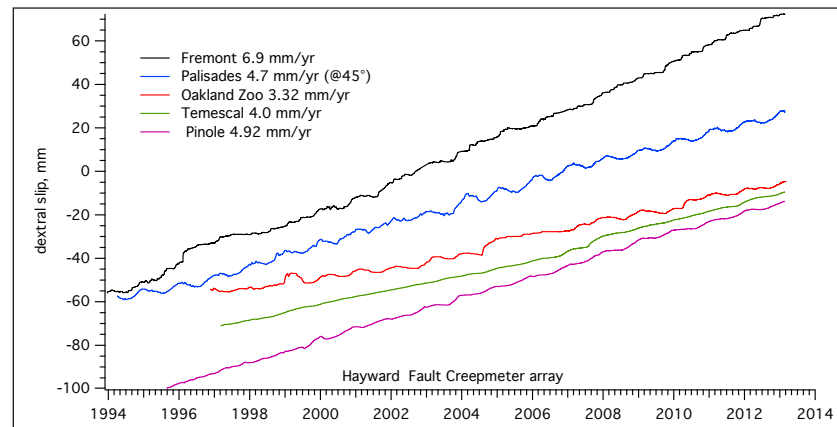
Earthquakes are the result of the rapid release of accumulated strain on a fault. In a few seconds, strain energy that has been developing for hundreds or thousands of years can manifest as meters of violent fault rupture. A special class of creeping faults, however, slip slowly, releasing strain before it amounts to dangerous levels. Few such faults slip entirely by creep, but numerous vertical faults in California do both, releasing strain in the form of viscous creep in the uppermost 5 kilometers of a fault and in the form of seismic rupture at deeper depths.

The Hayward Fault in San Francisco's East Bay area is one such fault. It last slipped in 1868, and experiences major earthquakes (6.5-7.1 moment-magnitude) every 161 ± 65 years, yet the surface fault slips steadily at 3 to 9 millimeters per year. Much of the surface fault has slipped 1 meter since 1868. For the past two decades, CIRES, with funding from the United States Geological Survey (USGS), has been monitoring surface creep at five locations on the Hayward Fault. Steady slip in Fremont at 6.9 millimeters per year occurs at rates of less than 1 micrometer per hour in the uppermost hundred meters of the fault, interrupted at several-month intervals by approximately 1.5-millimeter amplitude creep-events, each lasting a few hours, signifying slip in the uppermost 3 to 5 kilometers of the fault. Fluctuations in rate in the past two decades have been caused by local earthquakes (Lienkaem-

per et al, 2013).

Realizing that a magnitude 7 earthquake will soon occur on the fault, we have devised a new sensor designed to capture both slow slip and catastrophic rupture. A tensioned flexible wire fastened obliquely across the fault is wrapped around a 30-centimeter circumference wheel. Slip on the fault pulls the cable and rotates the wheel whose

angular position is monitored by a Hall effect sensor. The sensor has a sub-millimeter resolution per turn, and 10 turns realize a range of up to 3 meters—more than adequate to capture the 1 to 2 meters of slip anticipated on the Hayward Fault during the forthcoming earthquake. Cumulative slip is telemetered to the USGS for evaluation every 10 minutes.



Each line represents the slip at 15-km intervals along the Hayward Fault in California, in the past two decades: from south (Fremont 12 cm) to north (Pinole 8 cm). The creepmeters register small annual variations caused by seasonal temperature changes, but accelerated creep near Oakland and Temescal followed small (magnitude 4) local earthquakes. Creep events occur several times each year at Fremont. The sensors are now supplemented with 3-m range sensors to capture co-seismic rupture in a future earthquake.



Maxwell Boykoff

Cultural politics of science, policy, and the environment

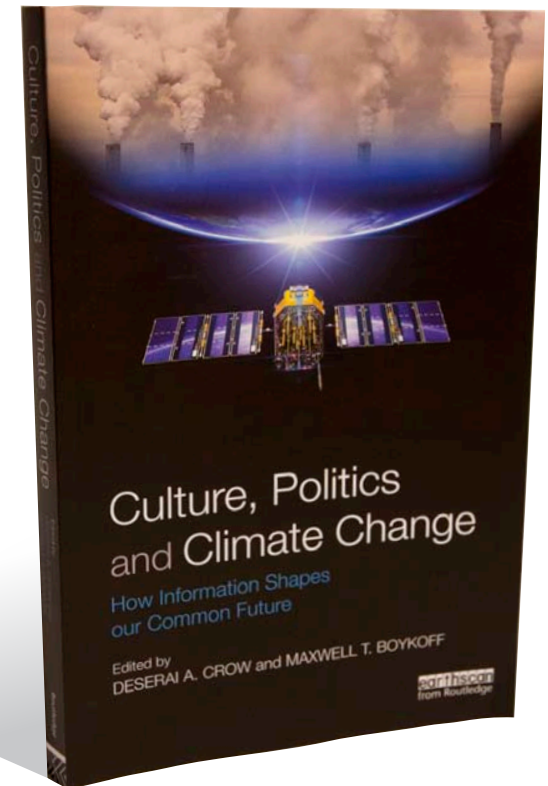
My research and creative work has two focal areas. One focus is on the ‘cultural politics of science, policy, and the environment,’ which refers to how the attitudes, intentions, beliefs, and behaviors of individuals and groups shape (and are shaped by) the perceived spectrum of possible action in the context of climate change. A second focus is on the transformations of carbon-based economies and societies, with a particular emphasis on the interface of science and practical action, including policies. Through many connected projects and collaborations, my research commitments have been fueled by my interests regarding how climate science and policy find meaning in people’s everyday lives, as well as how this, in turn, feeds back into science-policy decision-making.

My work in cultural politics of science, policy, and the environment has sought to critically analyze the role of various actors and organizations shaping political and cultural dimensions of environmental science and policy discussions in the public arena. For a few examples:

- Professor Deserai Crow (CIRES, University of Colorado Boulder Environmental Studies Program) and I have co-edited a book entitled “Culture, Politics and Climate Change: How Information Shapes Our Common Future” (Routledge/Earthscan, 2014). This book explores how cultural values shape and

are shaped by politics and policy outcomes via information. <http://sciencepolicy.colorado.edu/publications/special/cpcc/index.html>.

- Through our International Collective on Environment, Culture and Politics research group (<http://sciencepolicy.colorado.edu/icecaps/>), CU-Boulder graduate students Kevin Andrews, Meaghan Daly, Lauren Gifford, Lucy McAllister, and Xi Wang, CIRES postdoctoral scholar Joanna Boehnert, CIRES CSTPR Outreach and Engagement coordinator Ami Nacu-Schmidt, and I monitor media coverage of climate change at various scales (updated monthly at http://sciencepolicy.colorado.edu/icecaps/research/media_coverage/index.html). We also established and maintain appraisals of 50 sources across 25 countries around the world and also monitor country-level coverage in Australia, Canada, India, New Zealand, the UK, and the United States. In addition, through collaborations with Rogelio Fernandez-Reyes, in Spain, and Midori Aoyagi-Usui and Shoko Yamaguchi, we maintain counts at country levels as well.





John Cassano

Observing the Antarctic atmosphere with unmanned aerial vehicles (UAVs)

The Cassano research group has been using UAVs to study the Antarctic atmosphere since 2009. In 2009 and 2012, we flew relatively large (15 kilograms) Aerosonde UAVs to study air-sea coupling at Terra Nova Bay in the western Ross Sea, making the first in situ wintertime measurements in this climatically important area. These UAVs allowed us to conduct missions of up to 19-hours duration that covered 1,000-plus kilometers but required a six-person field team of engineers, pilots, and scientists and a dedicated runway for the UAV flight operations.

Starting in 2012, the Cassano research group began experimenting with a small and inexpensive UAV known as the small unmanned meteorological observer (SUMO) (photo). This UAV is based on a commercially available model-remote-control airplane, weighs less than 0.6 kilograms, and has a wingspan of 0.8 meter. Unlike the larger Aerosonde UAVs, this UAV can be operated by a field team of just two scientists and requires no dedicated facilities other than a laptop computer and a power supply to charge the UAV batteries, making it ideal for use at remote field camps.

In January 2014, John Cassano and a postdoctoral researcher in his group, Melissa Nigro, spent two weeks making atmospheric boundary layer observations with SUMO UAVs at a remote field camp on the Ross Ice

Shelf. The data collected during this field campaign were among the first in situ atmospheric profiles ever collected over the Ross Ice Shelf, providing us with new insights into the behavior of the atmosphere and its coupling to the ice sheet surface. We conducted SUMO flights as often as hourly to document the time evolution of the boundary layer. My group is using these data to determine the physical processes responsible for boundary layer evolution, estimate the amount of heat exchanged between the atmosphere and the ice sheet surface, and evaluate forecasts from numerical weather prediction models. During this field campaign, Cassano maintained a very popular blog on the CIRES website (<http://cires.colorado.edu/blogs/antarcticuavs/>) that described life and science in Antarctica.



Small unmanned meteorological observer and the 30-meter tall tower automatic weather station on the Ross Ice Shelf, Antarctica.

Photo credit: John Cassano/CIRES/CU-Boulder

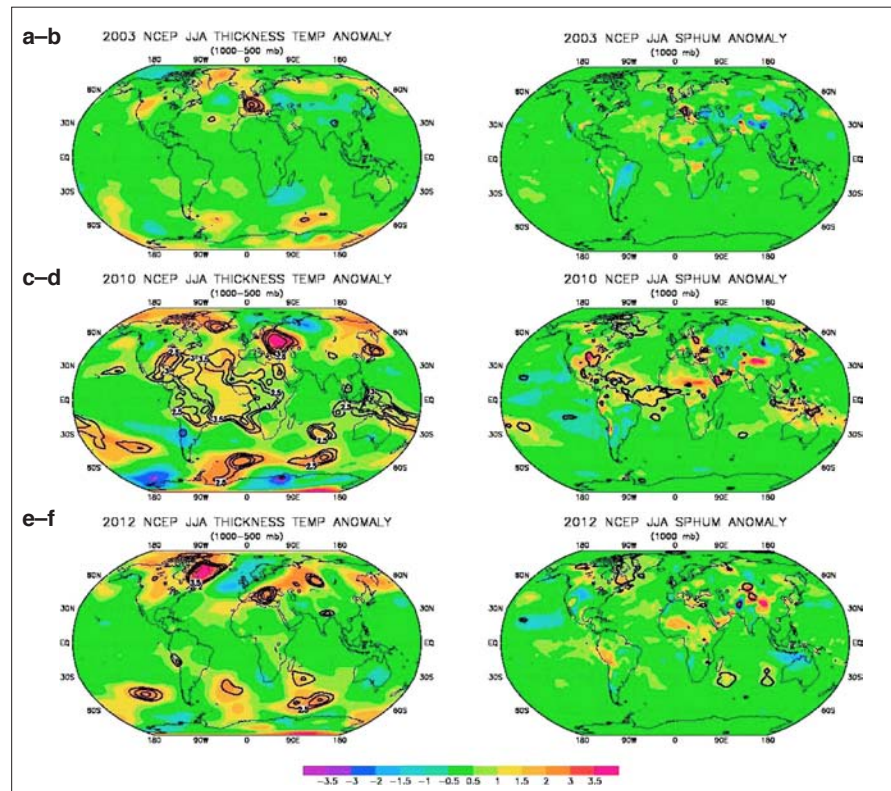


Thomas Chase

Variability in temperature extremes and atmospheric moisture

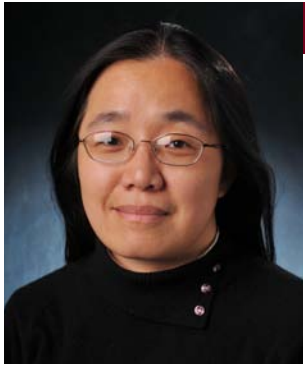
One theoretical consequence of the CO₂-warming hypothesis is that increases in atmospheric humidity will greatly amplify the warming signal due to CO₂ alone and will also amplify extremes. We investigated the magnitude and spatial extent of extreme temperature and specific humidity events in the extra-tropical northern hemisphere.

We found that there is an increasing trend in heat waves and positive specific-humidity anomalies and a decreasing trend in cold waves and negative specific-humidity anomalies. And similar patterns in the global trend in variability exist for both temperature and specific humidity. This means areas of increased variability are not necessarily the areas that have experienced extreme heat waves. The follow-up study to this work relates heat waves globally to changes in soil moisture.



A figure from a new analysis of Northern Hemisphere summer temperatures and specific humidity anomalies, co-authored by Chase. These figures show National Centers for Environmental Prediction Reanalysis temperature and specific humidity anomaly distributions for the three largest, most extreme heat waves in the NCEP record: (a–b) 2003, (c–d) 2010, (e–f) 2012. Contours encircle areas exceeding 2.5, 3.0, and 3.5 standard deviations.

Figure credit: Gill et al., *Journal of Geophysical Research: Atmospheres*



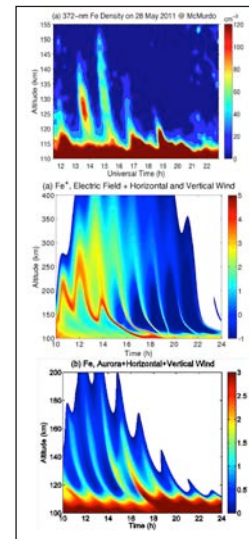
Xinzhao Chu

Lidar marathons in Antarctica and plasma-neutral atmosphere coupling

Discoveries of thermospheric neutral iron (Fe) layers (Chu et al., *Geophys. Res. Lett.*, 2011), solar effects on Fe layer bottomside (Yu et al., *J. Geophys. Res.*, 2012), persistent inertia-gravity waves (Chen et al., *J. Geophys. Res.*, 2013), and super-exponential growth of thermal tide amplitude above 100 kilometers (Fong et al., *J. Geophys. Res.*, 2014) by lidar observations in Antarctica are challenging our understanding of electrodynamic, neutral dynamics, chemistry, composition, and energetics in Earth's geospace environment. CIRES students Zhibin Yu and Weichun Fong in the Chu research group are developing numerical models to study the mechanisms. We achieved initial success, having successfully modeled the thermospheric Fe layers after carefully considering the neutral-plasma coupling and the influences of polar electric field, vertical wind, and aurora activity (figure). These science discoveries are motivating the atmosphere and space science community with a new initiative, Observatory for Atmosphere Space Interaction Studies (OASIS).

This also has been a year of setting records. The CIRES lidar team set a historic record for lidar observations: a continuous 174 hours of observations from Dec. 29, 2013, to Jan. 6, 2014, in Antarctica. CIRES student Cao Chen set new records, making continuous, sole-operator, 53- and 65-hour lidar observations in the harsh Antarctic winter. CIRES student John Smith and CIRES researcher Wentao

Huang achieved lidar signal levels of 2,400 counts per shot at Boulder, Colorado. These long and very high-resolution data sets are invaluable in pushing the envelope of upper atmosphere sciences. Another unprecedented record: CIRES students in the Chu group have won prizes every year from 2009 to 2014 in the Coupling, Energetic, and Dynamics of Atmospheric Regions (CEDAR) Student Poster Competition—most recently Zhibin Yu in 2013 and Weichun Fong in 2014. CIRES researcher Xian Lu won a CEDAR grant as the principal investigator for the first time. Congratulations to these creative students and researchers!



Thermospheric iron (Fe) layers (top), discovered by lidar observations at McMurdo in 2011, have been successfully modeled with a new thermospheric Fe/Fe⁺ model (middle, bottom).



“Members” of the lidar team (from left to right: Cao Chen, Xinzhao Chu, and Jian Zhao) deployed in the summer of 2013–2014 at McMurdo, Antarctica.



CIRES Ph.D. students Cao Chen and Jian Zhao jump up at Arrival Heights Lidar Observatory near McMurdo, Antarctica, to celebrate an extremely successful summer season and Chen's qualification to winter-over in 2014.

Photos: Xinzhao Chu/CIRES



Shelley Copley

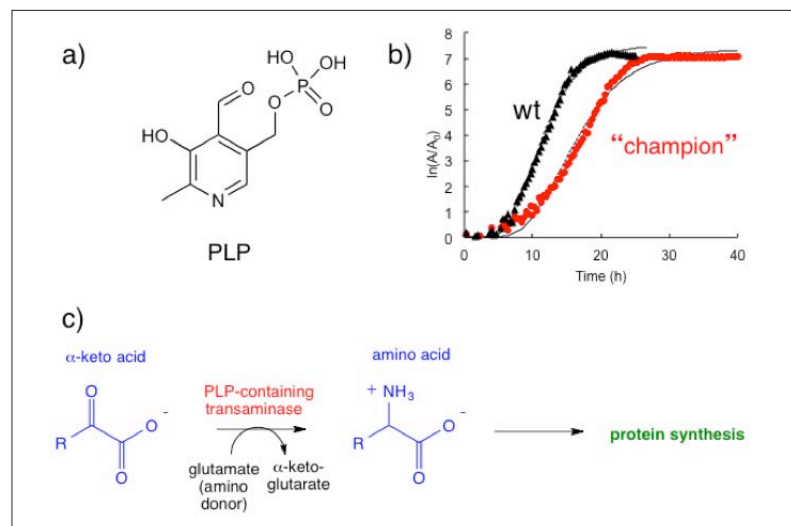
Adaptation of *E. coli* to use a novel pathway for vitamin B6 synthesis

Pyridoxal 5'-phosphate (PLP, aka vitamin B6) is a cofactor required for 40 different enzymes in *Escherichia coli*, including the transaminase enzymes that generate amino acids needed for protein synthesis. Deletion of a gene required for PLP synthesis prevents growth of *E. coli* on glucose as a sole carbon source because the cells cannot make amino acids. We have adapted a strain of *E. coli* (lacking an enzyme in the PLP biosynthesis pathway) to grow on glucose as a sole carbon source nearly as well as wild type *E. coli*. This strain, which we call the “champion,” has reconstituted a pathway for synthesis of PLP via a novel route as a consequence of only six mutations. By reconstructing strains containing various combinations of these mutations, we found that the order in which the mutations occur is critical; some of the mutations are beneficial in some genetic backgrounds, but detrimental in others.

We are currently investigating the mechanisms by which the six mutations enhance growth rate. This effort requires consideration of the effects of mutations on specific proteins, as well as effects that are propagated through the complex metabolic and regulatory networks. One mutation increases the concentration of an enzyme required in the novel and relatively inefficient pathway for PLP synthesis, presumably resulting in increased production of PLP. Two other mutations appear to act by redirecting

fluxes through the metabolic network. These mutations may increase the concentrations of the alpha-keto acid precursors of amino acids and compensating, to some degree, for the decreased level of PLP-containing transaminases.

This project is providing new insights into the ways in which mutations can reprogram the metabolic networks of bacteria and allow cells to adapt to new challenges.



a) The structure of pyridoxal 5'-phosphate (PLP). b) The “champion” grows nearly as fast as wild type (wt) *E. coli*.



Joost de Gouw

Natural versus man-made sources of fine particles in the air

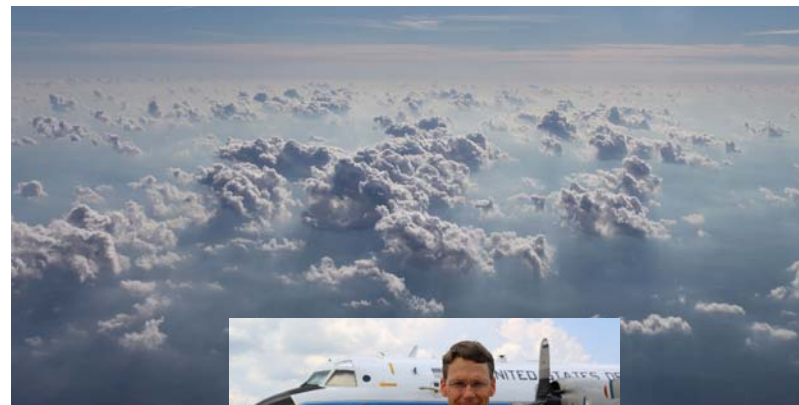
Organic molecules play an important role in the atmosphere. They provide the fuel for the formation of ozone in the lower atmosphere and contribute to fine particle formation. Ozone and fine particles are important air pollutants and play a role in the climate system: Ozone is a greenhouse gas, and fine particles cool the climate through the scattering of sunlight and by providing the nuclei for cloud droplets. Fine particles also can limit visibility and cause the air to appear polluted.

Organics have important natural and man-made emission sources, but the relative contributions of these sources to formation of ozone and, in particular, fine particles are poorly understood. In 2013, I led the NOAA Southeast Nexus of Air Quality and Climate Change (SENEX) study in the Southeast U.S. The Southeast is a region with high man-made emissions from power plants, industries, and urban areas, as well as some of the highest emissions from vegetation in the world. One of the major goals of SENEX was to investigate how these emissions combine to form ozone and fine particles.

To answer these questions, a team of 45 scientists from CIRES, NOAA, NASA, and three universities instrumented a NOAA WP-3D aircraft with a suite of chemical and physical instruments and conducted 18 research flights over a region spanning Florida to Texas in the south, and Missouri to Pennsylvania in the north. The

improved understanding of ozone and fine particle sources gained from SENEX is important for air quality: Only the man-made fraction of pollutants can be reduced through effective air-quality management. The knowledge is also important for climate: The global climate can be changed only through the forcing by man-made pollutants.

Another important direction of our research focuses on the environmental effects of new energy sources. For example, the production of shale gas has grown rapidly during the past decade, and ethanol made from corn now constitutes approximately 10 percent of gasoline in the United States. Research is underway to determine how the production and use of these energy sources have affected the atmospheric environment.



Top: Clouds in the U.S. Southeast seen from the NOAA WP-3D research aircraft during the SENEX study. Photo credit: Dan Lack/CIRES

Inset: Joost de Gouw in front of the NOAA WP-3D research aircraft. Photo credit: David Oonk/CIRES



Lisa Dilling

Governance of geoengineering research

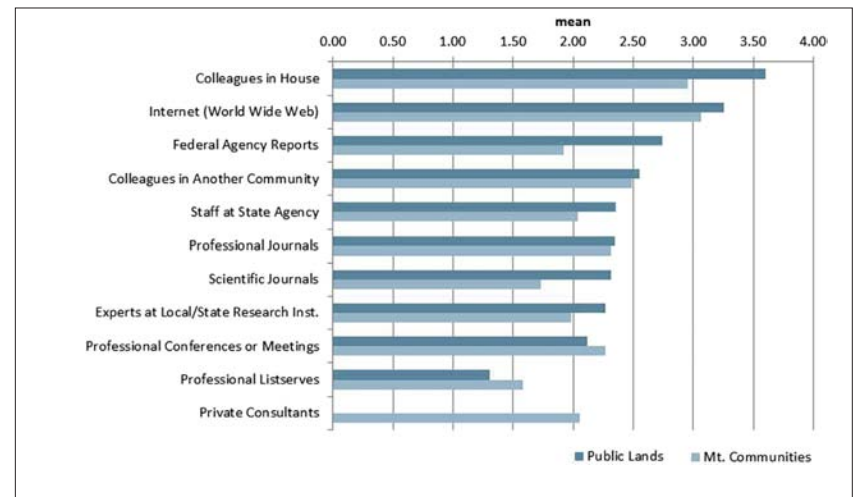
I study decision making, the use of information and science policies related to climate change, adaptation, geoengineering, and carbon management. My current projects examine drought in urban water systems, water governance and climate change, municipal adaptation to hazards, decision making in public lands management, and knowledge for adaptation in Tanzania.

My research focuses on what factors are associated with policy choices to mitigate weather- and climate-related risks and how information plays a role. I ask questions such as: How do communities perceive risk? How are choices and tradeoffs evaluated? How is information produced, evaluated, and used? I study this area along three major fronts: 1) How do science policies shape the usability of research for decision making?; 2) How do current decision processes incorporate climate-related risk or opportunity?; and 3) What factors shape the adaptive capacity of organizations?

My current project investigates the governing of geoengineering research. Research on geoengineering (the deliberate management of Earth's climate system) is being increasingly discussed within the science and policy communities. While justified as necessary in order to expand the range of options available to policy makers in the future, geoengineering research has already engendered public controversy. Proposed projects have been protested

or cancelled, and calls for a governance framework abound.

In this study, we consider the reasons why geoengineering research might be subject to additional governance and suggest mechanisms that might be usefully applied in developing such a framework. We consider criteria for governance as raised by a review of the growing literature on geoengineering and other controversial scientific topics. We suggest three families of concern that any governance research framework must respond to: the direct physical risks of the research; the transparency and responsibility in decision making for the research; and the larger societal meanings of the research. We review what mechanisms might be available to respond to these three families of concern, and consider how these might apply to geoengineering research.



Survey results from a recent paper analyzing barriers to climate change adaptation in the interior mountain West. Federal public lands and municipal respondents were asked, "What sources do you typically consult to obtain the data and information you need for your work?" The graph shows information sources consulted, by rank: Do not use in my work = 0, Rarely = 1, Occasionally = 2, Frequently = 3, and All the Time = 4. Figure credit: Archie et al., *Journal of Environmental Management*.



Lang Farmer

Investigating the provenance of “Grenville” age detrital zircon and the evolution of southwestern Laurentia

During the past year, the Farmer group continued studying the provenance of “Grenville” age detrital zircon in western North America and the Neoproterozoic-to-early-Paleozoic evolution of southwestern Laurentia. This project involves the combined use of hafnium (Hf) and uranium-lead (U-Pb) 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 some 500 million years ago.

The project was the focus of the master’s of science thesis completed by CIRES graduate student Amanda Howard, who demonstrated that the U-Pb ages and Hf isotopic compositions of approximately 1.1 giga-annum (Ga) zircon deposited along the western margin of North America during the Cambrian were not derived from distal sources in the present day Appalachians, as previously suggested, but instead were likely derived from more proximal areas in Texas and New Mexico.

To assess an alternative possibility that the approximately 1.1 Ga zircon were derived from northern Mexico, new CIRES master’s of science student Aaron Hantsche began a study of the zircon age and chemical characteristics of previously unstudied approximately 1.1 Ga anorthosites and granites in northern Sonora. This work is part of a long-term collaboration among researchers at CIRES

and at the University of Sonora, Hermosillo. Hantsche is currently setting up, in the CIRES clean-lab facility, the procedures required for the separation of hafnium from single dissolved zircon, in preparation for new high-precision Hf isotopic analyses of individual, approximately 1.1 Ga zircon.



CIRES master’s of science student Aaron Hantsche sampling a Mesoproterozoic anorthosite in northern Sonora, Mexico, November 2013.

Photo courtesy of Lang Farmer



Fred Fehsenfeld

Atmospheric science at the nexus of air quality and climate

My research is done with NOAA and CIRES colleagues in the Chemical Sciences Division (CSD) of NOAA's Earth System Research Laboratory. The goal of this research is to identify and quantify the emissions and processes that determine tropospheric chemical composition with a focus on ozone and aerosols. The aim of our work is to better understand how these atmospheric species influence regional air quality and climate forcing.

Our research approach involves making reliable measurements of the species that control tropospheric chemistry through comprehensive, integrated field studies that utilize state-of-the-art airborne, ship- and ground-based instrument packages that are deployed in regional assessments conducted throughout the United States, followed by a systematic analysis and appraisal of the results. Since 1999, NOAA and CIRES have jointly undertaken eight integrated field studies. These field programs follow a pattern that provides information concerning the similarity and differences in atmospheric chemistry and composition in the various regions across the United States and the surrounding regions that impact our air quality and climate.

I illustrate our approach by referring to the results from the 2010 California Research at the Nexus of Air Quality and Climate Change (CalNex) field study. The details

of the study are given in the recently published study overview (Ryerson et al., 2013). As the study acronym implies and the overview indicates, the study embodies a "one atmosphere" perspective that addresses both air-quality and climate-change issues.

There are several important aspects of this study. First, the study accomplished exceptionally productive, high-quality science. Thus far, 104 papers containing the analysis of the CalNex study have been published in the peer-reviewed scientific literature, with an additional four papers submitted and 35 in preparation. Second, scientific findings from the CalNex study have been distilled into a statement of findings concerning 23 policy-relevant science questions formulated by the California Air Resources Board (CARB) in consultation with NOAA (Synthesis of Policy Relevant Findings from the CalNex 2010 Field Study; <http://www.esrl.noaa.gov/csd/projects/calnex/synthesisreport.pdf>). This directly provides badly needed information on current national environmental concerns. Finally, the data from CalNex and the studies preceding and following it (CSD Air Quality Data; <http://www.esrl.noaa.gov/csd/groups/csd7/measurements/>) are available to the scientific community to compare with ongoing studies to better understand and predict the atmospheric environment of the future.



NOAA Twin Otter at Ontario, California, airport.

Photo credit: NOAA



Noah Fierer

A microbial perspective on air quality

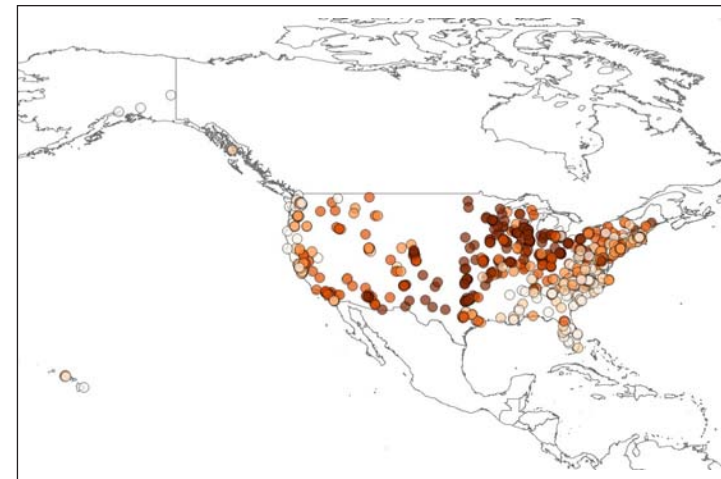
Microbes are ubiquitous and abundant in the atmosphere. There are typically millions of bacterial and fungal cells per cubic meter of air, and we inhale these microbes every time we step outside. Although most of these microbes are harmless, some can cause disease in livestock, plants, and humans. For the 10 percent of the U.S. population who suffers from asthma, airborne microbes are particularly important given that they are common triggers of allergies and allergenic asthma.

Despite the well-recognized importance of airborne microbes, the microbial diversity found in the near-surface atmosphere remains poorly studied. We have a limited understanding of the spatial variability in airborne bacterial and fungal communities and what factors influence this variability. In particular, we do not know how climatic conditions, surrounding land-use types, and proximity to point sources influence microbial air quality.

To address these knowledge gaps, my group has been using recent advances in high-throughput DNA sequencing to describe bacterial and fungal diversity in dust samples collected outside 1,500 homes located throughout the United States. These samples were collected as part of a unique citizen-science project (<http://homes.yourwildlife.org/>) that offers an opportunity for people across the United States to participate in the scientific process. This broad-scale survey has not only allowed us to build the

first maps of airborne bacterial and fungal diversity across the United States, but we also have been able to quantify how environmental conditions outside the home influence the relative abundances of bacteria and fungi found in the atmosphere.

For example, we have shown that fungal diversity varies in a predictable manner across the U.S. and that we can use information on the hundreds of fungal taxa found in individual dust samples to identify the geographic origin of that sample. Likewise, we have shown how proximity to point sources of bacteria (including livestock enclosures) can be determined by analyzing the types of bacteria found in dust samples. Current work is focused on understanding the distributions of specific microbial pathogens and allergens so we can begin to predict how climate change or land-use change may alter the relative abundances of these taxa in the near-surface atmosphere.



Map showing the relative abundance of fungi belonging to the *Alternaria* genus from house dust samples collected across the United States. *Alternaria* is a group of interest as it is one of the main triggers of allergies and allergenic asthma. Darker colors indicate higher relative abundances.



Timothy Fuller-Rowell

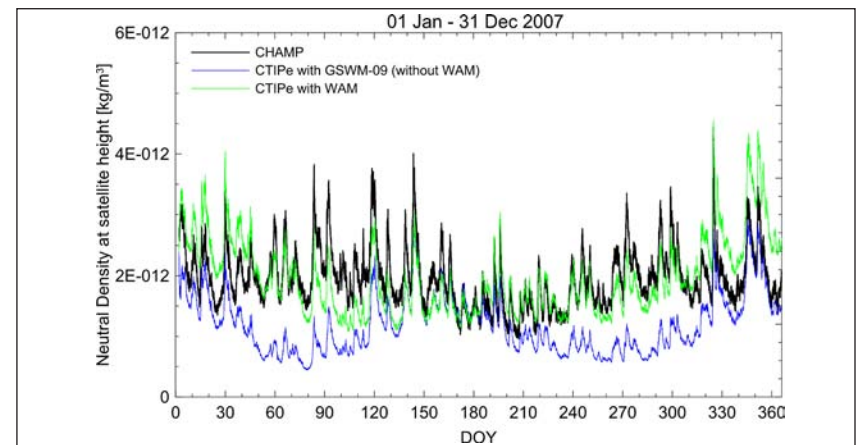
How waves from the lower atmosphere drive space weather

CIREs' broad sphere of science also includes "space weather." The term "space weather" refers to the variable conditions on the Sun, throughout space, and in Earth's magnetic field and upper atmosphere that can influence the performance of space-borne and ground-based technological systems. Near Earth, space weather impacts satellite drag and orbit prediction, as well as communication and navigation systems, which in extreme cases can endanger human life.

The Atmosphere-Ionosphere Modeling (AIM) group in CIREs targets the near-Earth response to solar variability, and also investigates the connections between terrestrial weather and space weather. When the Sun is active, the impact of solar variability, such as flares or coronal mass ejections, dominates space weather. Recently we have become increasingly aware of the impact of lower-atmospheric processes on space weather: A whole spectrum of waves is continually bombarding the upper atmosphere, and they originate from tropospheric convection, absorption of radiation by ozone and water vapor, sudden stratospheric warmings, jet stream adjustment, and ocean waves. To quantify the impact of this lower-atmosphere spectrum of waves, we have been working with our NOAA partners to build a whole atmosphere model (WAM). WAM can now simulate a large part of this neutral atmosphere wave spectrum.

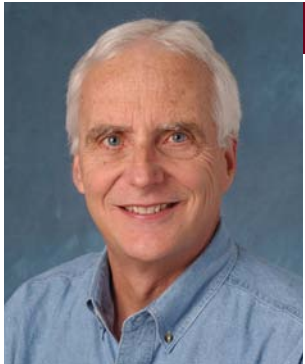
One of the impacts of these waves is on satellite drag. Most of the drag on a satellite in low-Earth orbit, such as the International Space Station (ISS), 250 miles above Earth, comes from the tenuous atmospheric gas it flies through, which is more than 1 billion times less dense than at sea level, yet is enough to perturb the ISS orbit. The figure shows neutral density measured at these altitudes from the German Challenging Minisatellite Payload (CHAMP) satellite. The episodic spikes of density come from increases in energy deposition from geomagnetic storms when the Sun suddenly becomes more active; these are superimposed on a longer-term seasonal modulation. Attempts to model the changes through the year using an upper atmosphere model by itself are good at capturing the spikes in density, but are not good at capturing the seasonal changes. The model underestimates the density at both equinoxes. When we used the WAM

spectrum of waves from the lower atmosphere to force the upper atmosphere in addition to solar and geomagnetic forcing, we were able to capture a large part of the semi-annual variation and improve orbit prediction.



Variation of orbit-averaged neutral density near 400 km altitude from observations on the German CHAMP satellite (shown in black) during 2007. Simulation using an upper atmosphere model by itself (shown in blue) falls short of predicting the density during both equinoxes. When the spectrum of waves from WAM is used to drive the upper atmosphere (shown in green), the semi-annual variation is captured, and orbit prediction is improved.

Figure courtesy of Mariangel Fedrizzi



R. Michael Hardesty

Characterizing the boundary layer for greenhouse gas emission measurement

Our work focuses on the application of Doppler lidar to characterize the boundary layer in top-down measurement of greenhouse gas emissions from large-area sources. The lidar investigation is one aspect of a multi-year research effort, the Indiana Flux Study (INFLUX), aimed at improving emissions-estimate methodologies at the urban scale. As part of INFLUX, an observational network—including periodic aircraft-based estimates of greenhouse gases and meteorological parameters, in situ tower-based measurements of carbon dioxide, methane, and carbon monoxide, eddy covariance and radiative flux observations, and a compact scanning Doppler—has been deployed in the Indianapolis urban region. We are using data from these sources to evaluate measurement methodologies and for inverse-modeling studies to estimate the urban area flux.

Information on boundary layer mixing, wind structure, turbulence, and thickness is a key requirement for both top-down emissions estimation and inverse modeling of emissions. During the past decade, we have employed our research High Resolution Doppler Lidar (HRDL) to develop and test Doppler lidar techniques from surface, ship, and airborne platforms for boundary layer investigations. For INFLUX, we are evaluating the effectiveness of a commercial Doppler lidar for continuous measurement of boundary layer wind and aerosol properties. The

commercial instrument, which employs components used in the telecommunications industry, operates at significantly lower pulse energy but a higher pulse repetition rate than our well-characterized HRDL system. Because the commercial lidar is designed for continuous operation, it is a good candidate for extended observation of the boundary layer; however, the lower pulse energy makes it susceptible to signal dropouts under low-aerosol conditions.

We have operated the lidar at a site northeast of downtown Indianapolis since April 2013. Since then, the instrument has operated continuously to provide measurements of wind speed and direction, aerosol backscatter signal intensity, and horizontal and vertical velocity variance. We use these observations to investigate nocturnal and seasonal variability in boundary layer mixing, depth, and structure. We also analyze the lidar measurements in combination with numerical models and aircraft observations of greenhouse gas concentrations for comparisons of the flux estimates with those computed from emissions inventories and to assess the feasibility of advanced modeling and measurement techniques for general application to urban areas. The next step in the research is to extend the methodologies developed during INFLUX to more complicated urban areas such as Los Angeles or Paris.



Compact Doppler lidar deployed on the roof at Ivy Tech Community College outside Indianapolis. The lidar steps through a series of conical and vertical scans and an interval of vertical staring to provide profiles of wind speed and direction, horizontal and vertical velocity variance, and aerosol backscatter signal strength three times per hour. Photo credit: Scott Sandberg/NOAA



José-Luis Jiménez

Sources, properties, and fate of organic aerosols in the atmosphere

Aerosols have major effects on climate forcing, human health, regional visibility, crops, and ecosystems. Sources of organic aerosols (OA), which comprise about half the mass of submicron aerosol, include anthropogenic pollution, biogenic compounds, and biomass burning. The amount, properties, and evolution of OA from these sources are poorly characterized, and our group combines field, laboratory, and modeling research to better constrain them.

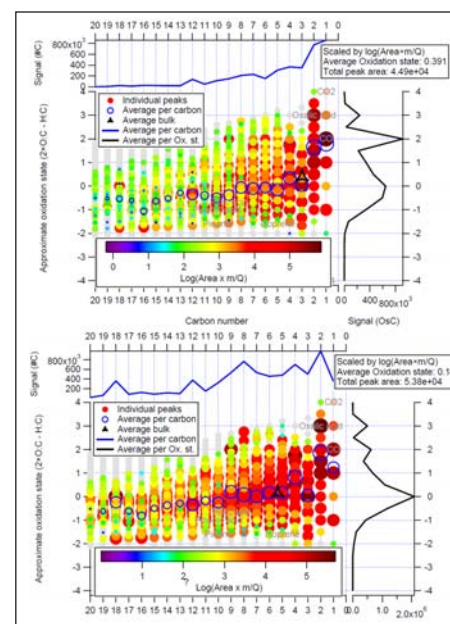
During the summer of 2013, our group participated in a large collaborative study in the U.S. Southeast: the Southeast Oxidant and Aerosol Study (SOAS). The project was part of the Southeast Atmosphere Study, which consisted of three ground sites and two aircraft platforms, and our goal was to better understand the role of emissions and oxidants and possible synergistic effects of anthropogenic and biogenic emissions in the formation of secondary OA (SOA). We deployed several real-time instruments at the SOAS supersite in Centreville, Alabama, capable of: 1) obtaining snapshots of the chemical composition of OA in the atmosphere and the atmosphere's potential to form SOA and how SOA ages under different conditions; 2) quantifying hundreds of organic molecules in the gas and aerosol phase to understand what controls the gas/particle partitioning and the chemistry leading to SOA formation; and 3) measuring

the volatility of bulk and speciated OA. The figure summarizes the organic acid gas- and aerosol-phase measurements (figure caption). We found that partitioning between gas and aerosol phases showed strong diurnal trends, that there was more partitioning to the gas-phase at higher temperatures, and that changes occurred on fast time scales (as quickly as temperature changes). These findings are contrary to much of current literature. Bulk OA showed major source contributions from daytime isoprene (primarily emitted from oaks and other deciduous trees) oxidation, nighttime reactions likely involving monoterpenes (primarily emitted from pines and other coniferous trees) and the nitrate radical (formed from ozone and mostly anthropogenic NO_x), and a very oxidized regional background component (likely from mixed, aged sources).

During February and March 2014, we participated in another intensive measurement campaign in the Amazon Basin near Manaus, Brazil, to investigate similar aspects of SOA formation, but in an environment dominated by tropical rainforests and during the wet season.

Another major focus this year has been designing and building a new laboratory facility with dual atmospheric simulation chambers with

controllable temperature, humidity, and visible/ultraviolet light. We plan to use the chambers to simulate and investigate gas and aerosol chemistry and physics for a variety of conditions found in the atmosphere.



Oxidation state versus carbon number for gas and aerosol organic acids. Higher oxidation state was observed for bulk gas-phase acids than particle-phase. Oxidation state decreases at lower carbon numbers and more so for the gas than particle phase.

Figure credit: Thompson, Jimenez, et al., 2014, in prep.



Craig Jones

Origins of the Sierra Nevada

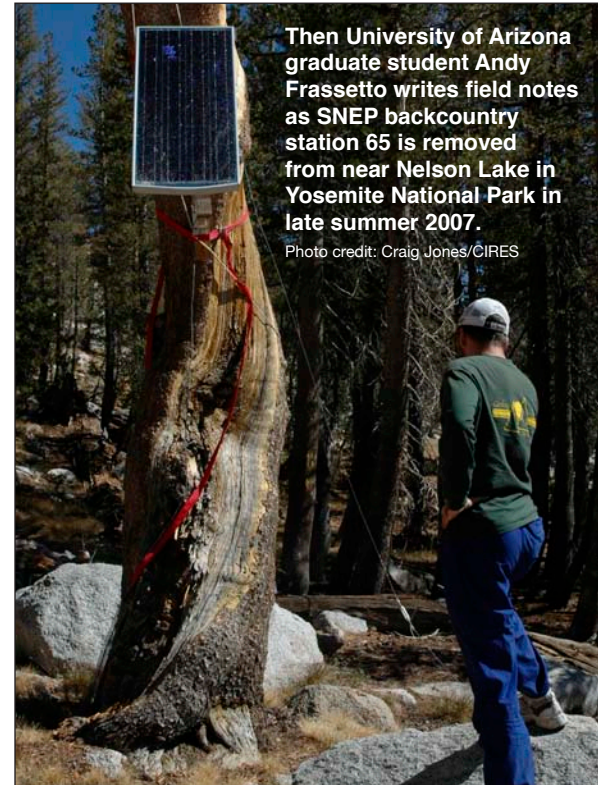
In the six to seven years since the last portable seismometer was removed from the Sierra, seismological analysis has revealed that the entire eastern side of the range (the high part) has a relatively thin crust over a fairly low wavespeed upper mantle. The granite that makes up so much of the “Range of Light” was extracted from lower crustal melts that should have left a residual thick mass of dense, quartz-poor rock, but the seismological work confirms that this material is missing over the entire length of the range. Because volcanic rocks sampled the residuum some 8 million to 12 million years ago, its absence today suggests that it has been removed recently.

The seismic images can be used more quantitatively. CIRES Ph.D. graduate student Will Levandowski and I used the seismic wavespeed variations to calculate the contribution to the elevation of the range from within the crust and from the mantle, finding that each had contributed roughly half to the modern elevation of the range. Because the crustal part had been made about 80 million years ago, this suggests that roughly half of the modern elevation of the Sierra arose as residuum that used to underlay the mountains sank.

But where did that residuum go, and how was it removed? Again using the seismic image, I, former master’s student Heidi Reeg, and collaborators determined the

equivalent of the mass anomaly removed from under the range and compared it to the anomaly present within a seismic anomaly in the upper mantle under the southwestern part of the range and the adjacent San Joaquin Valley. This analysis was unusual in taking care to avoid errors from the kinds of ambiguity in this kind of imaging that are evident in the section shown here. The mass anomaly removed and that present in the upper mantle today are the same, within uncertainties.

A surprising finding came as I helped co-principal investigator Jeff Unruh (Lettis Consultants International) and Egill Hauksson (Caltech) understand the seismicity near this mantle anomaly. Instead of variations in fault orientations consistent with the crust being pulled down, the seismicity suggests that the area might be moving upwards. If this is so, it means that less-dense crust has been pulled into the mantle anomaly and only now is starting to rebound as the mantle anomaly descends farther into the earth. Such a reversal has been suggested by theoretical work but has not been observed prior to this.



Then University of Arizona graduate student Andy Frassetto writes field notes as SNEP backcountry station 65 is removed from near Nelson Lake in Yosemite National Park in late summer 2007.

Photo credit: Craig Jones/CIRES

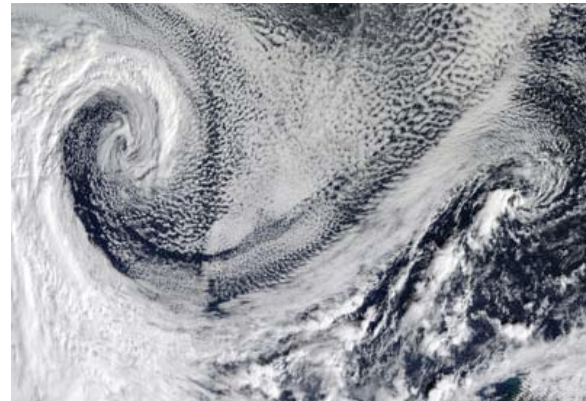


Jennifer Kay

Polar climate change and variability

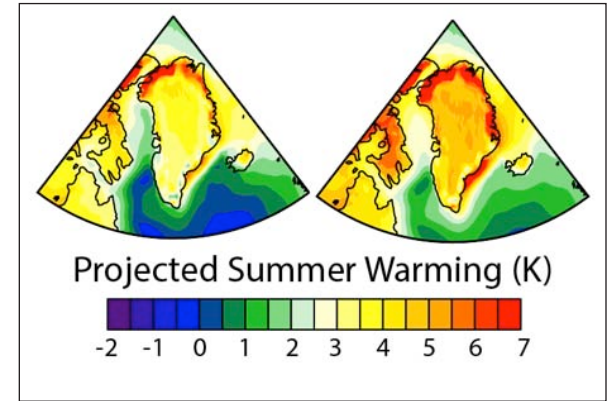
I joined CIRES/CU-Boulder in January 2014. Two Ph.D. students, Vineel Yettella and Ariel Morrison, start their research with me this summer. My group connects global coupled climate modeling with cloud, precipitation, and sea ice observations to understand the processes controlling polar climate change and variability. Working at the nexus of observations and modeling is challenging but rewarding. Here, I'll describe two recent projects.

During the last year, I co-led a large modeling experiment using a global coupled climate model: the Community Earth System Model (CESM). The experiment was designed to enable community assessment of climate change in the presence of internal climate variability. The core simulations replay 1920 to 2080 30 times under historical and large future greenhouse gas forcing. The ensemble members differ only in their 1920 atmospheric air temperature initialization. Early results document the surprisingly important and at times dominant influence of internal climate variability on climate trajectories. Nature is an ensemble member, not the ensemble mean. Accelerations and pauses in global warming occur. Sea ice loss is prevalent, but the loss amount varies from member to member. Now I am analyzing climate variables influencing Greenland Ice Sheet melt in the ensemble (figure).



Moderate Resolution Imaging Spectroradiometer (MODIS) satellite image of intriguing Southern Ocean clouds. Image credit: NASA MODIS satellite

The Southern Ocean is the cloudiest place on Earth. Climate models have large cloud and radiation biases and interesting cloud-climate feedbacks over the Southern Ocean. As a result, I am obsessed with the intriguing cloud structures found there (satellite image). In a 2014 *Geophysical Research Letters* paper, we found, using CESM, that the radiatively important clouds are low-level, liquid clouds. Interestingly, these clouds respond primarily to thermodynamics (warming and sta-



21st summer warming over Greenland in two Community Earth System Model (CESM) Large Ensemble members.

bility changes), not dynamics (jet variability and jet shifts), under climate change scenarios. We are now looking into reducing Southern Ocean radiation biases in CESM by improving the match between observed and modeled cloud supercooled liquid water. We anticipate our improvements will have both local and remote impacts.

The poorly observed and rapidly changing polar regions present many exciting research opportunities of global importance. The Kay group has plenty to keep us busy.



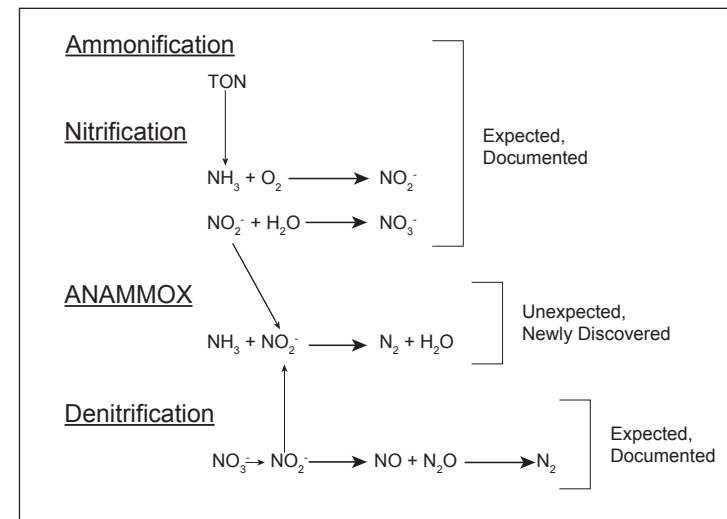
William M. Lewis Jr.

Nitrogen takes a detour along the South Platte

In aquatic environments, ammonia (NH_3) released from organic nitrogen (total oxidized nitrogen, TON) by microbes is oxidized to nitrate (NO_3^-) by the nitrification process of other microbes in the presence of oxygen through a series of steps involving nitrite (NO_2^-) as an intermediate (figure). The result is an increase of nitrate and a decrease in ammonia and TON in the environment. In addition, nitrate, when entering aquatic sediments where oxygen is absent, is converted by microbes through the process of denitrification to N_2 gas, an inert end product that corresponds to elimination of nitrogen pollution from the aquatic environment. These processes occur at very high rates in the South Platte River, which, like many other rivers that lie within the drainage of large population centers, receives substantial amounts of ammonia and nitrate from treated wastewater and agricultural practices. The two processes can be quantified based on mass balance of the input and output components for reactions as shown in the figure.

Validity of mass balance calculations for nitrification and denitrification processes can be checked independently by calculation of mass balance for oxygen. The nitrification process, which produces NO_3^- as an end product, uses a predictable amount of oxygen. Thus, the oxygen mass balance, which incorporates all processes affecting dissolved oxygen, incorporates a prediction of ammonia loss caused

by nitrification. Large inconsistencies between the computed oxygen loss caused by nitrification and the observed oxygen loss from the South Platte River indicates that another process is causing loss of ammonia. Assimilation of ammonia by algae is too small to account for this large difference, so the mass balance points to anaerobic ammonium oxidation (ANAMMOX), a process that is known to occur in aquatic environments but has never been quantified as a major factor in nitrogen mass balance for rivers. An estimation of the rates based on mass balance of oxygen and nitrogen components of the relevant processes suggests that ANAMMOX accounts for 50 percent of ammonia loss in the South Platte River below Denver. This information on the South Platte suggests that ecologists have not given sufficient attention to the importance of ANAMMOX, which is hidden within the related chemical transformations associated with the long-recognized processes of nitrification and denitrification in aquatic systems, and particularly those that carry large pollutant loads.



Summary of nitrogen fluxes relevant to concentrations of ammonia (NH_3) and nitrite (NO_3^-), important pollutants in the South Platte River below Denver.



Peter Molnar

Mantle convection and mountain building

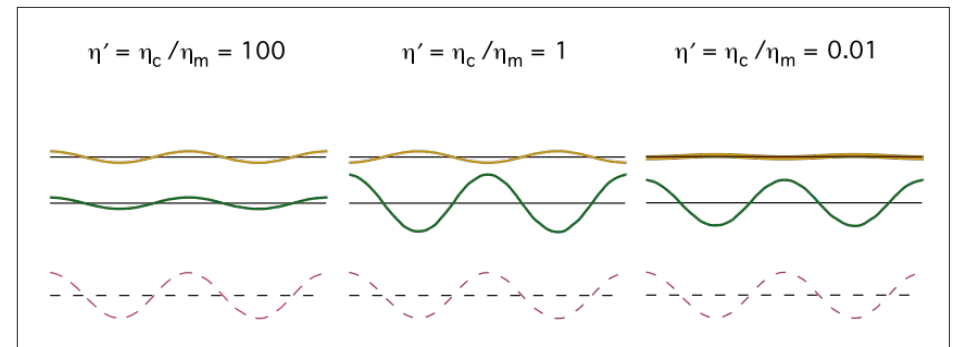
Mountain ranges are built where crust shortens horizontally and thickens. Whatever the forces are that act on plates and move two continental regions together, they obviously play a crucial role in building mountains. In addition, however, where the underlying mantle lithosphere also thickens beneath thickening crust, the mantle lithosphere should become gravitationally (or convectively) unstable and sink into the asthenosphere beneath it. The resulting flow in the mantle might enhance convergence of crustal material and its thickening and, hence, contribute to the building of mountains.

To study such a possible role for the mantle in building mountains, we studied Rayleigh-Taylor instability—which is associated with a dense layer (like the mantle lithosphere) overlying a less dense layer (like the asthenosphere). To that, we added a low-density crustal layer on top. For a wide range of plausible thicknesses of layers, densities of them, and ratios of viscosity of crust and mantle lithosphere, we found that the instability of the mantle lithosphere enhances crustal thickening. Moreover, except for extremely viscous crustal layers, the surface above converging and thickening crust rises, and hence creates a mountain range.

We also found, however, that the calculated heights of such simulated mountain ranges would be lower than

what we would expect if isostatic equilibrium applied. Isostasy is Archimedes' principle applied to the earth, and it describes well the balance of mass in mountain ranges: A deficit of mass, such as that due to thickened crust, must underlie high terrain, just as most of the ice in an iceberg lies below sea level.

As a definitive test of how thickening and converging mantle lithosphere might contribute to mountain building, we exploited gravity anomalies. Calculated anomalies for our simulated mountain ranges tend to be negative, or nearly zero, whereas those observed over ranges worldwide are positive. We conclude that localized convection beneath mountain belts plays only a minor role in creating their heights. The larger-scale forces that move lithospheric plates together seem to be much more important.



Examples of deflections of the lithosphere-asthenosphere boundary (LAB; red), Moho (green), and surface (brown) induced by a growing Rayleigh-Taylor instability, for three values of $\eta' = \eta_c / \eta_m$: 100 (left), 1 (center), and 0.01 (right). All deflections are scaled to that at the LAB, but relative to it, those for the Moho and surface are vertically exaggerated 25 times.

Molnar, P, and GA Houseman. 2013. Rayleigh-Taylor instability, lithospheric dynamics, surface topography at convergent mountain belts, and gravity anomalies. *J. Geophys. Res. Solid Earth*. 118:2544–2557.



R. Steven Nerem

The impact of changes in terrestrial water storage on global mean sea level variations

During the satellite radar altimeter era (1993 to present), global mean sea level has been increasing at a rate of 3.2 millimeters per year. However, there is considerable year-to-year variation (figure 1). Much of this variability is understood to be due to changes in land/ocean precipitation patterns in response to climate variability (El Niño Southern Oscillation, ENSO, Pacific Decadal Oscillation, PDO, etc.). The launch of the Gravity Recovery and Climate Experiment (GRACE) satellite gravity mission in 2002 gave us an additional tool with which to study these variations. GRACE allows us to track changes in land/ocean water storage, and determine where on the land the water is being stored or lost. In addition, GRACE can tell us how the mass of the water in the oceans is changing due to changes in land water storage (figure 1).

In the last few years, we have examined these interannual sea level variations by using a combination of tide gauge measurements, satellite radar altimeter measurements, and satellite gravity measurements. In particular, we examined the drop of global mean sea level during the 2011 La Niña by using GRACE estimates of land water storage (Boening et al., 2012; figure 2) and found a large water storage signal, driven mainly by Australia (Fasullo et al., 2013). The Australia event was rather unique in the satellite record (Fasullo et al., 2013), but in general, there tends to be more precipitation over land

during La Niña events and more precipitation over the oceans during El Niño events.

We also examined PDO's influence on global mean sea level changes. Hamlington et al. (2013) found that the PDO may have contributed as much as 0.5 millimeters per year to the 3.2 millimeter-per-year trend in global mean sea level since 1993. This means the anthropogenic component of sea level rise may be somewhat smaller than previously thought.

It is important to understand the causes of changes in global mean sea level so we can better isolate the anthropogenic and non-anthropogenic climate signals. The former is likely accelerating, but detecting this acceleration is difficult with the short 21-year satellite record. ENSO and PDO also have significant impacts on re-

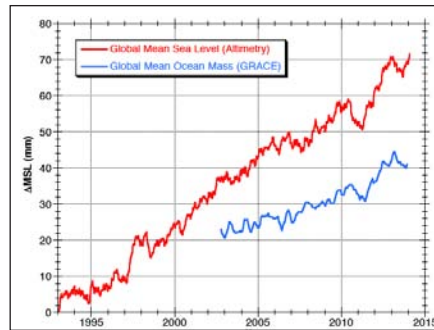


Figure 1. Global mean sea level variations from satellite altimetry (TOPEX/Poseidon, Jason-1, and Jason-2) and global ocean mass variations from GRACE. Note the decrease in both during the 2011 La Niña event. <http://sealevel.colorado.edu>.

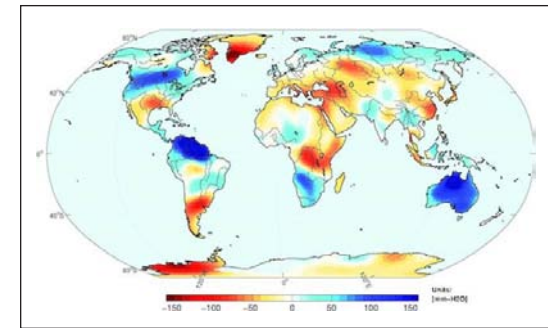


Figure 2. Change in water mass from beginning of 2010 (Jan.–Feb.–March average) to mid-2011 (March–April–May average). Blue colors indicate an increase in water mass over the continents.

gional sea level, which is an important consideration when studying the regional impacts of sea level change.

Boening, C, JK Willis, FW Landerer, RS Nerem, and J Fasullo. 2012. The 2011 La Niña: So strong, the oceans fell. *Geophys. Res. Lett.* 39:L18607.



David Noone

Carbonyl sulfide and the carbon budget

Understanding the processes that control the terrestrial exchange of carbon is critical for assessing atmospheric CO₂ budgets. Carbonyl sulfide (COS) is taken up by vegetation during photosynthesis following a pathway that mirrors CO₂ but has a small or nonexistent emission component, providing a possible tracer for gross primary production. Continuous high-resolution joint measurements of COS and CO₂ concentrations in the boundary layer can be used alongside flux measurements to partition the influence that leaf and soil fluxes and entrainment of air from above have on the surface carbon budget.

We made field measurements of COS and CO₂ mixing ratios in forest, senescent grassland, and riparian ecosystems using a laser absorption spectrometer installed in a mobile trailer. These data show 1) the existence of a narrow daytime uptake ratio of COS to CO₂ across vascular plant species of 1.7, providing critical information for the application of COS to estimate photosynthetic CO₂ fluxes and 2) a temperature-dependent uptake ratio of COS to CO₂ from soils. Significant nighttime uptake of COS was observed in broad-leafed species and revealed active stomatal opening prior to sunrise. The results provide a number of critical constraints on the processes that control surface COS exchange, which can be used to diagnose the robustness of global models that

are beginning to use COS to constrain terrestrial carbon exchange. This work was supported by a CIRES Inno-

vative Research Program award (page 64), and two prior CIRES Visiting Fellows collaborated in the research.



Making measurements of CO₂ and COS at the Boulder Atmospheric Observatory tall tower site operated by NOAA. Measurements were made by drawing sample air into a mobile laboratory fitted with gas analyzers and calibration equipment. Photo courtesy of David Noone/CIRES



Judith Perlwitz

Linking stratospheric extreme circulation events to the North Atlantic circulation

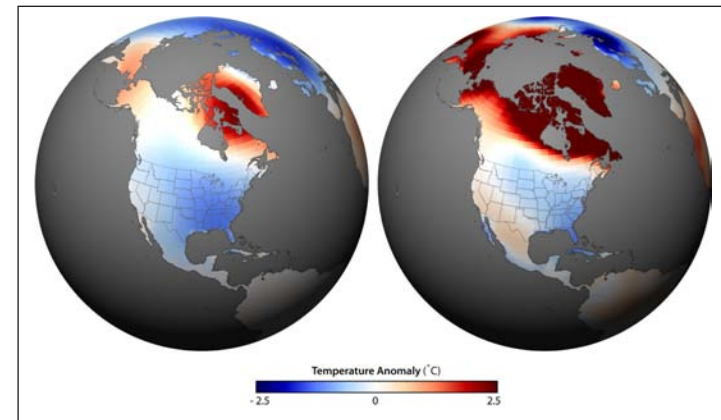
During the past two decades, observational and modeling studies have fundamentally changed our understanding of the role of the stratosphere in surface weather and climate. While we now have multiple evidence for a two-way interaction between troposphere and stratosphere, the mechanisms by which the stratosphere can affect tropospheric climate in the real world and climate models are still under investigation.

We established a new dynamical metric of troposphere-stratosphere coupling based on extreme stratospheric planetary-scale wave heat flux events. Positive and negative heat flux extremes are an indication of very strong upward and downward coupling between the troposphere and stratospheric circulation, respectively. We defined negative and positive extreme events as the 10th and 90th percentiles of the daily high-latitude averaged heat flux distribution at 50 hectopascal (hPa), using European Centre for Medium-Range Weather Forecasts Re-Analysis (ERA)-Interim reanalysis data.

We found that the stratospheric heat flux extremes are linked instantaneously to high-latitude planetary-scale wave patterns in the troposphere and zonal wind, temperature, and mean sea level pressure anomalies in the Atlantic Basin. The impacts are reminiscent of different phases of the North Atlantic Oscillation. In particular, extreme positive (negative) heat flux events

in the stratosphere are associated with an equatorward (poleward) jet shift in the North Atlantic Basin. The metric is used to evaluate troposphere-stratosphere coupling in models participating in the Coupled Model Intercomparison Project Phase 5 (CMIP5).

The results show that models with a degraded representation of stratospheric extremes exhibit robust biases in the troposphere relative to reanalysis. In particular, models with biased stratospheric extremes exhibit a biased climatological stationary wave pattern and Atlantic jet stream position in the troposphere. We determined that the stratospheric biases are connected to model lid height, but it is not sufficient for assessing the tropospheric impacts. The results presented suggest that stratospheric heat flux extremes are a good indicator of the vertical coupling of planetary-scale waves between the stratosphere and troposphere. If the coupling of planetary waves to the stratosphere is not properly represented, for example, due to excessive wave damping or reflection from the model lid, this can negatively impact tropospheric stationary wave structure.



These maps compare the observed temperature patterns for December 2010–February 2011 (left) to the patterns that would be expected based only on the relative strength and frequency of the positive and negative NAO phases that occurred (right). Temperatures are shown as warmer than (red), cooler than (blue), or near (white) the 1961–1990 average. The expected conditions are based on analysis of monthly surface temperature anomalies and NAO index values that have occurred throughout the past half-century. Maps credit: Ned Gardiner and Hunter Allen, based on analysis produced by the NOAA Attribution Team (CSI), led by Marty Hoerling of NOAA/ESRL

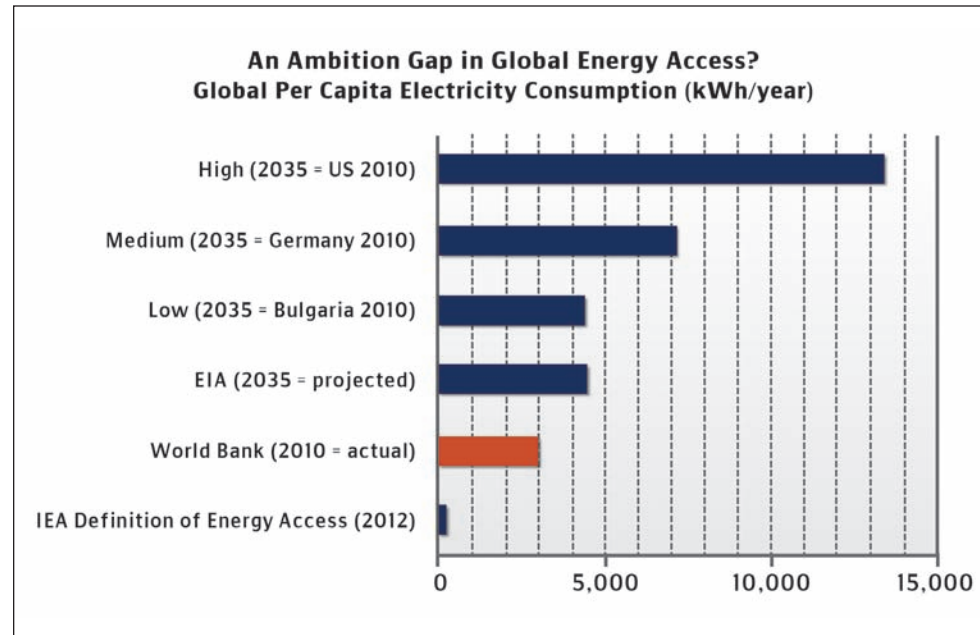


Roger Pielke Jr.

Making energy access meaningful

In an essay published in *Issues in Science and Technology*, Roger Pielke Jr. and Morgan Bazilian (then with the Joint Institute for Strategic Energy Analysis at the National Renewable Energy Laboratory) seek to help clarify the challenge of energy access, expose assumptions that are informing policy design in the development and diplomatic communities, and offer a framework for future discussions rooted in the aspirations of people around the world to achieve energy access compatible with a decent standard of living.

Compounding the difficulty of decision-making in such a complex space is that the concept of “energy access” is often defined in terms that are unacceptably modest. Discussions about energy and poverty commonly assume that the roughly 2 billion to 3 billion people who presently lack modern energy services will only demand or consume them in small amounts over the next several decades. This assumption leads to projections of future energy consumption that are not only potentially far too low, but therefore imply, even if unintentionally, that those billions will remain deeply impoverished. Such limited ambition risks becoming self-fulfilling, because the way we view the scale of the challenge will strongly influence the types of policies, technologies, levels of investment, and investment vehicles that analysts and policy makers consider to be appropriate.



Bazilian, M, and R Pielke Jr. 2013. Making energy access meaningful. *Issues Sci. Tech.* 74-79.



Balaji Rajagopalan with Peter Molnar

Predicting early- and late-season Indian monsoon rainfall

India's vital dependence on its summer monsoon rainfall for agriculture and other water resources makes improving forecasting of rainfall amount a continual challenge. Variability and predictability hinge on two widely regarded influences: local land warming and distant El Niño Southern Oscillation (ENSO). Most statistical methods for forecasting monsoon rainfall, used by the India Meteorological Department, use predictors related to these influences. Although a combination of such predictors once engendered optimism, marked variations in correlations with ENSO indices has cast doubt on such predictors. When applied to the entire monsoon season, such predictors generally account for less than 20 percent of variance in observed rainfall over India. Similarly, predictions exploiting general circulation models and surface boundary conditions account for less than 20 percent of observed monsoon variance.

We exploit ENSO indices and moist static energy (MSE) of surface air over the Indian subcontinent and surroundings as predictors of monsoon rainfall over India (figure 1) during early and late seasons (May 20–June 15 and September 20–October 15). Although these seasons only contribute about 22 percent of the entire seasonal rainfall, they affect planning of agriculture and water resources. A simple, non-linear statistical model applied to these predictors accounts for about 40 and 45 percent of observed variance of early-

and late-season rainfall, respectively, and similar fractions of three-day maximum rainfall intensity (figure 2).

Forecasted average and three-day maximum rainfall at grid points covering India show greatest success over Central India during the early season and over West-Central, Northwestern, and Northern India during the late season, regions where agriculture dominates land use. But these predictors offer virtually no predictability of peak season rainfall, at least with ENSO and MSE. This is noteworthy because the target, if not holy grail, of Indian monsoon prediction has been the seasonal total rainfall, which apart from being less predictable might also ultimately be of limited use. This research prompts a re-thinking of

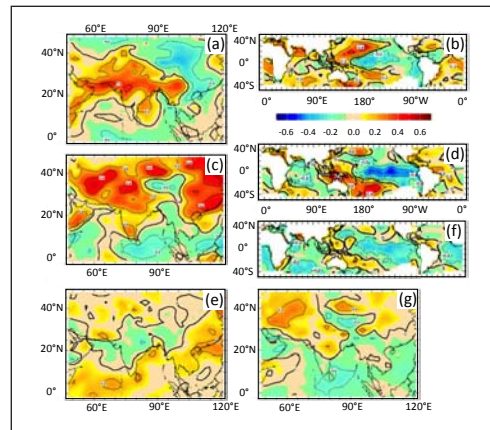


Figure 1. Correlation maps of Indian rainfall with moist static energy (MSE) and sea surface temperatures (SST). Full caption in DOI: 10.1002/2014GL060429

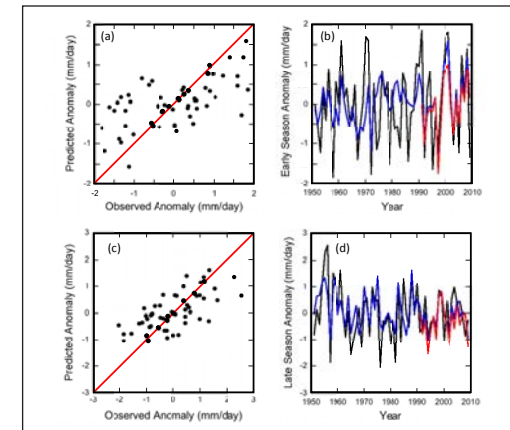


Figure 2. Observed, modeled, and forecasted standardized rainfall anomalies. Full caption in DOI: 10.1002/2014GL060429

monsoon forecasting to attributes that not only are more predictable but also of value for agriculture and water-resources planning.

Rajagopalan, B, and P Molnar. 2014. Combining regional moist static energy and ENSO for forecasting of early and late season Indian monsoon rainfall and its extremes. *Geophys. Res. Lett.* 41.



Prashant Sardeshmukh

How has global warming affected the tropical Pacific Walker Circulation?

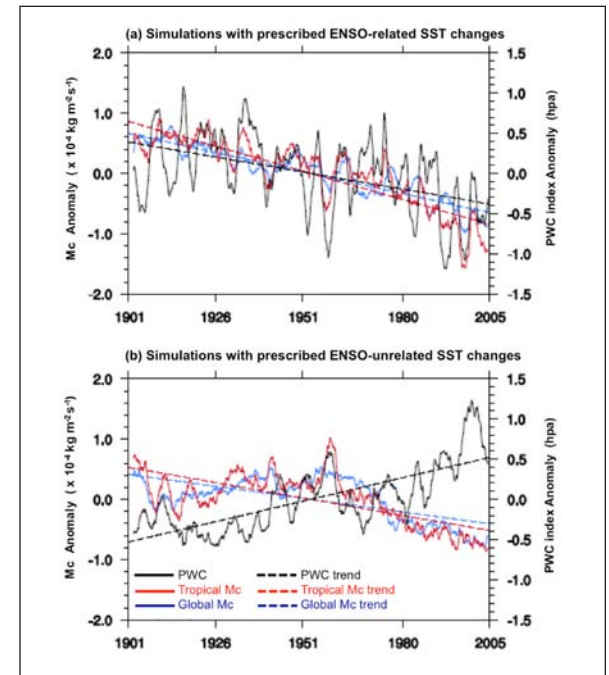
The tropical Pacific Walker Circulation (PWC) is a planetary scale east-west overturning of the equatorial atmosphere with ascent over the western Pacific and descent over the eastern Pacific ocean. There's great interest in how the PWC has been affected by 20th century global warming. As yet, however, there's no clear observational consensus on whether it has weakened, strengthened, or stayed unchanged. On the other hand, a general slowdown of overturning atmospheric circulations has been argued to be physically necessary to explain the relatively weak response of global precipitation to global warming obtained in many climate models, but it's not clear to what extent such an argument applies to regional overturning circulations such as the PWC. Still, many climate models do also simulate a 20th century weakening of the PWC. Is this correct?

We have recently published a detailed study (Sandeep et al., 2014) of 20th century PWC changes and their physical mechanisms using a combination of observational data sets and atmosphere-ocean coupled climate model simulations included in the latest Intergovernmental Panel on Climate Change report. The PWC weakens over the century in the coupled model simulations, but strengthens in the observational 20th Century Reanalysis data set and also in separate uncoupled atmospheric general circulation model (AGCM) simulations with prescribed observed changes in radiative forcings and sea surface temperatures

(SSTs). We argue that the weakening in the coupled simulations is not a consequence of a reduced global convective mass flux expected from the simple argument outlined above, but is rather due to a weakening of the zonal equatorial Pacific SST gradient.

We provide further clarification through additional uncoupled AGCM simulations in which portions of the observed SST changes that are related or unrelated to the El Niño Southern Oscillation (ENSO) are prescribed separately as lower boundary conditions. Both sets of SST fields have a global warming trend, and both sets of simulations produce a weakening of the global convective mass flux (figure). However, consistent with the strong role of the zonal SST gradient, the PWC strengthens in the simulations with the ENSO-unrelated SST forcing, which has a strengthening zonal SST gradient, despite the weakening of the global convective mass flux. Overall, our results suggest that the PWC strengthened during 20th century global warming, but also that this strengthening was partly masked by a weakening trend associated with ENSO-related PWC variability.

Sandeep, S, F Stordal, PD Sardeshmukh, and GP Compo. 2014. Pacific Walker Circulation variability in coupled and uncoupled models. *Climate Dynam.* 43(1-2):103-117.



Variations of a PWC index and atmospheric convective mass flux (Mc) in NCAR/CAM4 model simulations in which only the ENSO-related and ENSO-unrelated portions of observed SST changes are prescribed.



Mark Serreze

Understanding the environmental impacts of a changing Arctic

As the Arctic loses its summer sea ice cover, the region becomes more accessible to marine transport, tourism, and extraction of energy resources. As the economic and strategic importance of the Arctic grows, so does the need to better understand its climate and weather patterns, and to communicate the implications of Arctic change to the public. Research during the past year has been guided by these principles. My group's work continued to elucidate processes leading to "Arctic amplification," the observed outsized rise in temperatures in the Arctic relative to the rest of the globe.

While sea ice loss is a primary driver of Arctic amplification, a number of other processes appear to contribute, including changes in cloud cover and atmospheric heat transport into the region. It has been argued by some scientists that Arctic amplification is having influences on mid-latitude weather patterns in autumn and winter. While there is evidence of such impacts from modeling studies, observational evidence is, at best, conflicting. In the coming year, in collaboration with other CIRES scientists from both modeling and observational frameworks, we will examine in detail responses to Arctic amplification both within the Arctic and at middle-latitudes.

A new line of research started during the past year focused on better understanding the characteristics, variability, and environmental impacts of the Summer Arctic

Frontal Zone and how this seasonal feature may change in the future. Most prior research work concludes that the Arctic Frontal Zone develops in response to summer heating contrasts between the Arctic Ocean and snow-free land. Areas where the frontal zone is best expressed are regions of frequent cyclogenesis (storm formation). It appears that these cyclones have significant impacts on summer precipitation not only along the Arctic coast, but also over the central Arctic Ocean, which is where many of the storms eventually migrate.

Another major accomplishment of the past year was the completion of the second edition of my textbook with Roger Barry, titled "The Arctic Climate System." As has been the case for the past seven years, I participated in field work in the Alaskan Arctic to monitor snow-cover conditions.



Heading out to assess snow conditions over the North Slope of Alaska.

Photo credit: Mark Serreze/CIRES



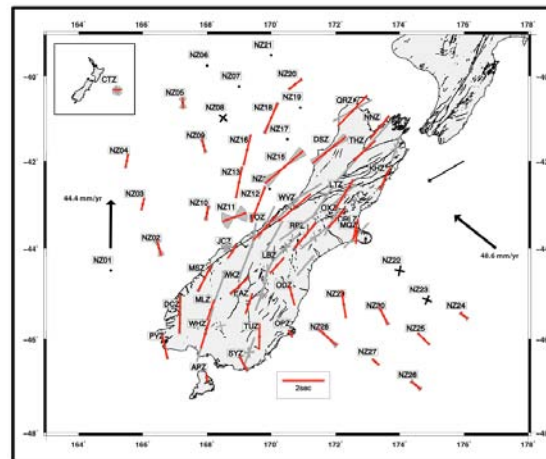
Anne Sheehan

Earthquake and oceanography studies with ocean-bottom seismometers

In May 2014, CIRES graduate students Justin Ball and Jenny Nakai and I joined an international team with researchers from the United States, Japan, and New Zealand to deploy 34 ocean-bottom seismometers and seafloor pressure gauges offshore the east coast of the North Island of New Zealand. The project is part of a study of earthquake processes and slow slip.

Slow-slip events are earthquake-like tectonic movements that take days to weeks to happen rather than seconds. They are best detected using strain measurements such as GPS, and in the Hikurangi experiment we will experiment with detecting the vertical component of slow slip by using seafloor pressure readings. Understanding slow slip can help us understand earthquake processes, particularly at plate convergence zones where huge earthquakes are possible. The ‘megathrust’ earthquakes that happen at subduction zones can generate tsunamis and are a large threat to coastal communities. Some studies have suggested that slow slip may precede large earthquakes, but more research is needed to confirm that hypothesis.

In other research efforts related to ocean-bottom seismic recordings, I, along with graduate student Daniel Zietlow and CIRES Fellow Peter Molnar, have published results from a previous ocean-bottom seismic experiment held off the South Island of New Zealand. Zietlow used recordings



Summary of splitting measurements during the Marine Observations of Anisotropy Near Aotearoa experiment. Red bars indicate orientations of the polarizations of the faster quasi-shear wave; the black crosses indicate null measurements. A full caption is in Zietlow et al., 2014, *Journal of Geophysical Research: Solid Earth*.

from distant earthquakes to map out variations in seismic anisotropy in the mantle beneath New Zealand. The anisotropy is caused by alignment of minerals in the mantle

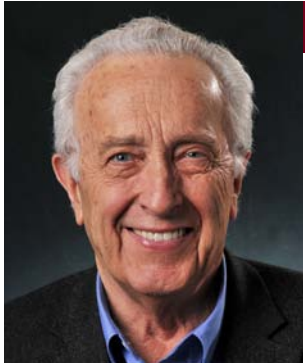
and can be used to infer the history of a localization of deformation. This study provides information for better understanding plate boundary transform faults, in particular the Alpine Fault in New Zealand but also the San Andreas Fault in California, which has many similarities.

The ocean-bottom seismic recordings have proven useful for a number of other studies of earth structure (Ball et al., 2014), earthquakes (Wech et al., 2013; and Boes et al., 2013), and oceanography (Godin et al., 2013; and Godin et al., 2014), which have been conducted with CIRES and international collaborators.

Ball, JS, AF Sheehan, JC Stachnik, FC Lin, and JA Collins. 2014. A joint Monte Carlo analysis of seafloor compliance, Rayleigh wave dispersion and receiver functions at ocean bottom seismic stations offshore New Zealand. *Geophys., Geochem., Geosyst.* Submitted.

Godin, OA, NA Zobotin, AF Sheehan, and JA Collins. 2014. Interferometry of infragravity waves off New Zealand. *J. Geophys. Res. Oceans.* 119.

Zietlow, DW, AF Sheehan, PH Molnar, MK Savage, G Hirth, JA Collins, and BH Hager. 2014. Upper mantle seismic anisotropy at a strike slip boundary: South Island, New Zealand. *J. Geophys. Res. Solid Earth.* 119.



Robert Sievers

Development of needle-free and water-free inhalable dry powder aerosol vaccines

Inhalable dry powder aerosol vaccines require no needle, no purified water for reconstitution, and no electricity or batteries for delivery, which makes them especially useful in developing countries. Working in Prof. Sievers' Global Health group in CIRES, in collaboration with Aktiv-Dry LLC, in Boulder, Colorado, the Serum Institute of India, Ltd., Johns Hopkins Bloomberg School of Public Health, and the U.S. Centers for Disease Control and Prevention, our team developed the first dry powder aerosol vaccine to complete Phase I trials without any adverse events.

To facilitate aerosol delivery, our CIRES team earlier invented the PuffHaler®, an “active” dry powder inhaler with only one moving part, a simple squeeze bulb with its pressure release valve. We also invented a special form of spray drying, Carbon Dioxide Assisted Nebulization with a Bubble Dryer (CAN-BD), that produces aerosol microparticles small enough (1-5 microns aerodynamic diameter) to be distributed throughout the moist respiratory tracts of humans and test animals in which immune responses are generated.

This dry powder aerosol vaccine has been administered to 40 human volunteers without any serious adverse events observed while following the patients 180 days after this Phase I safety clinical trial began in India. This development over the past nine years by a

team of 35 chemists, engineers, physicians, immunologists, public health specialists, students, and post-doctoral researchers has been made possible by a \$20 million grant (FNIH Grant 1077) from the Foundation for the National Institutes of Health as part of the Grand Challenges in Global Health Initiative created by the Bill and Melinda Gates Foundation.



Robert Sievers demonstrates easy vaccination by inhalation of dry powder aerosol vaccines in a needle-free inhaler that he co-invented.

Photo credit: Glen Asakawa/CU-Boulder



Margaret Tolbert

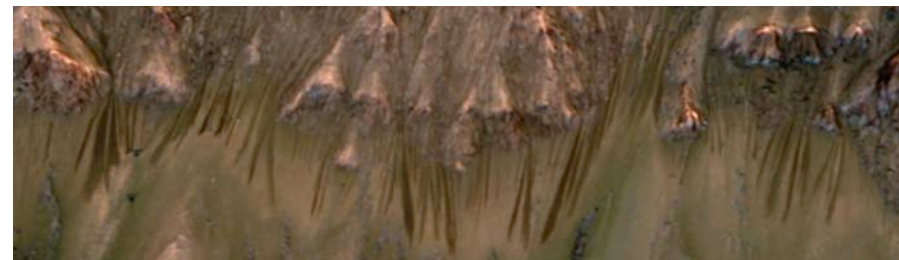
Water uptake and loss by salt particles: Application to Mars

Research in the Tolbert group is focused on heterogeneous atmospheric chemistry, specifically determining the chemical, physical, and optical properties of atmospheric particulate. Along with fundamental studies of particles, we are exploring how atmospheric particulate impacts current problems such as stratospheric ozone depletion, global climate change, urban smog, and visibility degradation. As well as studies of atmospheric aerosols on Earth, we are also probing particles present on other worlds including Titan and Mars. Here we highlight recent results relevant to possible liquid water on present-day Mars.

A surprising discovery made by the Phoenix Lander's Wet Chemistry Laboratory (WCL) in the Martian arctic plains was the presence of 0.5 percent by weight perchlorate (ClO_4^-). Perchlorate's presence is interesting due to its impact on the soil's ability to retain water, thus influencing the water cycle and habitability. Perchlorate salts are known to readily absorb water vapor from the atmosphere and deliquesce into aqueous solution. Perchlorates, like most salts, also tend to remain in a supersaturated aqueous phase instead of efflorescing back into a solid crystal. This hysteresis behavior allows liquid brine solutions to exist at low relative humidity (RH) values. Such brines may explain observations of residual slope lineae, resembling running water, that appear on Mars today. Work in our group recently reported the deliquescence and efflorescence RH values of $\text{Ca}(\text{ClO}_4)_2$

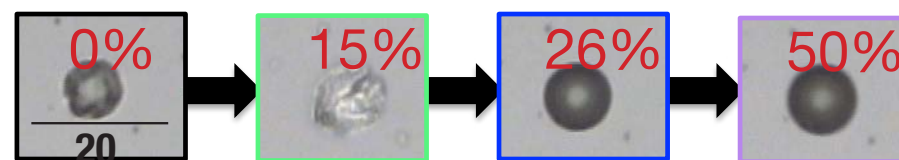
as a function of temperature and applied the results to Martian surface and subsurface conditions. To characterize the deliquescence and efflorescence of $\text{Ca}(\text{ClO}_4)_2$, we studied changes in salt phase and hydration state, using Raman and optical microscopy. To probe phase state and morphology of individual $\text{Ca}(\text{ClO}_4)_2$ droplets free from substrate, we levitated droplets in an optical trap recently developed in our lab. The figure shows optical images of a $\text{Ca}(\text{ClO}_4)_2$ particle during a deliquescence experiment in which RH was raised. It shows the initially dry particle at 0 percent RH underwent a hydration phase transition at 15 percent RH, followed by deliquescence at 26 percent RH, and growth at higher RH values. Experiments with increasing and decreasing RH, combined with martian temperatures and RH values,

allow us to suggest that calcium perchlorate could be aqueous for several hours per day on Mars' surface, and for more than half a day in the subsurface.



Recurring slope lineae (RSL) on Mars may indicate subsurface water flow. The image was taken by an instrument onboard the Mars Reconnaissance Orbiter.

Image credit: NASA/JPL/University of Arizona



Optical images of a $\text{Ca}(\text{ClO}_4)_2$ particle during a deliquescence experiment in which relative humidity (RH) was raised. The initially dry particle at 0% RH underwent a hydration phase transition at 15% RH, followed by deliquescence at 26% RH, and growth at higher RH values.



Greg Tucker

Measuring fire impacts with laser technology

Forest fire impacts can be felt long after the flames have been quenched. Loss of forest-floor litter and changes to the soil can enhance runoff during heavy rains, potentially leading to flooding. Greater runoff, in turn, carries ash and sediment downhill and downstream, potentially contaminating water supplies, filling reservoirs, modifying stream geometry, and altering aquatic habitats. Vulnerability to runoff and erosion can persist for months to years following an intense fire, yet our knowledge of the sources of eroded material is limited by the difficulty in measuring sediment sources and sinks. In the past, researchers have had to rely on sediment trapping and similar methods to gauge the erosional yield following a wildfire; these methods, in addition to being highly labor intensive, provide only sparse, integrated measurements of soil loss.

CIRES Ph.D. student Francis Rengers and I ran a field experiment in measuring post-wildfire erosion with ground-based laser-scanning technology. The study followed the 2010 Fourmile Canyon Fire, Colorado's most costly wildfire at the time. Working with a U.S. Geological Survey team, who installed rainfall- and runoff-monitoring equipment on a ridge several miles west of Boulder, Colorado, our team used a high-precision laser scanner to obtain detailed terrain measurements. We collected five surveys over 20 months.

The surveys revealed several surprises. Although the most obvious sign of erosion was scour of the site's main channel,

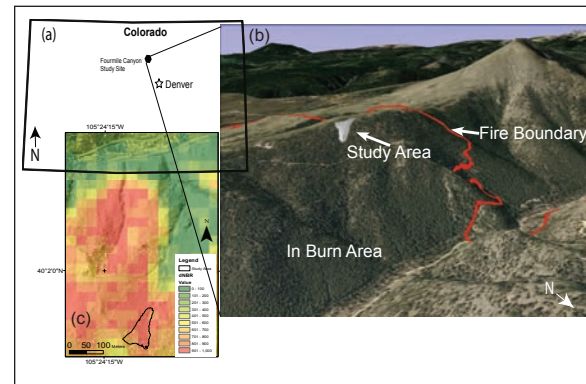


Figure 1: a) Site location in Colorado. b) Oblique view of study site, with gray-shaded relief polygon delineating the study area. c) Map of differenced normalized burn ratio (ΔNBR), a proxy for burn intensity. Green represents low-burn severity, yellow represents medium, and red represents high-burn severity.

Figure courtesy of Francis Rengers/CIRES; map courtesy Sheila Murphy/USGS

the majority of sediment actually derived from widely distributed erosion of a relatively thin (several-centimeter) soil layer. Over the 20-month period, sediment yield gradually decreased, while surface roughness increased as erodible soil patches were depleted. The correlation between runoff force and erosion was surprisingly subtle; instead, the erosion pat-

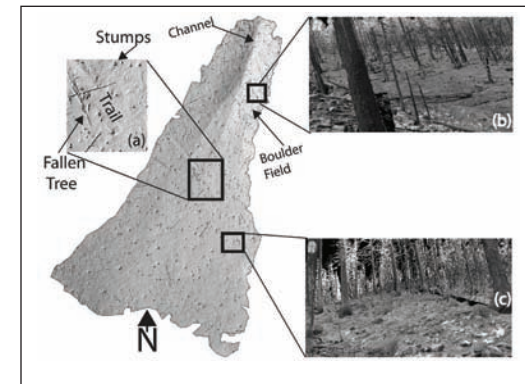


Figure 2. Digital elevation model (DEM) image built from laser survey data, showing micro-topography, e.g., boulder field on watershed's east side. a) Standing trees are filtered out, but some fallen trees, boulders, and stumps are left in the DEM. b) 3-D image of unfiltered laser data, looking southwest. c) 3-D image of unfiltered laser data, looking south. Figure courtesy of Francis Rengers/CIRES

terns were notably correlated with soil thickness and terrain smoothness. Overall, the study demonstrates ground-based laser scanning can document spatial patterns of post-fire erosion efficiently, non-destructively, and with centimeter-scale precision. The results will provide rich fuel for the next generation of post-fire runoff and erosion models.



Veronica Vaida

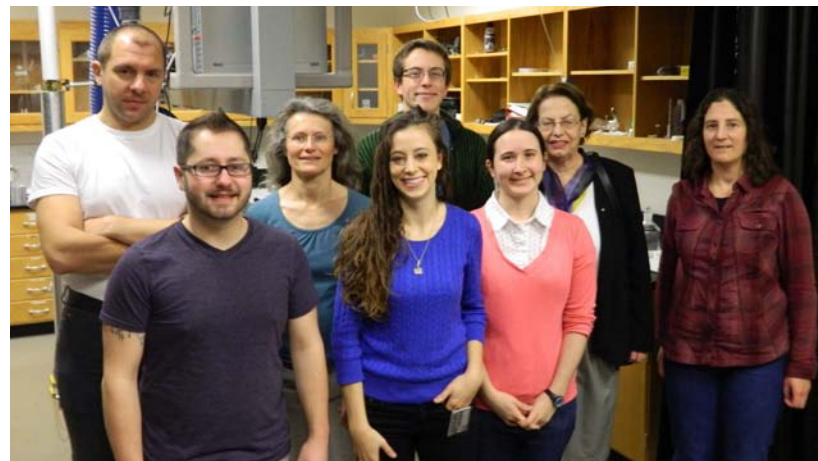
Atmospheric photochemistry of organic molecules

Our program explores water- and sunlight-mediated processes in planetary atmospheres including the contemporary and prebiotic Earth. My approach aims to provide new input for models of atmospheric chemistry and climate, using fundamental chemical physics to address complex multiphase chemistry. Using solar simulators in laboratory studies, our group has been exploring the importance of water and the environment to the photochemistry of organic species involved in isoprene oxidation. Pyruvic acid is a small organic molecule found in the atmosphere in the gas phase, as well as in fogs, aerosols, and clouds. While the gas-phase photochemistry for pyruvic acid has been well-understood for decades, the sunlight-driven reaction pathways for the aqueous phase have remained more elusive. Our group has recently deduced a mechanism for the aqueous phase photolysis of pyruvic acid. This mechanism is not only fundamentally different from the gas-phase chemistry, but it is also dependent on the presence of oxygen in solution, highlighting the immense importance of water and the environment to photochemical processes.

Collaboration within CIRES allowed analysis of the importance of the aqueous phase photolysis of pyruvic acid in the atmosphere. Our laboratory measurements of the rate of the photochemical reaction in solution were used as input for an atmospheric model that compared the loss

of pyruvic acid through aqueous photolysis to the loss from the gas-phase photochemistry and oxidative processes. Results indicated that in an acidic environment, the aqueous photolysis is equally as important as the gas-phase photolysis, emphasizing the importance of developing a mechanistic understanding of aqueous-phase photochemical processes.

We have scaled the fundamental experimental work with pyruvic acid to realistic atmospheric conditions by using environmental chamber studies. Specifically we are using the CESAM (French acronym for Experimental Multiphase Atmospheric Simulation Chamber) at the Université Paris-Est Créteil Val de Marne (UPEC) in collaboration with Professor Jean-François Doussin with UPEC. By combining these laboratory and chamber studies, we connect our understanding of the photolysis of pyruvic acid to mechanisms for aerosol nucleation and growth.



The Vaida Group and some current collaborators. Front row, left to right: Jay Kroll (Vaida group), Allison Reed Harris (Vaida group), and Rebecca Rapp (Vaida group). Back Row, left to right: Pascal Renard (Aix-Marseille Université), Anne Monod (Aix-Marseille Université, CIRES 2013 Visiting Fellow), Russell Perkins (CIRES), Veronica Vaida, and Barbara Ervens (NOAA, CIRES).

Photo credit: Jay A. Kroll/CIRES/CU-Boulder



Rainer Volkamer

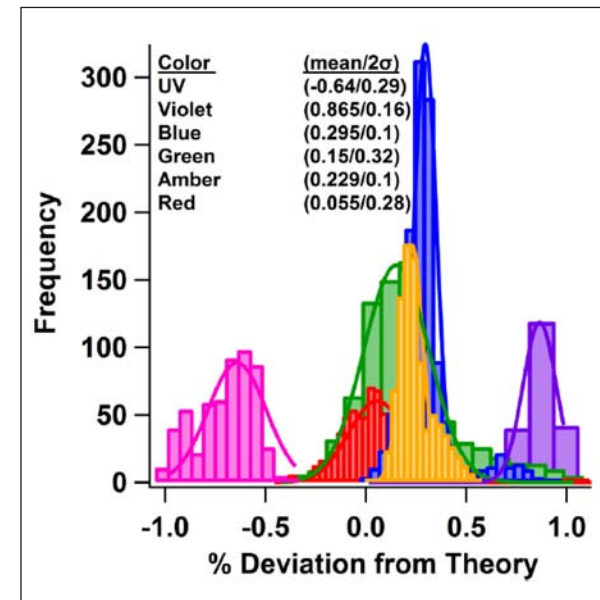
Keeping track: Solar photons to study Earth’s atmospheric composition

The collisions between two oxygen molecules give rise to O₄ absorption in Earth’s atmosphere. O₄ absorption is relevant to atmospheric transmission and Earth’s radiation budget. O₄ is further used as a reference gas in Differential Optical Absorption Spectroscopy (DOAS) applications to infer properties of clouds and aerosols, and calibrate measurements of trace gases relevant to air quality and climate (Baidar et al., 2013a,b; Dix et al., 2013). Previous measurements of the absorption cross-section of O₄ did not characterize changes in the spectral band-shapes of O₄ with temperature under atmospherically relevant pressure conditions. We have measured the temperature dependent absorption cross section of O₄ in the laboratory, and derive a very low upper limit on the enthalpy of formation for O₄ (Thalman and Volkamer, 2013). We conclude that the atmospheric O₄ distribution is for all practical means and purposes independent of temperature, and attribute previous reports about temperature dependencies in the O₄ cross section to changes in the spectral band shape. O₄ provides a very well-characterized atmospheric reference gas if the oxygen concentration profile is known (accuracy better than 10⁻³).

Rayleigh scattering of incoming solar photons gives rise to blue clear skies and red sunsets. Accurate knowledge about Rayleigh scattering cross sections of the major atmospheric components (oxygen, nitrogen, argon, and air) is

relevant to accurate predictions by radiative transfer models (RTM) and calibrations of the reflectivity of mirrors used in high-finesse optical cavities. In collaboration with CIRES’ Tolbert group, we have measured Rayleigh scattering cross sections of the major air components (Thalman et al., 2014). Using a combination of Cavity Ring Down Spectroscopy (CRDS) and multispectral Cavity Enhanced Extinction Spectroscopy (CEES), we extend the range over which Rayleigh scattering cross sections have been measured at ultraviolet wavelengths, and we find remarkable agreement with refractive index–based theory (within 0.2 percent). Better knowledge about O₄ and Rayleigh scattering facilitates more robust calibrations for high-finesse optical cavity techniques, and the University of Colorado Airborne Multi-AXis DOAS instrument (Baidar et al., 2013a,b; Dix et al., 2013).

Thalman, R, K Zarzana, MA Tolbert, and R Volkamer. 2014. Rayleigh scattering crosssection measurements of nitrogen, argon, oxygen and air. *J. Quant. Spectrosc. Radia. Transfer*. Forthcoming.



Deviations of the Rayleigh scattering cross section of argon measured by Cavity Enhanced Extinction Spectroscopy (CEES) from refractive index–based theory (Thalman et al., 2014).



Carol Wessman

Multiple forest disturbances, their interactions, and cumulative effects on carbon dynamics in forest ecosystems

Disturbances have a strong role in the carbon balance of many ecosystems, and the cycle of vegetation growth, disturbance, and recovery is very important in determining the net carbon balance of terrestrial biomes. Despite potentially large losses of carbon in disturbance events (due to combustion, decomposition, or other mechanisms), resilient systems can recover that balance to remain neutral over the disturbance return interval. Conversely, lack of recovery may initiate alternate regimes with a different carbon balance. Compound disturbances are phenomena of growing concern and can further impact ecosystems in novel ways, altering disturbance intensity, severity, and recovery trajectories.

This research focuses on carbon stocks in a compound disturbance environment, with special attention on black carbon (charcoal). Black carbon is a potential source of long-term carbon sequestration, as it is very resistant to decomposition, formed in fires, and has numerous other benefits such as increasing soil fertility. We extensively surveyed a compound disturbance event (wind, logging, and fire) in a Colorado subalpine forest for impacts on carbon stocks, black carbon, and regeneration. We considered all major pools, including organic and mineral soil, and contrasted them with neighboring undisturbed forests as a reference.

The 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 decay rates, it appears that high-intensity fires may actually reduce net black carbon in these forests over the entire fire return interval, with additional disturbances compounding the loss.

Overall, high-intensity disturbances remove a large amount of carbon, and multiple disturbances compound this effect. Differences in regeneration have a small but significant difference on current carbon stocks, a difference that likely will get larger as time progresses due to differential species characteristics. Disturbances, and their interactions, will have long-lasting legacies for carbon, black carbon, and ecosystem structure and function.



Standing dead and regeneration 10 years after the 2002 Mt. Zirkel Complex fires, Colorado. Photo credit: Carol Wessman/CIRES/CU-Boulder



Paul Ziemann

Atmospheric chemistry of organic aerosols

My research group and I conduct experimental studies of the atmospheric chemistry of submicron organic aerosol particles. These small particles are usually formed by combustion or by a process referred to as gas-to-particle conversion, in which atmospheric reactions involving volatile organic compounds, oxidants, and oxides of nitrogen and sulfur produce low-volatility oxidized organic species that condense to form particles. In urban-influenced areas, these particles affect human health and visibility, whereas globally they exert a major influence on Earth's radiation balance, climate, and hydrologic cycle by scattering and absorbing light and by acting as seeds for the formation of clouds. The chemistry of organic aerosol particles and the processes that determine their composition and distribution in the atmosphere are still poorly understood.

We conduct laboratory experiments in large environmental chambers under simulated atmospheric conditions to investigate fundamental processes responsible for gas-to-particle conversion in the atmosphere. In particular, our work is aimed at elucidating the mechanisms by which volatile organic compounds emitted from anthropogenic and biogenic sources react with the atmospheric oxidants OH, O₃, and NO₃ to form oxidized low-volatility compounds that condense to form

particulate material. We analyze the composition of particles and gases by using a thermal desorption particle beam mass spectrometer my team developed in our laboratory, as well as gas and liquid chromatography, chemical ionization mass spectrometry, and spectrophotometry. We use information on the chemical composition and volatility of the products formed to develop mechanisms of reactions of gaseous and particle-phase organic species. The results of these studies improve our understanding of atmospheric aerosol chemistry and aid in the development of air-quality

models for predicting the formation and properties of organic aerosol particles and the impact of human activities on the atmospheric environment.



Organic aerosol particles under scrutiny in Paul Ziemann's laboratory play important roles in urban and regional smog formation processes and can affect human health and visibility as well as global climate. Photo credit: David Oonk/CIRES

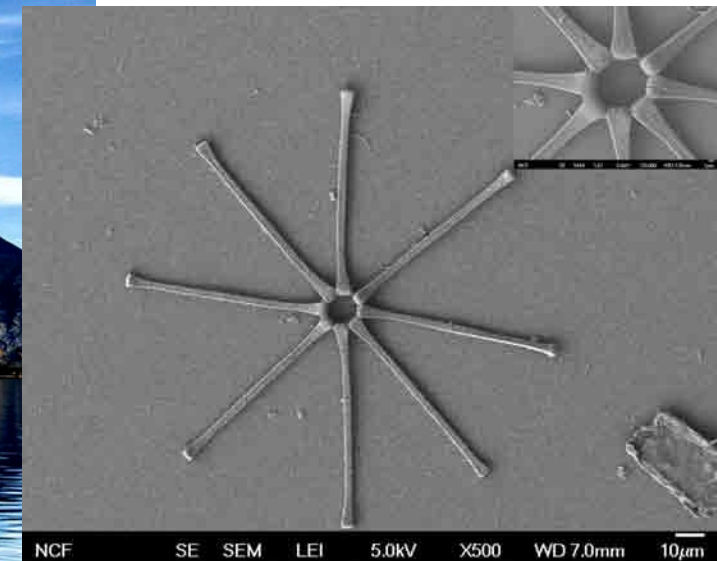
Center for Limnology

A new study for the CIRES Center for Limnology during 2013 is related to the important question of transparency in Grand Lake, Colorado's largest and deepest natural lake. Located near the Continental Divide in Grand County, Grand Lake originally had a transparency as high as 9 meters as measured with a white disk (Secchi disc) that is used for measurements of water clarity. Measurements now typically are 2 to 4 meters. Because the lake now is used in water management as an outlet for waters from nearby reservoirs (Granby, Shadow Mountain), its transparency appears to have

been affected adversely by water management practices. The exact causes of this change in transparency are the subject of research by the Limnology Center in collaboration with the Northern Colorado Water Conservancy District, the U.S. Bureau of Reclamation, and Grand County.

During 2013, the Limnology Center research staff discovered an unsuspected source of turbidity (suspended particulate material) for waters reaching Grand Lake. The Colorado River, which has headwaters just upstream of Grand Lake but not reaching Grand Lake directly, flows through the western edge of Rocky Mountain

National Park. These waters are unpolluted and undisturbed. During periods of high flow, these headwaters of the Colorado yield high sediment concentrations, as shown by visible muddiness and low transparency. This is an unusual characteristic for headwaters in the Colorado Rockies, where turbidity is usually low because the supply of fine particulate material is sparse. Particulate material of the type observed in the upper Colorado under the influence of high flows would not have affected the transparency of Grand Lake prior to water resource development in the Grand Lake region, because



A scanning electron microscope image of the diatom *Asterionella* (eight cells) found in Shadow Mountain Reservoir (at left).

Photo and image credit: James McCutchan/CIRES

During periods of high flow, these headwaters of the Colorado yield high sediment concentrations, as shown by visible muddiness and low transparency.

the Colorado River passes alongside the lake but does not enter the lake; the lake instead is fed instead by small streams that are tributary to the lake basin itself. Water management, however, established a diversion that passes Colorado River water into Shadow Mountain Reservoir, which, in turn, passes Colorado River water, along with its turbidity, to Grand Lake via Shadow Mountain Reservoir.

The unusual amounts of fine particulate material in the waters of the upper Colorado is likely natural, and the diversion that was established to bring this water into Grand Lake would explain some or much of the loss of

transparency of Grand Lake as compared with the natural transparency of the lake.

A second factor contributing to loss of transparency in Grand Lake may involve diversion of water into Grand Lake from Granby Reservoir by pump through Shadow Mountain Reservoir. When the pumps are off during the summer, the lake rapidly loses transparency as algal populations increase. Growth of algal populations in Shadow Mountain Reservoir is stimulated by nutrient concentrations in water from Granby Reservoir; when pumping resumes, algal populations of Shadow Moun-

tain Reservoir are transferred to Grand Lake.

The Limnology Center has shown through its research in 2013 and earlier that water management probably is related to low transparency in Grand Lake through two mechanisms: import of water from the Colorado River containing an amount of suspended solids (turbidity) that is not natural for Grand Lake water sources and, when the suspended solids are not added to the lake, development of algal populations stimulated by nutrients from Granby Reservoir. It is possible that management practices may be able to address one or both of the problems.

During this reporting period, the Center for Limnology also investigated water quality in the South Platte River below Denver (page 31).

Photo credit: James McCutchan/CIRES



Center for Science and Technology Policy Research

The Center for Science and Technology Policy Research (CSTPR) was established 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's research is integrated with the ongoing activities of CIRES, NOAA, CU-Boulder, and the broader national and international 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 those choices affect the coevolution of science, technology, and policy. Outcomes of particular interest include trends in natural disaster losses and their underlying causes; factors affecting the supply and demand of scientific research; problems in adapting to both environmental extremes and changes at the local scale; and ethics and trends in environmental management and policy. Our work is reported via research articles, books, reports,

a regular newsletter, briefings for decision-makers, faculty blogs, lectures and talks, news media, and frequent seminars and workshops.

The Center conducts research at the interface of science and decision-making on a broad range of topics. In 2013:

- CSTPR's Deserai Crow received a grant to study policy responses to flooding after Colorado's historic September 2013 flood.
- The U.S. Agency for International Development awarded CIRES Fellow Lisa Dilling and CIRES graduate student Meaghan Daly a grant titled "Identifying Constraints to and Opportunities for Co-Production of Climate Information for Improved Food Security." Their research aims to reduce impacts of climate variability and change on food security by systematically identifying opportunities for and constraints to the use of climate forecasts for improved adaptation planning.
- CSTPR's Katie Dickinson is working on a project that explores social interactions and homeowners' wildfire

mitigation behaviors.

- CIRES Fellow Max Boykoff and CIRES graduate student Shawn Olson received a scholar's award from the Center to Advance Research and Teaching in the Social Sciences (CARTSS) for a project titled "Power Politics: The Political Ecology of Wind Farm Opposition in Wyoming." The project seeks to understand opposition to industrial-scale development of energies such as wind power and solar photovoltaic systems, with the goal of proposing conflict mitigation strategies that simultaneously aid rapid climate mitigation while empowering rural communities.
- Science, Technology, Policy and Politics of Sport (STePPS) is a new CSTPR project focused on the governance of sport, with a special emphasis on the roles of science and technology in how sport is governed. STePPS will focus on original research, as well as university education and outreach to the broader community.

Selected highlights from June 1, 2013, to May 31, 2014, include:



An Oxford-style debate on unionization among college athletes. The class event was also made public. Photo credit: Nanci Filice/CIRES



Noted environmental writer and former New York Times reporter Andy Revkin joins CSTPR's Max Boykoff and CIRES Director Waleed Abdalati at a reception following Revkin's talk at the University of Colorado Boulder. Photo credit: Eric Schullek/Thunderbolt Pictures

Much of our work poses questions about how people and institutions make decisions under uncertainty, how perception and technical information influence choices.

Outreach

Roger Pielke Jr. testified before the U.S. House Science Committee on Environment about “A Factual Look at the Relationship Between Climate and Weather,” and before the Senate Committee on Environment and Public Works about “Climate Change: It’s Happening Now.” As part of its proceedings, the Senate Committee reviewed a 2012 paper by CSTPR graduate student Jessica Weinkle (with Ryan Maue and Pielke Jr.) titled “Historical Global Tropical Cyclone Landfalls.” Boykoff’s Inside the Greenhouse project hosted noted environmental writer and former New York Times reporter Andy Revkin as well as Climate Wise Women, a global platform for the promotion of women’s leadership on climate change. Center personnel gave 42 presentations at events including the annual meeting of the National Academy of Sciences and AGU Conference on Science Policy. The center continued to host its popular noontime seminar series.

Education

CIRES student Jessica Weinkle received a Ph.D. in environmental studies, and CIRES students Shawn Olson and Lucy McAllister received master’s degrees in environmental studies. The Red Cross/Red Crescent Climate Centre Internship Program placed three student interns in Kenya, Uganda, and Zambia.

Publications

Center faculty and students had 57 publications in journals such as *Mitigation and Adaptation Strategies for Global Change*, *Global Environmental Change*, and *Climatic Change*, as well as in popular publications such as The Guardian, Financial Times, The Atlantic, and Wall Street Journal.

Personnel

Roger Pielke Jr. assumed the position of center director in 2013 after Bill Travis’ term ended. The center welcomed to its staff Katherine “Katie” Dickinson, an environmental economist who studies how humans behave in the face of environmental risks, as a research associate/research scientist.

Recognition

Max Boykoff was selected as a Leopold Leadership Fellow. CIRES graduate student Xi Wang received the Albert E. Smith Emerging Scholar Award from CARTSS. CIRES graduate student Marisa McNatt was chosen as a 2013 Climate Media Fellow for the Heinrich Boll Foundation.

CIRES Visiting Fellow Joanna Boehnert (CSTPR) provided facilitation, framework design, and other visual resources during the International Global Atmospheric Chemistry (IGAC) Project’s workshop on Air Pollution and Climate Change in 2013. Pictured is CIRES’ Megan Melamed, standing.

Photo credit: David Oonk/CIRES



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 this reporting period (June 1, 2013, to May 31, 2014), our cryospheric research focused on understanding the physical processes of glacier and ice-sheet surfaces. This research included the use of remote-sensing observations as well as in situ measurements for the purpose of interpreting observations made by space-borne and airborne instruments. These activities included: understanding the drainage behavior of supraglacial lakes in Greenland and their subsequent effects on the ice-flow rates; determining the characteristics of firn compaction and surface meltwater percolation to interpret satellite and airborne altimetry data; integrating space-based gravity, altimetry, and visible observations to develop a high-spatial-resolution estimate of sea level contributions from Greenland, its peripheral glaciers and ice caps, and the Canadian glaciers and ice caps; and assessing changes in the snow/ice zones of the Greenland Ice Sheet, which show that the melt and loss regions are encroaching on the higher elevations and the net accumulation region is shrinking.

Land surface and extreme weather events

We have been investigating whether extreme weather events are on the rise and the connections of these events to land

surface conditions. Our recent research has addressed whether anomalies in soil moisture and temperature have been correlated temporally and/or spatially in the Northern Hemisphere, and how they may be physically related. Our results indicate that for land surfaces in the Northern Hemisphere, both negative soil moisture anomalies (dry soils) and positive temperature extremes are increasing with time since 1979. We also found that, in a number of regions in the Northern Hemisphere, occurrences of very dry soil were significantly correlated with summers with extreme temperatures, indicating that changes in land cover might be one variable for changing weather extremes.

Climate processes

We have established advanced measurements and models to evaluate the way in which changes in climate modify,

and are linked to, the water cycle. Water vapor is by far the most abundant greenhouse gas in the atmosphere, and the changing distribution of water in the atmosphere and on the land surface has significant implications for water resources as climate changes. The continental boundary-layer moisture balance regulates water and energy exchange between the land surface and atmosphere. Land-surface feedbacks are important for regional moisture balances and are not well-represented in climate models.

By examining isotope ratios in water we have been gaining insight into the mechanisms controlling these processes. Our studies of the boundary layer at the 300-meter Boulder Atmospheric Observatory (BAO) tall tower have shown that upward diffusion of water vapor within the soil matrix is an important contributor to the water budget in semi-arid environments, and that contrary to current



Lightning flickers over Kuwait and Saudi Arabia as seen from the International Space Station. Photo credit: NASA

A long-term goal of ESOC research is to investigate problems in global geosciences through remote-sensing observations.

assumptions in climate models, boundary layer water vapor is very rarely in equilibrium with falling raindrops. With this water isotope budget, we are able to accurately characterize the strength of evaporation and transpiration sources, condensation sinks and air mass mixing.

Oceanographic studies

The El Niño Southern Oscillation (ENSO) phenomenon is a large-amplitude global-scale perturbation to the general circulation of Earth's atmosphere and ocean. At the mature stage of an ENSO warm event, eastern tropical Pacific Ocean temperatures are several degrees warmer than average values in December through February, and there are widespread weather impacts including both droughts and deluges leading to fires and floods in various regions of the globe. ENSO warm events evolve over

the preceding year with anomalous signals and evolutions in a variety of atmosphere and ocean fields (e.g., sea surface temperature, or SST, sea-level pressure, or SLP, surface winds, upper-ocean heat content, etc.). Harry van Loon and colleagues have described the evolution of SLP fields several seasons in advance of the warm anomalies in tropical eastern Pacific SSTs. These precursor signals offer the possibility of predicting ENSO warm event amplitudes before they fully develop. Colleagues Benjamin Hamlington and Ralph Milliff have recently applied an advanced data analysis technique, so-called cyclostationary empirical orthogonal functions (CSEOFs), to monthly SLP data sets over the period 1948 to present. The method identifies a time series of spatial patterns and an amplitude time series that match very closely with previously suggested predecessors, demonstrating

the potential for the CSEOF technique to enable ENSO warm-event forecasting.

Lidar observations and analysis of the upper atmosphere

We have been investigating the chemical and physical processes in the mesosphere and thermosphere, using ground-based lidar to better understand Earth's upper atmosphere and its couplings to the near-space environment. This work has sometimes kept us close to home in Colorado and also has taken us far away to Antarctica, where we made critical lidar observations through the long winter. Through our observations and modeling efforts, we have developed important insights into the structure, movement, chemistry, and electrodynamics of the relatively unexplored regions of our atmosphere at altitudes well in excess of 100 kilometers.



Bangladesh alluvial fan. Image credit: NASA



Antwerp, Brussels, city lights. Image credit: NASA

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 June 1, 2013, to May 31, 2014, include:

Satellite observations of Arctic change

To make data on Arctic change accessible to a wider audience, NSIDC developed a website for exploring data on Arctic change. Users can view and interact with data on a map, animate a time series, zoom in or out, and view a bar graph of anomalies through time. Additional pages provide brief scientific discussion and scientific overviews. Presently, Satellite Observations of Arctic Change (SOAC) offers data sets on anomalies in near-surface air temperature, sea ice concentration, snow cover duration, monthly NDVI (providing information on photosynthetic activity), periods of unfrozen soil surface, and annual minimum exposed snow and ice.

Coldest place on Earth

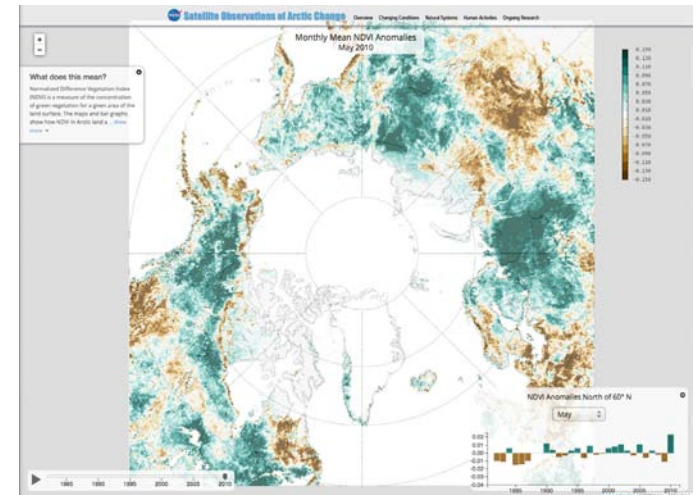
Lead NSIDC scientist Ted Scambos, who is on the Landsat 8 Science Team, used Landsat 8 and Moderate Resolution Imaging Spectroradiometer (MODIS) imagery to find the coldest place on Earth. Temperatures reach minus 92 to minus 94 degrees Celsius in a 1,000-kilometer-long swath on the highest section of the East Antarctic ice divide. This research shows Landsat and MODIS can map temperature patterns in regions that are difficult to access.

Rescue of 1960s satellite data

NSIDC obtained original films and processed data from the Nimbus 1 satellite, recovering images showing Arctic and Antarctic sea ice extent in 1964. Data show September



Sastrugi are prominent in this photograph taken near Plateau Station in East Antarctica. Most of Antarctica looks quite flat, despite the subtle domes, hills, and hollows. Photo credit: Atsuhiko Muto/Penn State



This map, from SOAC, for May 2010 indicates a strong increase in Arctic greenness, as indicated by strong positive Normalized Difference Vegetation Index (NDVI) anomalies (green), compared to the long-term average for the period 1982 to 2010. NDVI is a measure of plant greenness. Figure credit: NSIDC

The mission of NSIDC is to improve our understanding of Earth's cryosphere, including sea ice, lake ice, glaciers, ice sheets, snow cover, and frozen ground.

Antarctic sea ice extent measured about 19.7 million square kilometers, higher than any year from 1972 to 2012. These data lengthen the modern satellite record, which reaches back to 1979. Nimbus 2 and 3 data processing is ongoing.

Arctic Data Explorer

Through the Advanced Cooperative Arctic Data and Information Service (ACADIS) project, NSIDC, in collaboration with the National Center for Atmospheric Research, has put together a data search tool for scientists who study the Arctic. The Arctic Data Explorer (ADE, <http://nsidc.org/acadis/search>) crosses disciplines and offers Arctic data on sea ice, biology, permafrost, meteorology, chemistry, demography, marine ecology, anthropology,

oceanography, hydrography, biodiversity, and terrestrial ecology. ADE brings diverse data together by storing metadata from top Arctic data centers, including NSIDC, the ACADIS Gateway, the Earth Observing Laboratory/ Computing, Data and Software Facility, the National Oceanographic Data Center, and the Norwegian Meteorological Institute.

Yup'ik environmental knowledge

The Exchange for Local Observations and Knowledge of the Arctic (ELOKA) program at NSIDC and its partners developed several digital atlases that document local and traditional knowledge about changes in the Arctic environment. As climate warms in the Arctic, animal and

plant life cycles shift to adapt to thinning ice and shorter winter seasons. The atlases help preserve and share community knowledge and observations that help shed light on how small, regional processes are behaving.

NASA Distributed Active Archive Center

In 2013, NASA renewed its contract with NSIDC to operate and manage the Earth Observing System Data and Information System Snow and Ice Distributed Active Archive Center (DAAC), which offers more than 250 cryospheric data products, primarily from Earth observation satellites. NSIDC has managed the data center since 1993, and the new contract keeps the DAAC in NSIDC until May 2014 with an optional one-year extension all the way to 2018.



Young Nenets boy Anton Taleev on a reindeer sledge in Nenets Autonomous Okrug, Northwest Russia. Photo credit: B. Forbes



Icy water in the fjord of the Kangerdlugssuaq Glacier in eastern Greenland, as seen from NASA's P-3B aircraft during an Operation IceBridge flight. Diverse data on the Arctic, including IceBridge data, can be discovered through the Arctic Data Explorer. Photo credit: Jefferson Beck/NASA

interdisciplinary programs

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 co-produce policy-relevant information about climate variability and change. By building relationships with networks of decision-makers, WWA develops practical research projects and useful information products.

During the reporting period of June 1, 2013, to May 31, 2014, 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.

Climate adaptation guidance for Salt Lake City public utilities

WWA's Tim Bardsley spearheaded a climate change assessment and adaptation planning effort for the Salt Lake City Department of Public Utilities. The results of this first phase of work, consisting of a water-supply climate-sensitivity analysis, was published as "Planning for an Uncertain Future: Climate Change Sensitivity Assessment Towards Adaptation Planning for Public Water Supply" in

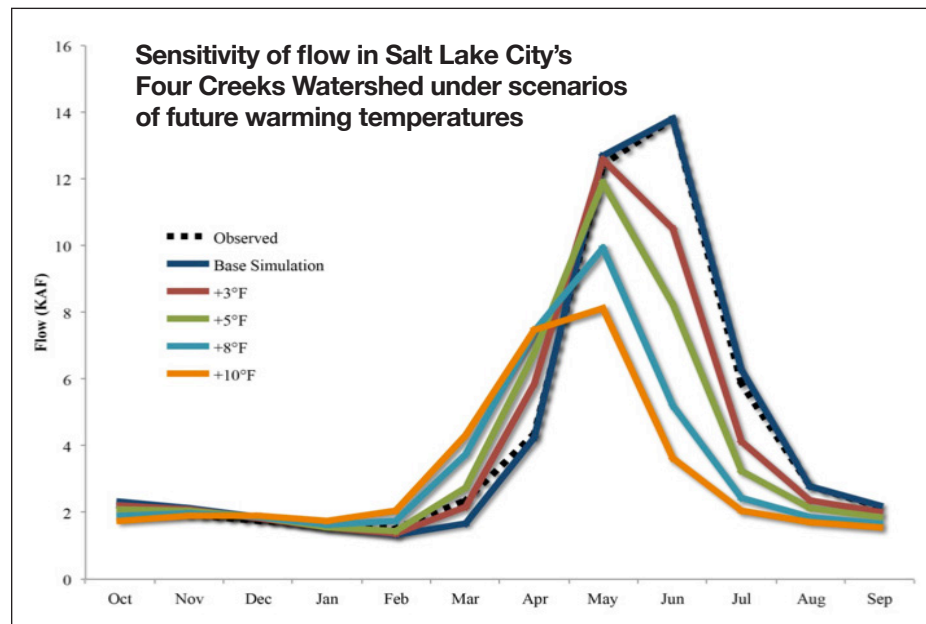
ated in combination with future water demand, supply, infrastructure, and management scenarios. To improve available information on climate impacts to water supplies, Bardsley will work with colleagues to integrate soon-to-be-available high-resolution dynamically downscaled climate projections, test an expanded systems model, and develop more advanced water-supply and demand scenarios to evaluate a range of possible future impacts to water supply to assist in defining low-regrets management strategies.

Drivers of adaptation in the American West

As a complement to studies that examine barriers to adaptation, a team of WWA researchers (Lisa Dilling, Krister Andersson, John Berggren, and Ashwin Ravikumar) conducted a study of the drivers that lead to planning for and responding to weather- and climate-related hazards at the municipal scale as a proxy for understanding what might drive adaptive behavior toward climate change. They chose municipalities in Colorado, Utah, and Wyoming for the study, and researchers conducted face-to-face and phone interviews with multiple key informants in a randomly selected sample of 60 municipalities with populations of more than 10,000.

Ongoing efforts in this project include a pilot study on one of Salt Lake City's watershed creeks, where a reservoir-systems planning model has been developed and expanded to include the full water-supply system. In addition, assessments of changes in system reliability are being eval-

uated in combination with future water demand, supply, infrastructure, and management scenarios. To improve available information on climate impacts to water supplies, Bardsley will work with colleagues to integrate soon-to-be-available high-resolution dynamically downscaled climate projections, test an expanded systems model, and develop more advanced water-supply and demand scenarios to evaluate a range of possible future impacts to water supply to assist in defining low-regrets management strategies.



Salt Lake City region climate projections show peak streamflow will occur earlier in the year as temperatures continue to rise. Figure credit: WWA/CIRES

By building relationships with networks of decision-makers, WWA develops practical research projects and useful information products.

of 2014. Following the initial interviews, the researchers conducted in-depth case studies with six of the municipalities to better understand the combinatorial relationship of the potential explanatory factors. They are currently completing analysis of the case studies and will submit it for publication.

Rapid response to the Colorado Front Range flooding

The September 2013 flooding along Colorado's Front Range demonstrated the capacity of WWA to respond rapidly to science-information needs about an extreme climate event—one that personally impacted many on its team. With colleagues from WWA, the NOAA Earth System Research Laboratory's Physical Sciences Division, and the Colorado Climate Center at Colorado State University,

WWA's Jeff Lukas authored a four-page preliminary assessment report that explained the large-scale weather patterns responsible for the rains, compared the precipitation and flooding to historic events, and discussed potential linkages to climate change. Just 10 days after the rains ended, Lukas and his colleagues released the assessment at a public briefing and panel discussion in the CIRES Auditorium, attended by about 100 people on site, including local and national media, and another 200 online. Feedback from water-resource managers and other decision-makers confirmed that the assessment provided useful and relevant information on this destructive event.

Contributions to the National Climate Assessment

On May 6, 2014, the U.S. Global Change Research Program released the third National Climate Assessment (NCA), entitled "Climate Change Impacts in the United States." This 829-page report assesses the science and impacts of climate change, now and through the 21st century, with the goal of better informing public and private decision-making. WWA's Kristen Averyt served as a lead author of the "Energy, Water, and Land Use" chapter. Eleven members of the WWA team also contributed to the "Assessment of Climate Change in the Southwest U.S." (Island Press, 2013), a regional report used as technical input for the overall NCA report.



September 2013 flooding in Boulder, Colorado. Photo credit: Raul Valenzuela/CIRES



Western Water Assessment staff co-authored parts of the 2013 National Climate Assessment, "Climate Change Impacts in the United States."

Education and Outreach

The CIRES Education and Outreach (EO) group is active across the spectrum of geosciences education, including teacher professional development, digital learning resources and courses, pre-college student programs, program and project evaluation, and more. During the last year, EO was active on 23 projects. Some example projects are described below.

Climate education

CIRES climate education strives to meet educator needs for climate science learning resources that are current, data-driven, and accurate.

The Climate Literacy and Energy Awareness Network (CLEAN) Collection is a peer-reviewed educational resource collection (cleanet.org). CLEAN is also syndicated through NOAA as the official collection of teaching resources on the climate.gov portal. The CLEAN collection 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. Teachers are also provided with background information on how to teach all aspects of climate and energy science; furthermore they can join an active climate education professional community (CLEAN Network). In recognition of the quality of this collection, the “Teaching Climate” section of climate.gov, which syndicates the resources from the CLEAN collection, won both the juried and the People’s Choice “Best of the Web” awards in the Green category. The CLEAN collection is currently funded through the NOAA Climate Program Office.

While CIRES has provided introductory climate science professional development for years, our participants asked us to provide a deeper look at selected climate science topics. To serve those requests, EO partnered

with the University of Colorado Boulder LearnMore>AboutClimate project to offer an in-depth webinar series, which has been repurposed as an online course. Participants registered for two series focused on Water in the West and Extreme Weather, serving 498 unique participants. These moderated studio discussions with CU-Boulder and NOAA scientists are available in full and in thematic segments, and form the basis of a free, four-week online course offered through Canvas.net.

Science educators want to bring current science into their classrooms, and to help their students build quantitative skills and an understanding of the scientific process. In collaboration with CIRES/NOAA researchers Ola Persson and Andrey Grachev, EO developed a new curriculum that does this. The curriculum has been piloted with 475 students since an educator workshop in spring 2014. Based on data from the International Arctic Systems for Observing the Atmosphere (IASOA)



Aleya Kaushik explains water isotopes and Colorado rainwater origins at Lyons High School as part of the Water Spotters program. Photo credit: Lesley Smith/CIRES EO



Teachers test soil temperatures at the Arctic Climate Connections teacher workshop February 2014.

Photo credit: David Oonk/CIRES

CIRES climate education strives to meet educator needs for climate science learning resources that are current, data-driven, and accurate.

network, students manipulate data and use Google Earth to answer questions based on research scenarios. Educators feel more connected to the research through their interactions with the project scientists and use video to bring the same feel to students.

Reaching students

EO projects for students include a student-scientist opportunity to participate in research, research experience for community college students, and a student video project to document and communicate about local climate change impacts.

This summer, seven community college students experienced water sciences research firsthand as part of Research Experiences for Community College Students (RECCS). This pilot, funded through the CIRES

Diversity Initiative and the National Science Foundation (supplement to Critical Zone Observatory), helped community college students develop relationships with scientists and develop valuable skills that may lead to a career in science. Students mentored by CIRES and other university scientists worked as a group during the summer to learn writing, presentation, and other skills necessary to science in addition to doing research. <http://cires.colorado.edu/education/outreach/projects/reccs/index.html>.

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 under-represented in science, participating schools are monitoring weather with stations at their school, collecting precipitation samples, and sending those

back to CIRES for isotope analysis. Project scientists and graduate students interact with schools to support the data collection and develop relationships. For more information, see <http://cires.colorado.edu/education/outreach/waterspotters/>.

The Lens on Climate Change project supported middle and high school students to craft videos about local climate change impacts. Graduate students mentored school teams. Films included interviews with area scientists on topics including the Boulder flood, agriculture, impacts on wildlife, glaciers, and more. Undergraduate students in the “Inside the Greenhouse” course at CU-Boulder developed video “answers” to the student videos, and all were premiered during an event at the CU-Boulder campus.

<http://cires.colorado.edu/education/outreach/LOCC/>



Nederland students work on a video about Colorado’s largest glacier, Arapahoe Glacier.

Photo credit: David Oonk/CIRES



Lens on Climate Change screening, Old Main auditorium, CU-Boulder.

Photo credit: Robin Strelow/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 300 people have been Visiting Fellows at CIRES, including previous CIRES Directors Susan Avery and Konrad Steffen.



Michele Betsill

Sabbatical
Ph.D., University of Colorado
Boulder
Project: Politics and governance of climate change in the city: Municipalities and renewable energy transitions

Sponsors: Max Boykoff and Lisa Dilling

Michele Betsill is a professor of political science and coleader of the Environmental Governance Working Group at Colorado State University. She studies the politics and governance of climate change from the global to the local level across the public and private spheres.

Working with CIRES' Center for Science and Technology Policy Research, Betsill is investigating the role cities play in the global governance of climate change and how cities can transition to low-carbon societies. Betsill's specific project will investigate whether Colorado's New Energy Economy program was successful in supporting local authorities while they develop and implement local initiatives related to renewable energy. "I hope this research will provide insight for state and local governments on how to work together to provide opportunities for local innovation in the renewable energy sector and contribute to a better understanding of how state-local relations shape local climate protection and renewable energy activities," Betsill says.



Joanna Boehnert

Postdoctoral
Ph.D., University of Brighton,
United Kingdom
Project: Visualizing climate discourses and the green economy
Sponsor: Max Boykoff

Joanna Boehnert is conducting two research projects focused on the visual communication of complex ecological and socio-political systems. Her first project will map the organizations, individuals, discourses, methods, and funders that contribute to climate communication, using network visualizations, timelines, and system maps. Her second project will visualize proposals for valuing nature, especially the United Nations Environment Programme's Green Economy initiative, using a variety of analytical perspectives. This work will communicate proposed methodologies and practices for addressing the accelerating biodiversity crisis.

Boehnert sees her work as a means of supporting ecological literacy. "Working on making environmental information meaningful and relevant to more people is enormously satisfying for me," she says. "Images are a powerful means of communicating ecological concepts since images are so effective at displaying context, relationships, and dynamics in complex systems." Boehnert is working with Max Boykoff and CU-Boulder's International Collective on Environment, Culture and Politics and also is looking for new collaborators in the environmental research community.



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: R. 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.



Marin Clark

Sabbatical
Ph.D., Massachusetts Institute of Technology
Project: Lithosphere deformation and the effect of earthquakes on erosion budgets of actively deforming mountain belts

Sponsor: Roger Bilham

Marin Clark is an associate professor in the field of geomorphology, geodynamics, tectonics, and thermochronology in the Department of Earth and Environmental Science at the University of Michigan. Her research involves the study of topography and how it relates to lithospheric deformation. Clark looks at the evolution of rivers and other landforms; these systems are a sensitive record of the vertical movement of Earth’s surface caused by deformation.

Sometimes this deformation occurs very deep in Earth’s crust or upper mantle, making direct observation an impossible task. To study these deep processes, Clark has developed ways of using topography as a proxy for motion at great depths beneath the continents. She uses a variety of tools including field geology, GIS modeling, geodynamic modeling, and thermochronology.



Christopher Cox

Postdoctoral
Ph.D., University of Idaho, Moscow
Project: Boundary layer meteorology and cloud physics over ice sheets and the reconstruction of paleotemperatures from ice cores

Sponsors: David Noone and William Neff

Christopher Cox is collaborating with David Noone’s Climate Processes Research group and the Integrated Characterization of Energy, Clouds, Atmospheric state and Precipitation at Summit project. These projects have neighboring observatories at Summit Station, Greenland. Cox is researching the relationship clouds and fogs at Summit have with the

meteorology near the surface of the ice sheet, including isotope ratios in precipitation that will become part of the ice sheet. Scientists estimate paleotemperatures from the isotope ratios trapped in the ice, and Cox hopes to elucidate the influence of clouds on these isotope ratios, which are poorly understood. “Understanding the relationship that clouds, fogs, and precipitation have with the ice sheet is important for understanding the influence that clouds have on the ice sheet, including its mass balance,” Cox says.

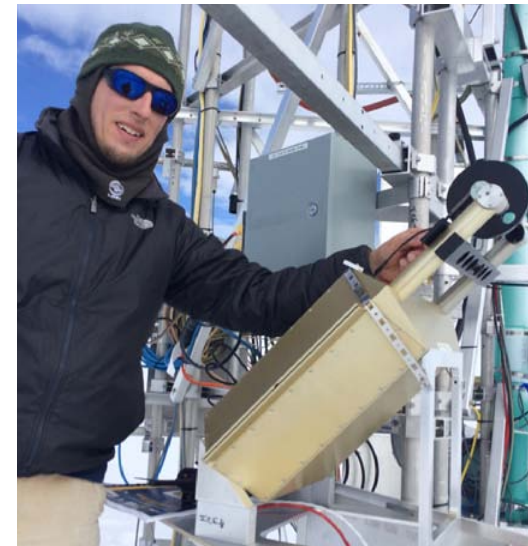


Photo courtesy of Christopher Cox/CIRES



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."



Louise Gall

Postdoctoral
Ph.D., University of Oxford,
United Kingdom
Project: Unraveling the great oxidation event with nickel isotopes
Sponsor: Lang Farmer

During the Great Oxidation Event, which occurred approximately 2.5 billion years ago, oxygen began to accumulate in the atmosphere due to an increase in photosynthetic organisms. In collaboration with CU-Boulder's Department of Geological Sciences, Louise Gall is studying the possible decline of methanogenic bacteria (which are archaeobacteria that produce methane) during this time period.

Gall's work could help date the events leading to the oxygenation of the atmosphere and identify the main triggering factors. "By using new techniques to measure the stable isotope ratios of nickel—a method I developed during my Ph.D.—we can theoretically trace the presence of these methanogenic bacteria in the geological archive, since they cannot live without nickel," Gall says.



Anne Monod

Sabbatical
Ph.D., University of Paris, France
Project: Formation of organic oligomers in the atmosphere via photochemical reactivity in the bulk aqueous phase and at the air-water interface
Sponsor: Veronica Vaida

Anne Monod is an atmospheric chemistry professor at Aix-Marseille Université. Her recent work has shown that the tendency of dissolved organic compounds to react under sunlight leads to the formation of macromolecules that can be a significant source of secondary organic aerosols in the atmosphere.

Working with Veronica Vaida, Monod is investigating the formation and fate of organic oligomers, compounds composed of a relatively high number of repetitive chemical structures and which are able to partition at the interface between air and water. The generation and movement of oligomers at this boundary can affect atmospheric chemistry and climate.



Nathan Niemi

Sabbatical
Ph.D., California Institute of
Technology

Project: Paleotopography of the basin and range and the geodynamics of intracontinental extension
Sponsor: Craig Jones

As an associate professor of earth and environmental sciences at the University of Michigan, Nathan Niemi studies continental deformation—specifically actively deforming tectonic systems. Niemi has travelled west to study the tectonic activity in the Great Basin region. “Every year, the distance between Salt Lake City and Reno increases by about 1 centimeter,” Niemi says. “This process has been ongoing for millions of years, creating the Great Basin.” In most places, this kind of stretching of Earth’s crust leads to it breaking in two and forming a new ocean, he explains. Here, Earth’s crust appears to continually stretch instead of breaking.

By studying the deformation of Earth in the basin, Niemi hopes to uncover the processes that accommodate plate tectonic motions around the globe. Niemi and his collaborators in the Geodynamics group in CU-Boulder’s Department of Geological Sciences also hope to identify any implications the study has for seismic hazards in the western United States. As part of his research, Niemi will conduct fieldwork, including geological mapping and sample collection, in Colorado, Utah, Nevada, and California.



Robert Rhew

Sabbatical
Ph.D., Scripps Institution of
Oceanography, University of
California, San Diego

Project: Variability of biogenic emissions of alkenes and methyl halides
Sponsor: Joost de Gouw

An associate professor with the Department of Geography and the Department of Environmental Science, Policy and Management at the University of California, Berkeley, Robert Rhew researches the mechanisms that control the flux of environmentally important trace gases between the biosphere and atmosphere. “I am investigating the fluxes of biogenic trace gases from forest ecosystems in Colorado and Brazil and how those fluxes vary with time,” says Rhew, who will be collaborating with scientists from NOAA and NCAR. “Our net ecosystem flux measurements will focus on light alkenes and halocarbons.”

Light alkenes and halocarbons, which affect ozone concentrations, are emitted from natural and human-caused sources. Emissions from the terrestrial environment are quite variable and poorly quantified. “This project will test our ideas regarding the driving

factors behind the production and variability of these reactive trace gases,” Rhew says. “I hope to shift the way we consider ecosystem fluxes to be somewhat analogous to human disease: incorporating a ‘genes x environment’ approach to understanding temporal variability.”



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 R. Michael Hardesty



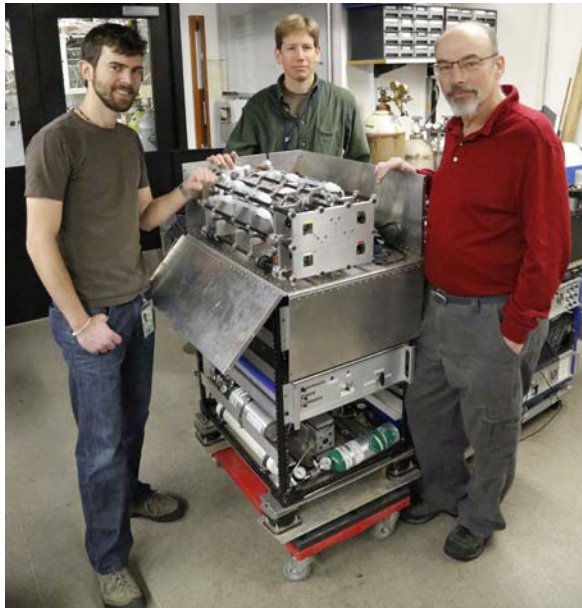
Geology research in a remote part of northern Tibet.

Photo credit: Nathan Niemi/CIRES

innovative research program

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.

<http://cires.colorado.edu/science/pro/irp/>



Robert Wild (left), Steven Brown (middle), and Bill Dubé (right) next to an instrument designed and built with support from a 2013 Innovative Research Program award.

Photo credit: David Oonk/CIRES

2014 Innovative Research Program Awards

Thomas Chase, Benjamin Herman (University of Arizona), and Roger Pielke Sr.
Bracketing Northern Hemisphere mid-tropospheric temperatures: Relation to circulation indices

Shelley Copley and William Old
Development of an unbiased method for identifying regulatory proteins bound to DNA in vivo: Finding the needle in the haystack

Sean Davis, Russell Chadwick, Lars Kalnajs (Laboratory for Atmospheric and Space Physics), Dale Hurst, Karen Rosenlof, Randy Collander (Cooperative Institute for Research in the Atmosphere), and Joan Alexander (North-West Research Associates)
Blowing in the wind: Fiber optic temperature profiler measurements from drifting high-altitude balloons

Gijs de Boer, Christopher Fairall, Dale Lawrence (Aerospace Engineering), and Daniel Wolfe
Development and evaluation of low-cost, unmanned, aircraft-based turbulent flux measurement techniques

Barbara Ervens and Veronica Vaida
Modification of aerosol air/water interfaces due to aqueous and surface chemical reactions

Janet Machol and Paul Loto'aniu
Geocoronal hydrogen density estimates using solar absorption in the exosphere

Vladimir Ostashev, Daniel Wolfe, and Stuart Bradley (University of Auckland, New Zealand)
New theory of sound pulse scattering with applications to remote sensing of the atmosphere

Carsten Warneke, Patrick Veres, and Joost de Gouw
Fast-time-response detection of small alkanes from oil and natural gas extraction using mass spectrometry

graduate student research fellowships

CIRES supports the long-established CIRES Graduate Student Research Fellowship (GSRF). The fellowship is competitively awarded to new or existing CIRES-affiliated graduate students in good standing. A committee of CIRES Fellows serves as the review and selection committees for the Fellowship. At right are the recipients for this reporting period (June 1, 2013–May 31, 2014).

cires.colorado.edu/education/cu/gsrf

Emily Gill

Civil, Environmental and Architectural Engineering
Advisor: Balaji Rajagopalan

Abigail Koss

NOAA ESRL/CIRES Volatile Organic Compounds (VOCs) Research group
Advisor: Joost de Gouw

Jordan Krechmer

Analytical/Atmospheric Chemistry
Advisor: José-Luis Jiménez

Jonathan Leff

Ecology and Evolutionary Biology
Advisor: Noah Fierer

Xi Wang

Environmental Studies Program (ENVS)
Advisor: Maxwell Boykoff

Eleanor Waxman

Analytical/Atmospheric Chemistry
Advisor: Rainer Volkamer

Anthony Wong

Atmospheric and Oceanic Sciences
Advisor: David Noone

Daniel Zeitlow

Geophysics
Advisor: Anne Sheehan



Jordan Krechmer installs a sampling line in the Caltech Atmospheric Chamber during the Focused Isoprene Experiments (FIXCIT) campaign in January 2014.

Photo credit: Manjula Canagaratna/Aerodyne Research

diversity and undergraduate research

CIREs engages in many important efforts to educate undergraduate students and involve them in hands-on research. Our institute also runs and participates in diversity programs designed to broaden participation in atmospheric and other Earth sciences. Some highlights from the reporting period (June 1, 2013–May 31, 2014) are described on these two pages.

Lens on Climate Change (LOCC)

Through this new CIREs Education and Outreach program, middle and high school student teams from across Colorado create short (three- to five-minute) films about how climate change affects their lives and their community. Every student team was mentored by a CU graduate student helping with the science content and a CU graduate or undergraduate student helping with the videography. Most of the student teams interviewed CU scientists about their topic. During the 2014 reporting period, the kickoff year for this program, nine schools, and 62 students participated. Topics included the Colorado flood, local snowpack, shrinking Arapahoe glacier, drought, mountain pine beetle, and food security/agriculture. <http://cires.colorado.edu/education/outreach/LOCC>



Nederland Middle School and High School working on a video about the Arapahoe Glacier, Colorado's largest glacier.

Photo credit: David Oonk/CIREs

The most beneficial thing that I got from making the video was that to be confident, because when we first started making the video I was kind of thinking to drop out of the group and not do it. Then my teacher had a conversation with me that once you start something and you finish it you'll feel good about it and it will help me in life. That really helped me because when we got the video done I was really glad that I made something and finished it. It helped me to be confident with my self because I'm the kind of person who doesn't have confidence in doing something and finishing it.

Research Experience for Community College Students (RECCS)

This is an internal CIREs program for underserved communities. CIREs and the Institute of Arctic and Alpine Research (INSTAAR) offer up to six paid summer research opportunities for Colorado Community College students. These research opportunities offer a unique opportunity to conduct research, both field- and laboratory-based, working in a team with scientists, learning basic research, writing, and communication skills, and presenting research work at a science conference. <http://cires.colorado.edu/education/outreach/projects/reccs/>

CIREs-Funded RECCS Students

Patrick Barber

Project: The difference in sediment transport between the east and west sides of the Kawuneeche Valley in Rocky Mountain National Park
CIREs Mentor: James McCutchan

Jessica Johnstone

Project: Human-induced adaptations to the hydrology of the Gunnison Basin as a result of climate change
CIREs Mentor: Imtiaz Rangwala

Patrick Marsden

Project: What percentage of microbial metagenomic analysis is from live viable organisms?
CIREs Mentor: Noah Fierer

Mary Cruz

Project: Fate and transport of rare earth elements in the Snake River watershed: A mass balance approach
CIREs/INSTAAR Mentor: Diane McKnight

Research Experiences in Solid Earth Sciences for Students (RESESS)

RESESS at Unavco, in Boulder, Colorado, is a summer research internship program aimed at increasing the diversity of students in the geosciences. RESESS was founded with support from SOARS (see next program).

<http://resess.unavco.org/>

RESESS Student

Amy Asanuma

Poster: Determining the recipe for a flash flood: An east-central Colorado analysis of high-resolution rainfall, flow, and infiltration in a semi-arid grassland.

CIRES Research Mentor: Greg Tucker

Significant Opportunities in Atmospheric Research and Science (SOARS)

SOARS is a learning community and mentoring program for promoting ethnic and gender equity in the atmospheric and related sciences. The National Center for Atmospheric Research created and administers the highly regarded four-year mentorship and research program for protégés majoring in an atmospheric or related field. More: <http://www.ucar.edu/soars/>

SOARS Protégé

Adrianna Hackett

Project: Research evidence for elevated stratopause events in historical meteorological data (1957 to present)

CIRES Mentor: Leslie Hartten

Undergraduate Research Opportunities Program (UROP)

This program funds research partnerships between faculty and undergraduate students at CU-Boulder. 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.

<http://enrichment.colorado.edu/urop/>

UROP Students

Eva Adler

Project: Multiple disturbances in subalpine forest: Using tree cores to determine disturbance history

CIRES Sponsor: Carol Wessman

Chris Beliveau

Project: Crust and mantle structure from seismic waveforms

CIRES Sponsor: Anne Sheehan

Stephen Blaskoski

Project: Effect of five mutations on PLP production in wild type *E. coli*

CIRES Sponsor: Shelley Copley

Maria Furtney

Project: Characterization of seafloor pressure anomalies from an ocean-bottom seismic experiment

CIRES Sponsor: Anne Sheehan

Robert Kowalsky

Project: Geophysical electrical conductivity study of the Betasso Watershed, Colorado

CIRES Sponsor: Anne Sheehan

Sean Kuusinen

Projects: Energy efficiency opportunity guide: A practical tool for reducing CO₂ emissions and saving energy, 2014.

Charcoal production across fire severities, 2013

CIRES Sponsor: Carol Wessman



RECCS students tour Boulder City Betasso water treatment facility. Photo credit: David Oonk/CIRES

selected 2013 awards

CIRES Outstanding Performance Awards Science and Engineering Awards

Bernardet, Ligia (GSD)

For outstanding leadership to the Hurricane Task of the Developmental Testbed Center, which has enabled the growing use of NOAA's Hurricane Weather Research and Forecasting model. Bernardet's communication and advanced technical skills were instrumental in unifying code in support of a broad range of model users and partners.



Pichugina, Yelena (CSD)

For her groundbreaking research focused on dynamic atmospheric processes at the heights of modern wind turbine rotors. Her work has revolutionized the measurement, characterization, and visualization of atmospheric phenomena, turbulence, and boundary layers—all of which are important for a growing wind energy industry.

Warneke, Carsten (CSD)

For coordinating and leading the instrumentation of NOAA's WP-3D research aircraft for the very successful SENEX 2013 field study. Warneke's own research on the roles of volatile organic compounds in the atmosphere as well as knowledge gained from the SENEX project have profoundly influenced the way scientists think about air quality and climate change.

Service Awards

Cullis, Patrick (GMD)

For his stunning training and outreach videos. Cullis' videos not only help CIRES achieve excellence in Earth science research through improved data collection, but they also foster public interest and awareness of our work.

Jencks, Jennifer, and Meyer, Brian (NGDC)

For their innovative ideas and outstanding teamwork, which have resulted in the creation of a Web interface that allows scientists across the world to easily access 30-plus years of foundational marine research data.



Pendergrass, Linda (CIRES Administration)

For her superb work planning, coordinating, and managing the many events hosted by CIRES. Pendergrass' never-ending enthusiasm for helping CIRES put its best foot forward leaves CIRES members and our visiting colleagues excitedly awaiting the next workshop, meeting, and other events.

CIRES Silver and Bronze Medals

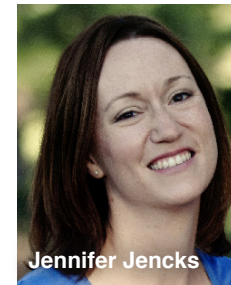
CIRES scientists are often integral to NOAA award-winning science and engineering teams but cannot receive certain federal awards, such as the prestigious Department of Commerce Silver and Bronze Medals. The CIRES director recognizes the extraordinary achievements of CIRES scientists working in partnership with federal colleagues through the CIRES Silver and Bronze Medals.

CIRES Silver Medal

Andrews, Betsy, Hageman, Derek, and Jefferson, Anne (GMD)

In collaboration with NOAA GMD colleagues, these CIRES scientists were part of a NOAA Silver Medal team lauded “for establishing an international, cooperative network to make coordinated, long-term measurements of aerosol climate-forcing properties.”

CIRES Bronze Medal



Jencks, Jennifer (NGDC)

In collaboration with NOAA NGDC colleagues, Jencks was part of a NOAA Bronze Medal team lauded “for superior leadership and interagency collaboration in creating the comprehensive digital information publication, Gulf of Mexico Data Atlas.”

Federal, State, and University Awards

Anderson, Charles (NGDC)

U.S. Department of Commerce (DOC) Certificate of Appreciation for “outstanding, innovative work establishing data and metadata pipeline for NOAA's Water Column Sonar Data Archive.”

Coloma, Francine (NGDC)

U.S. DOC Certificate of Appreciation for “migrating NGDC's initial data set to the CLASS Archive.”

Crotwell, Andy, Miller, John, and Montzka, Steve (GMD)

NOAA Oceanic and Atmospheric Research Outstanding (OAR) Scientific Paper Award for their co-authorship of Dlugokencky, EJ, et al., 2009, Observational constraints on recent increases in the atmospheric CH₄ burden. *Geophys. Res. Lett.* 36. L18803.

Darnel, Jonathan (NGDC)

U.S. DOC Certificate of Appreciation for extending the capabilities of the future GOES-R series of satellites by developing the Space Weather products.



Fierer, Noah (EBIO)

Boulder Faculty Assembly Award for Excellence in Research, Scholarly, and Creative Work.

Jencks, Jennifer (NGDC)

U.S. Department of State Superior Honor Award for research and interagency cooperation in leading an Integrated Regional Team of the U.S. Extended Continental Shelf Project.

U.S. DOC Certificate of Appreciation for outstanding and lasting contribution to the U.S. Extended Continental Shelf Project.

Karion, Anna, Kitzis, Duane, Petron, Gabrielle, Sweeney, Colm, and Wolter, Sonja (GMD; Pieter Tans group)

Along with NOAA's Pieter Tans (GMD) and other NOAA team members, these CIRES scientists received the CO-LABS Governor's Award for High-Impact Research in Atmospheric Research "for their research on the effects of humans on our atmosphere."

Lim, Elliot (NGDC)

U.S. DOC Certificate of Appreciation for outstanding and lasting contribution to the U.S. Extended Continental Shelf Project.

Mabie, Justin

U.S. DOC Certificate of Appreciation for outstanding support of the NGDC mission by managing solar and geomagnetic databases.

Machol, Janet, and Rowland, William (NGDC)

U.S. DOC Certificate of Appreciation for "outstanding performance and contributions to the GOES-R Space Weather Program."

Scambos, Ted (NSIDC)

Selected to the National Research Council's Future of Antarctic Research committee. Selected to the Scientific Committee on Antarctic Research (SCAR) Horizon Scan committee.

Scott, James (PSD)

NOAA OAR Scientific Paper Award for his co-authorship of Hare, JA, et al., 2010. Forecasting the dynamics of a coastal fishery species using a coupled climate population model. *Ecol. Appl.* 20:452-464.

Tucker, Gregory (Geog)

Boulder Faculty Assembly Teaching Excellence Award, Spring 2013.

Volkamer, Rainer (Chem)

Faculty Early Career Development (CAREER) award from the National Science Foundation, as mission scientist for the Tropical Ocean Troposphere Exchange of Reactive halogen species and Oxygenated VOC (TORERO) project.

Weatherhead, Betsy (GSD)

University of Colorado's Elizabeth D. Gee Memorial Lectureship Award from the University of Colorado for efforts to advance women in academia, interdisciplinary scholarly contributions, and distinguished teaching.

Wolter, Klaus (PSD)

CO-LABS Governor's Award for High-Impact Research in Sustainability for his work helping Colorado plan for drought.

Other Awards



Boykoff, Maxwell (CSTPR)

One of 20 environmental researchers across North America to receive a Leopold Leadership Fellowship at the Stanford Woods Institute for the Environment.

Campbell, Garrett, and Gallaher, Dave, along with Balabanova, Anna, Fowler, Cathy, Fowler, Doug, Harris, Will, Meier, Walt, Miller, Deann, Vizcarra, Natasha, and Wyatt, Pamela (NSIDC)

International Data Rescue Award in the Geosciences, from the Integrated Earth Data Applications of Lamont-Doherty Earth Observatory and Elsevier Research Data Services, for the team's Nimbus Data Rescue Project, which prepared decades-old data for widespread use.

International Data Rescue Award in the Geosciences, from the Integrated Earth Data Applications of Lamont-Doherty Earth Observatory and Elsevier Research Data Services, for the team's Nimbus Data Rescue Project, which prepared decades-old data for widespread use.

Compo, Gil (PSD)

International Data Rescue Awards Honorable Mention for oldWeather, an international citizen science effort (which Compo helps lead) to transcribe handwritten historical weather records.

Jiménez, José-Luis (Chem), Scambos, Ted (NSIDC), and Serreze, Mark (NSIDC), along with Roya Bahreni (then CIRES)

Co-authored papers included in *Geophysical Research Letters'* top-40 list of most impactful papers.

Livneh, Ben (PSD, WWA)

Named a Dissertations Initiative for the Advancement of Climate Change Research (DISCCRS) VIII Symposium Scholar for demonstrated research quality, commitment to crossing disciplinary boundaries, professional service, and outreach activities.

Lynds, Susan (EO)

National Association of Geoscience Teachers Outstanding Paper Award for co-authoring Ledley TS, et al., 2012. A model for enabling an effective outcome-oriented communication between the scientific and educational communities. *J Geol Educ.* 60:3. 257-267.

Oltmans, Samuel (GMD)

American Geophysical Union's Yorum J. Kaufman Unselfish Cooperation in Research Award for broad influence in atmospheric science through exceptional creativity, inspiration of younger scientists, mentoring, international collaborations, and unselfish cooperation in research.

Pope, Allen (NSIDC)

One of only three students elected to be an AGU Council Member.

Named Fellow at the Software Sustainability Institute, which encourages Fellows to develop their interests in the area of software sustainability, capacity building, and policy development.

Sheehan, Anne (Geological Sciences)

Distinguished Lecturer for EarthScope, which uses freely available data from instruments to conduct multidisciplinary research across the Earth sciences.

University of Tokyo Earthquake Research Institute's Visiting Professor Award

Smith, Catherine (PSD)

Special Award from the American Meteorological Society for producing and sustaining an extremely user-friendly, Web-based interface, making weather and climate data widely accessible to users at all levels.



CIRES hosts diverse symposiums, seminars, workshops, and other events throughout the year. This year, one highlight was a Distinguished Lecture by Pamela Matson from Stanford University, who spoke about “A new form of global change science: Science for a sustainability transition,” in April 2014. Other events include the following:



Photo credit: David Oonk/CIRES

Analytical Chemistry Seminars

- **Christopher D. Cappa** Characterizing the influence of multi-generational chemical processing on organic particles (9/13)
- **Margaret Tolbert** Deliquescence of calcium perchlorate: A route to liquid water on Mars and other possibly habitable planets. **Robert Sievers** Group studies of needle-free delivery of dry powder aerosol vaccines and pharmaceuticals (9/13)
- **Paul Ziemann** Comprehensive laboratory studies of the chemistry of secondary organic aerosol formation: Scientific questions, techniques and open graduate student projects
- Erin E. McDuffie** A new instrument for the analysis of single aerosol particles (9/13)
- **Rainer Volkamer** Marine trace gases and aerosols: Novel Chemistry at atmospheric interfaces (9/13)
- **Daniel James Cziczo** Combining field and laboratory studies to understand the dominant sources and mechanisms of cirrus cloud formation (10/13)
- **Joost de Gouw** Organic carbon in a changing atmosphere: How our energy choices affect air quality and climate change (10/13)
- **José-Luis Jiménez** Instrument and technique development, field studies, and computer modeling to elucidate organic aerosol sources, properties, processes, and fate (10/13)
- **Amanda McLaughlin** Characterization of copolymers of vinylbenzyl thymine (VBT) and vinylbenzyl chloride (VBC) using size exclusion chromatography and Ingril Mielke-Malay Water sensing by localized surface plasmon resonance on HKUST-1 and ZIF-8 multilayer metal organic frameworks (11/13)
- **Roger Atkinson** Products of OH + furan reactions and some implications for aromatic hydrocarbon atmospheric degradation (11/13)
- **Fernando Rosario-Ortiz** Photochemical formation of reactive oxygen species from wastewater organic matter (12/13)

- **Yanxu Zhang** Mercury cycling in the atmosphere-ocean-land system: Insights from regional and global modeling (2/14)
- **Eleanor Browne** Chemical Changes to Light Absorbing Carbonaceous Aerosol with Oxidative Aging (2/14)
- **Tim Bertram** Chemistry at atmospheric aqueous interfaces: In situ constraints on halogen activation at the air-sea and air-particle interface (2/14)
- **Susan Tegtmeier** The role of ocean halogen and sulfur compounds for the middle atmosphere (2/14)
- **Andrew Rollins** Chemical and physical processes controlling organic aerosols and tropopause cirrus: An observational perspective (2/14)
- **Laura Gonzalez** Chemistry at air-water interfaces: Glyoxal sources in the marine boundary layer and radical production from photosensitizers (3/14)
- **Ryan Davis** Novel phase transitions of optically levitated microdroplets: Contacts and glasses relevant to the atmosphere (3/14)
- **Charles J. Weschler** Chemical reactions among pollutants indoors—the human touch (4/14)
- **Yu Xia** Can mass spectrometry be more radical? (4/14)
- **Samantha Thompson** Gas/particle partitioning of organic acids: Instrument development and field deployment (4/14)

Center for Science and Technology Policy Noontime Seminars

- **Bjorn-Ola Linner** International negotiations survey: Exploring possible avenues for climate diplomacy (10/13)
- **Amy Quandt, Arielle Tozier de la Poterie, and Kanmani Venkateswaran** Climate change communication and adaptation decision-making in the humanitarian sector in East Africa—three cases (10/13)
- **Joseph Kasprzyk** Balancing cost, performance, and efficiency for complex water problems: A many objective approach to sustainability (10/13)

- **Aaron Clauset** Estimating the historical and future probabilities of large terrorist events (11/13)
- **Michele Betsill** Multi-level governance, climate change and urban energy transitions: State-local relations in Colorado's 'New Energy Economy' (11/13)
- **Phillip Fernbach** Political extremism is supported by an illusion of understanding (12/13)
- **Saffron O'Neill** Place attachment, performance and climate change adaptation (1/14)



Kristy Tiampo, Special Seminar: Advanced DInSAR analysis of natural and anthropogenic hazards.

Photo credit: David Onk/CIRES

- **Meaghan Daly, Eric Lovell, Mara J. Goldman, and Lisa Dilling** Knowledge production, access, and use for climate adaptation at local scales in Northern Tanzania (2/14)
- **Kristen Averyt** The energy-water nexus: Where climate adaptation and greenhouse gas mitigation policies collide (2/14)
- **Amanda Carrico** Psychological and community correlates of adaptation to water stress among smallholding farmers in Sri Lanka (3/14)
- **Adam Briggie** Guinea pigs of the shale: Informed consent and the politics of fracking (3/14)
- **Samuel Tang** Reporting, regulation, and the governance of climate change in the U.K. (4/14)
- **Joanna Boehnert** Visualising the environment and the politics of representation (4/14)
- **Katie Dickenson** Playing with fire: Social interactions and wildfire mitigation behaviors in Colorado (4/14)

Cryospheric and Polar Processes Seminars

- **Petr Chylek** Atlantic multi-decadal oscillation and the Arctic temperature variability (8/13)
- **Elchin E. Jafarov** The effect of snow on permafrost and modeling of the permafrost thermal state dynamics in Alaska (10/13)
- **A.L. Ramanathan** Jawaharal Nehru University research activities and results from studies on Himalayan glaciers of India over the past decade (10/13)
- **Allen Pope** Multispectral classification of glaciers; and estimating supraglacial lake depth with Landsat 8 (11/13)
- **James McCreight** GPS snow depth measurements on the Plate Boundary Observatory, modeled daily SWE from GPS-observed depth, and validation (12/13)
- **Mark Demitroff** Late Pleistocene periglacial processes and the origin of pinelands closed basins (3/14)
- **Albert Chen** InSAR remote-sensing: Principles and applications to Greenland and Alaska (3/14)

- **Andy Parsekian** GPR applications for permafrost research (4/14)
- **Ivan Sudakov** Mathematics of the Arctic tipping points (4/14)

CIRES Special Seminars

- **Kristopher Karnauskas** An undercurrent of change in the Pacific: Climate dynamics with ecosystem impacts (2/14)
- **Sam Stevenson** Understanding the tropical Pacific response to climate change: Roadblocks, progress, and future challenges (2/14)
- **Pedro N. DiNezio** The role of the ocean in tropical Pacific climate variability and change (2/14)
- **David Roy** My career in land remote sensing: from little to big analysis of satellite terrestrial information (3/14)
- **Gregg Jacobs** Predicting processes of dynamic deformation across the ocean surface: Why did oil in the Gulf of Mexico do what it did? (3/14)
- **Kyle Armour** The ocean's role in polar climate change (3/14)
- **Steve Nerem** Two decades of observing sea level: How it has shaped my vision for ESOC (3/14)
- **Kristy Tiampo** Advanced DInSAR analysis of natural and anthropogenic hazards (3/14)

National Snow and Ice Data Center Workshops

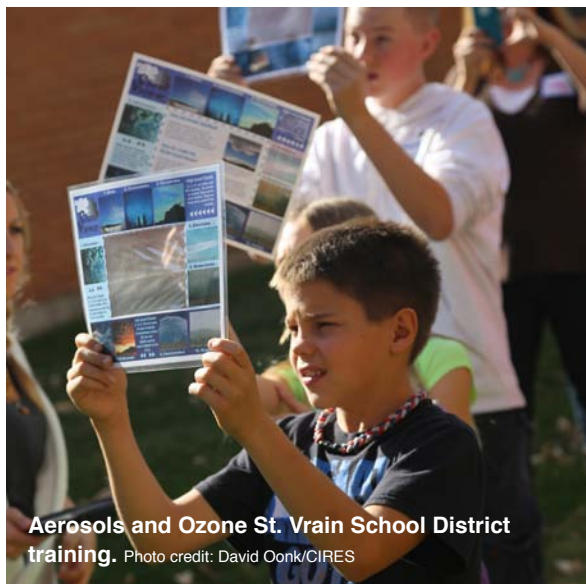
- 1st Snow Remote Sensing Workshop, August 14–16, 2013, Boulder, Colorado
- 2nd Snow Remote Sensing Workshop, January 14–16, 2014, YMCA Snow Ranch near Fraser, Colorado
- Winter School for Field Snowpack Measurements Fraser Experimental Forest, January 7–9, 2014, Fraser, Colorado

Education and Outreach

- Next Generation Science Standards Meeting (9/13)
- Climate Change & Water in the West Part 1: The Colorado River Basin Webinar (10/13)
- GSA—Short Course: 519B. Teaching and Learning about Climate in Geoscience Classrooms, Colorado Convention Center (10/13)
- WaterSpotters Kick Off, St. Vrain School District (10/13)
- Aerosols and Ozone (St. Vrain School District training) (11/13)
- Climate Change & Water in the West Part 2—The Great Flood Webinar (11/13)

Miscellaneous

- **Nolan Doesken, Kelly Mahoney, Klaus Wolter, Martin Hoerling, and Jeff Lukas** Western Water Assessment Front Range Flood Panel (9/13)
- **Max McGillen** CSD Seminar: The atmospheric chemistry of n-, i-, s- and t- butanol biofuels (9/13)



Aerosols and Ozone St. Vrain School District training. Photo credit: David Onk/CIRES

- University Theatre Climate Wise Woman (10/13)
- **Andreas Ytterstad** CSTPR Seminar: Climate change policy in the media: Between hegemony and good sense (10/13)
- **Jennifer Kay** CSD Seminar: Definite, possible, and unlikely mechanisms for Arctic climate change (10/13)
- **Ben Hamlington** ATOC Ocean Seminar (10/13)
- **David Parrish** CSD Seminar: Long-term changes in lower tropospheric baseline ozone concentrations: Comparing chemistry-climate models and observations at northern mid-latitudes (10/13)
- **Roger Pielke Jr.** INSTAAR Seminar: IPCC and extreme events (11/13)
- **Katherine McCaffrey** ATOC Ocean Seminar: Characterizations of turbulence at a tidal energy site (11/13)
- **Mikael Roman** RASEI Big Energy Seminar Series: Energy and innovation in Brazil (11/13)

- **Joanna Boehnert** Visualising the environment (2/14)
- Lens on Climate Change (2/14)
- **Andrew Revkin** An evening of conversation and music with 'climate communicator' Andrew Revkin (4/14)
- **Max Boykoff, Susan Buhr, Susan Lynds, Julienne Stroeve, Pieter Tans, Betsy Weatherhead, and Carol Wessman** Feelings and facts, emotion and intellect: How do we really receive what we see and hear? (4/14)
- Debate on college athletics: Resolved—college athletes should be allowed to unionize (4/14)
- CIRES Rendezvous (5/14)



An Evening of Conversation and Music with 'climate communicator' Andrew Revkin. Pictured left to right: **Beth Osnes, Maxwell Boykoff, Andrew Revkin, Waleed Abdalati, and Rebecca Safran.**

Photo credit: Katy Human/CIRES

CIREs' mission goes beyond nurturing and producing world-class research. It also includes a commitment to communicate the institute's scientific discoveries to the global scientific community, decision-makers, and the public. By providing trusted and engaging multimedia products, the CIREs Communications group fosters public awareness of Earth system science for the benefit of society. CIREs communicators collaborate closely with NOAA, CU-Boulder, our centers, and international colleagues in academic and government institutions.

During the 2014 reporting period (June 1, 2013, to May 31, 2014), communications efforts included news releases, media relations, videos, social media, a new edition of Spheres magazine, press conferences, and more. CIREs scientists and research were 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, Discovery, The Christian Science Monitor, Popular Science, U.S. News & World Report, Los Angeles Times, Reuters, CNN, The Wall Street Journal, UPI, Time, New Scientist, MSNBC, and other local, national, and international media outlets.

News releases

CIREs, NOAA team leads investigation of Southeast air quality, climate questions (June 2013)

As part of the Southeast Nexus mission, CIREs and NOAA scientists are studying the movement and transformations of natural and man-made emissions in the U.S. Southeast, to gain insight into air quality, haziness, and climate change throughout the region.

Clearing up confusion about the future of Colorado River flows (June 2013)

The Colorado River's flow is projected to decrease with climate change, and a new analysis explains why future-flow estimates differ and summarizes what is known—and not known—about the river's future.

New CIREs director: Waleed Abdalati (June 2013)

The Council of Fellows and University of Colorado Boulder selected Waleed Abdalati, Ph.D., as the new CIREs director.

Like butter: Study explains surprising acceleration of Greenland's inland ice (July 2013)

Surface meltwater draining through cracks in an ice sheet can warm the sheet from the inside, softening the ice and letting it flow faster, according to a new study by CIREs scientists.

Asteroid impact that killed dinosaurs spared freshwater species (July 2013)

The natural biological resilience of freshwater species likely spared them from the otherwise devastating effects of the Chicxulub asteroid impact 66 million years ago, which had caused massive extinction in terrestrial and marine environments.



From a June 11, 2013, flight over Alabama as part of the Southeast Nexus mission. Photo credit: Joost de Gouw/CIREs

Significant methane leaks in a Utah natural gas field (August 2013)

CIRES scientists and NOAA colleagues found that methane emissions from the oil and natural gas fields in Uintah County, Utah, were much higher than expected, representing about 6 to 12 percent of the average hourly natural gas production in the county.

Earth is breathing deeper (August 2013)

Atmospheric CO₂ concentrations rise and fall as plants release CO₂ in winter and take up CO₂ during the growing season. New data show that the magnitude of these swings is increasing in the Northern Hemisphere as more CO₂ is emitted from the burning of fossil fuels and other human activities.

Soot suspect in mid-1800s Alps glacier retreat (September 2013)

Scientists have uncovered strong evidence that soot sent from a rapidly industrializing Europe caused the abrupt retreat of mountain glaciers in the European Alps.



Bison in Konza Prairie, Kansas. Photo credit: Suzanne Prober/CIRES

Today's worst watershed stresses may become the new normal (September 2013)

Nearly one in 10 U.S. watersheds is "stressed," with demand for water exceeding natural supply, according to a new analysis of surface water in the United States.

Water vapor in the upper atmosphere amplifies global warming (October 2013)

A new study shows that water vapor high in the sky and the temperature at the Earth's surface are linked in a "feedback loop" that further warms our climate.

Encouraging information from this year's observations of the ozone hole (October 2013)

New data from NOAA and CIRES showed that the Antarctic ozone hole was a little smaller than in years past, and ozone levels in a critical region of the atmosphere did not drop as low as usual.

A first look at diverse life below rare tallgrass prairies (October 2013)

For the first time, scientists have described the diverse assortment of microbes that thrived in the dark, rich soils beneath the grass.

Rising temperatures challenge Salt Lake City's water supply (November 2013)

By midcentury, warming Western temperatures will cause some streams surrounding Salt Lake City to dry up several weeks earlier than now, according to a new CIRES-led study.

Dust, warming portend dry future for the Colorado River (November 2013)

The adoption of land management efforts could help protect snowpack and water resources from a warming climate.



Dell Creek in Parley's Canyon is a source of water for Salt Lake City. Photo credit: Patrick Nelson/Salt Lake City Department of Public Utilities

U.S. methane emissions exceed government estimates (November 2013)

A new collaborative atmospheric study indicates that fossil fuel extraction and animal husbandry are major contributors to methane emissions.

Landsat 8 helps unveil the coldest place on Earth (December 2013)

Scientists recently recorded the lowest temperatures on Earth at a desolate and remote ice plateau in East Antarctica, trumping a record set in 1983 and uncovering a new puzzle about the ice-covered continent.

U.S. power plant emissions down (January 2014)

CIRES, NOAA scientists find switch to natural gas power plants means fewer air pollutants.

CIRES Fellow awarded science prize from Royal Swedish Academy (January 2014)

CIRES geophysicist Peter Molnar has been awarded the prestigious 2014 Crafoord Prize in Geosciences by the Royal Swedish Academy of Sciences for his groundbreaking research in geophysics and geological sciences.

Sequencing butterfly bacteria, scientists find surprises (January 2014)

A CU-Boulder-led team has sequenced the internal bacterial makeup of the three major life stages of a butterfly species, a project that showed some surprising events occur during metamorphosis.

Amazonian drought conditions add carbon dioxide to the atmosphere (February 2014)

As climates change, the lush tropical ecosystems of the Amazon Basin may release more of the greenhouse gas carbon dioxide into the atmosphere than they absorb, according to a CIRES-led study.

Measuring wind with microphones (February 2014)

To a small group of physicists, the noisy nuisance of the Diagonal Highway, between Boulder and Longmont, proved inspirational. The group used the roar of traffic to accurately measure wind speed, a scientific first.

Serving up climate data in usable formats (March 2014)

NOAA and CIRES scientists and their collaborators have

built an open-source program package, OpenClimateGIS, which aids users in the interpretation of climate data.

Climate considerations on Navajo lands (April 2014)

A new report led by the University of Colorado Boulder synthesizes state-of-the-science information on the region's climate, water cycle, and ecology and offers hope for resilience.

Common factors behind Greenland melt episodes in 2012, 1889 (April 2014)

A CIRES-led analysis shows that similar weather and climate factors were at play during Greenland's 1889 and 2012 melt events.

Greenhouse gases continued rising in 2013 (May 2014)

NOAA's Annual Greenhouse Gas Index shows that the warming influence from human-emitted gases continues to increase. The combined heating effect of human-emitted, long-lived greenhouse gases currently in the atmosphere has increased by 34 percent since 1990.



Butterfly bacteria sequenced. Tobin Hammer/CU-Boulder



Measuring wind with microphones as a car zooms by on the Diagonal Highway, Boulder, Colorado. Photo credit: Mikhail Charnotskii/ZelTech and NOAA

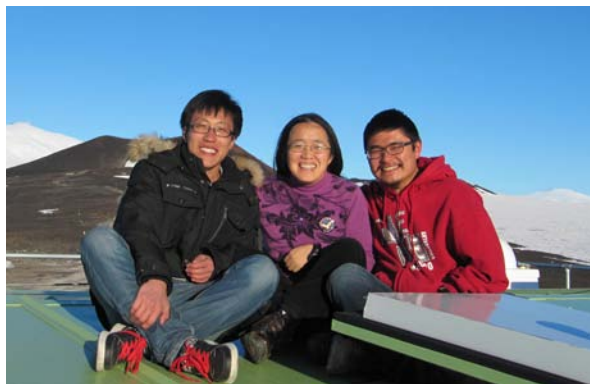
Airborne measurements confirm leaks from oil and gas operations (May 2014)

During two days of intensive airborne measurements, oil and gas operations in Colorado's Front Range leaked nearly three times as much methane, a greenhouse gas, as predicted based on inventory estimates, and seven times as much benzene, a regulated air toxic.

Web feature

Life and lasers in Antarctica (September 2013)

Every year, members of Xinzhao Chu's research group spend many months at McMurdo Station in Antarctica, using laser light to analyze the middle and upper atmosphere. Their research is shedding light on the planet's weather patterns, climate processes, and even the fertilization of life on Earth with essential minerals, such as iron. This Web feature highlights their research and what it's like to conduct research during minus-30-degree temperatures, 40-mile-per-hour winds, and four months of darkness.



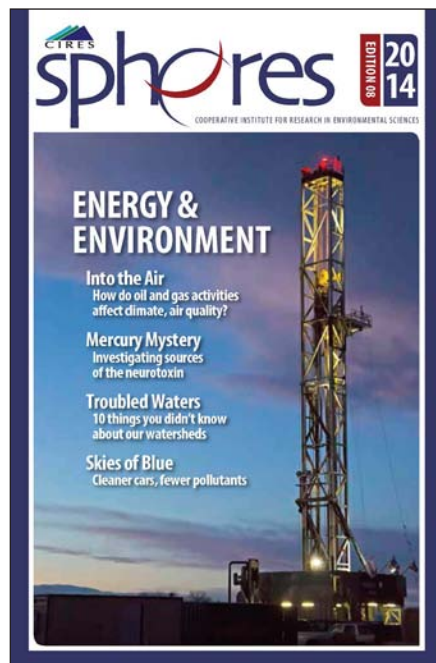
Left to right: Jian Zhao, Xinzhao Chu, and Chris Chen at Arrival Heights near McMurdo, Antarctica.

Photo courtesy of Xinzhao Chu/CIRES

Spheres science magazine

Produced by the CIRES communications group, Spheres magazine highlights the diverse research conducted at CIRES. Our scientists study all aspects of the Earth system, including the atmosphere, cryosphere, hydrosphere, geosphere, and biosphere. These spheres of expertise give our magazine its name.

During this reporting period, we produced the Energy & Environment edition of Spheres. Inspired by the CIRES Energy and Environment Initiative, this issue focuses on the intersection of environmental science and energy. CIRES scientists study the impacts of energy production (both renewable and fossil fuel-based) on the environment, and they also seek scientific understanding of the environment that can help others more successfully implement new energy sources.



Webcasts, photos, and social media

CIRES communications provides webcasting services for Institute seminars, workshops, and meetings (with more than 15 webinars cast during this reporting period); develops short educational and newsy videos; and provides compelling photographs that highlight our science and scientists. We also maintain a robust social media presence and support scientists with their blogs.

<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>

Videos

Bright lights in the Bakken

Unfrozen: Understanding the Arctic's influence on extreme weather

Bark beetles and water

Terrestrial to celestial: Earth's impact on the ionosphere

Melting glacier mystery

Science in flight



Bright lights in the Bakken oil field in North Dakota. Photo credit: NASA

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Air Quality in a Changing Climate

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

■ CIRES Lead: Andy Neuman ■ NOAA Lead: David Parrish

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, CIRES and NOAA scientists participated in several intensive regional field studies designed to enhance our understanding of air quality and climate. We investigated different parts of the atmosphere using a wide variety of measurement platforms. Accomplishments from four studies are described here.

Utah. For the third year in a row, we conducted a ground-based study of high wintertime ozone in an oil and gas extraction region in Utah: the Energy and Environment Uintah Basin Winter Ozone Studies (UBWOS). High wintertime ozone levels, which are damaging to human health, occur in several regions where emissions associated



CIRES and NOAA scientists outfitted this NOAA Twin Otter aircraft with sophisticated instruments for a series of spring 2014 flights around the oil-rich Bakken Formation in North Dakota, described on page 80. Photo credit: David Oonk/CIRES

with oil and gas extraction are trapped in geologic basins. The chemistry and meteorology that cause these large ozone values are not understood, making effective and efficient mitigation strategies challenging and uncertain. 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. In 2014, the ground was often snow-covered and ozone levels were substantially enhanced. These results provide valuable contrast to the previous year's study, when the ground was snow-free and ozone levels were lower, as reported by Edwards et al. (2013).

U.S. Southeast. During the Southeast Nexus Experiment (SENEX) mission, CIRES researchers and colleagues used an extensively instrumented aircraft to sample the atmosphere over the southeastern United States. The Southeast has 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 their sources and climate effects are not fully understood. Using the NOAA WP-3 aircraft, we conducted 18 research flights over the U.S. Southeast during the summer of 2013. Already, we have presented results at national meetings (American Geophysical Union, 2013 fall meeting) and data workshops (Southeast Atmosphere Study



Researcher Jessica Gilman (CIRES and NOAA) next to the whole air samplers aboard the NOAA WP-3D aircraft. Each sampler holds a “snapshot” of ambient air collected every few minutes during a research flight. Each gas sample is then analyzed for hundreds of different compounds back on the ground.

Photo credit: Dagen Hughes/Hendrix College

data meeting, Boulder, Colorado, 2014).

SEAC4RS. This NASA mission, Studies of Emissions and Atmospheric Composition, Clouds, and Climate Coupling by Regional Surveys (SEAC4RS), included comprehensive vertical sampling over the southeastern United States during August and September 2013, using a large jet and a high-altitude aircraft. The measurements will elucidate the role of deep convection in redistributing pollutants from the Southeast and the effects of natural and anthropogenic aerosol particles on meteorology and climate.

TOPDOWN. The Twin Otter Projects Defining Oil/gas Well emissionNs (TOPDOWN) study used a light aircraft to quantify emissions from oil and gas extraction operations in North Dakota in the spring of 2014 (photo page 79). Oil and gas extraction in this region is substantial, and emissions to the atmosphere are inadequately constrained by emissions inventories. Quantification of emissions improves the ability of models to estimate future climate and air quality. These field studies are providing the scientific understanding of emissions, atmospheric chemistry, and transport to support development of effective mitigation strategies.



SEAC4RS Mission's SPEC Lear jet with starboard wingtip instrumentation.

Photo credit: NASA

CSD-02: Chemistry, Emissions, and Transport Modeling Research

■ CIRES Lead: Stu McKeen ■ NOAA Lead: Michael Trainer

NOAA Theme: Climate Adaptation and Mitigation

Goals & Objectives:

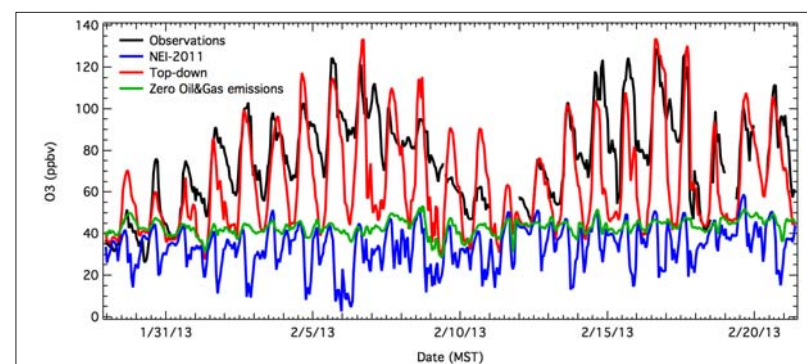
This project will use field observations and laboratory studies to provide better representation of atmospheric chemical, physical, and dynamical processes in numerical models, which will improve predictions and projections of climate and air quality.

Accomplishments:

Recent increases in oil and gas production throughout the western United States have triggered scientific and public interest in emission rates, air quality, and climate impacts related to this activity. The highest concentrations of ozone (O_3) recorded in the United States during the past four years occurred in the winter of 2013 in the Uintah Basin, which is dense with thousands of oil and gas wells.

CIRES researchers and collaborators have made aircraft-, tethered-, lidar-, and ground-based observations during 2012 and 2013 field studies in the Uintah Basin, to characterize the emissions of ozone precursors and the meteorological conditions that contribute to the high wintertime ozone seen in 2013, but absent during 2012.

The researchers also applied a high-resolution, regional-scale, 3-dimensional photochemical model to the Uintah Basin to help understand the factors responsible for high-ozone events. The high-resolution meteorology within the simulations allows



Observed and model-simulated ozone during winter of 2013 at the Horsepool intensive measurement site, Uintah Basin, Utah. “Top-down” refers to the measurement-based emission case; “NEI-2011” refers to the U.S. EPA inventory case.

researchers to qualitatively reproduce the wintertime cold pool conditions that occurred in 2013, and the model reproduces the observed multi-day buildup of ozone precursors and accompanying photochemical ozone formation in the Basin.

However, a correct model simulation of high-ozone events requires the correct specification of ozone precursor emissions. When oil/gas activity emissions from the most recent U.S. EPA inventory are used, the model fails to reproduce the high levels of ozone and other oxidants recorded during the 2013 field study. High ozone levels are accurately simulated only when the model is forced by emissions that are based solely on the field study measurements.

We used a novel approach to derive the measurement-based emission data set, by using aircraft observations of the methane (CH_4) flux emanating from the Basin during 2012, and the observed ratios of 59 volatile organic compound (VOC) species and NO_x relative to CH_4 at an intensive surface measurement site within the Basin. A model sensitivity analysis shows the major factors driving high winter ozone levels in the Basin are: shallow boundary layers with light wind, high emissions of VOCs from oil and gas operations compared to NO_x emissions, and the influence of snow cover on the enhancement of photolysis fluxes and reduction of ozone deposition. Simple emission reduction scenarios show ozone production in the Uintah Basin is VOC-sensitive and NO_x -insensitive. The model also shows a disproportionate contribution of aromatic VOCs to ozone formation (relative to all other VOC emissions). The air-quality model together with the measurement-based emission framework may help to address emerging science- and policy-related questions surrounding the environmental impact of oil and gas drilling in the U.S. West.



Natural gas condensate tanks in the Uintah Basin of Utah. Photo credit: Scott Sandberg/NOAA

GSD-04: Improve Regional Air Quality Prediction

■ CIRES Lead: Steven Peckham ■ NOAA Lead: Georg Grell

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:

CIRES scientists and colleagues continued to work on the development of the Weather Research and Forecasting-Chemistry (WRF-Chem) and Flow-following, Finite-volume Icosahedral Model-Chemistry (FIM-Chem) models. The development community decided to refrain from significant additions to the model and instead focused on improving interoperability of the various options. Therefore, improvements to the model were made in code fixes such as improving the performance of the global version of WRF-Chem. Results from scientific research were presented at several 2013 conferences (e.g., the European Geophysical Union and American Meteorological Society) and workshops, and the model development team continued international outreach efforts.

During 2013, the WRF-Chem model continued to produce daily real-time forecasts on a high-resolution domain and the forecasts were made available to the community through Web pages and applications (e.g., FX-Net). In the forecasts, the smoke from satellite-observed wildfires is included, and smoke particles interact with the regional



Satellite-observed 2012 Colorado wildfires. Image credit: NASA

meteorological forecast via absorption and reflection of downward shortwave radiation. The initial fine particle aerosols for the forecast are generated using previous forecast data along with chemical data assimilation via the Grid point Statistical Interpolation (GSI) methodology. During the chemical data assimilation segment, observations from more than 380 cities across the lower 48 United States are used 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.

In the summer of 2013, intensive field studies took place in the U.S. Southeast, a region with significant anthropogenic emissions, meteorological conditions that are conducive to active photochemistry, and where natural hydrocarbon emissions are the highest in the nation. These field studies were SENEX 2013, or Studying the Interactions Between Natural and Anthropogenic Emissions at the Nexus of Climate Change and Air Quality, and SOAS, the Southern Oxidant and Aerosol Study. Together, SENEX and SOAS comprised a six-week field campaign headquartered in Alabama and focused on the study of biosphere-atmosphere interactions. These studies included many national and international scientists and organizations. CIRES scientists and colleagues contributed daily air-quality forecasts by using the WRF-Chem model and the Rapid Refresh (RAP – <http://rapidrefresh.noaa.gov>) WRF configuration, including its North American domain. The simulation domain is similar to the operational NOAA National Centers for Environmental Prediction’s RAP, but with chemistry. NASA and NOAA’s Real-time Air Quality Modeling System (RAQMS) provided data for the chemical boundary conditions. CIRES provided support for this field program by overseeing the real-time set up and execution of WRF-Chem model runs for the studies and answering questions related to the interpretation of the model configuration and forecast results.

PSD-01: Relationship of Air Quality to Weather

■ CIRES Lead: Tim Coleman ■ NOAA Lead: Allen White

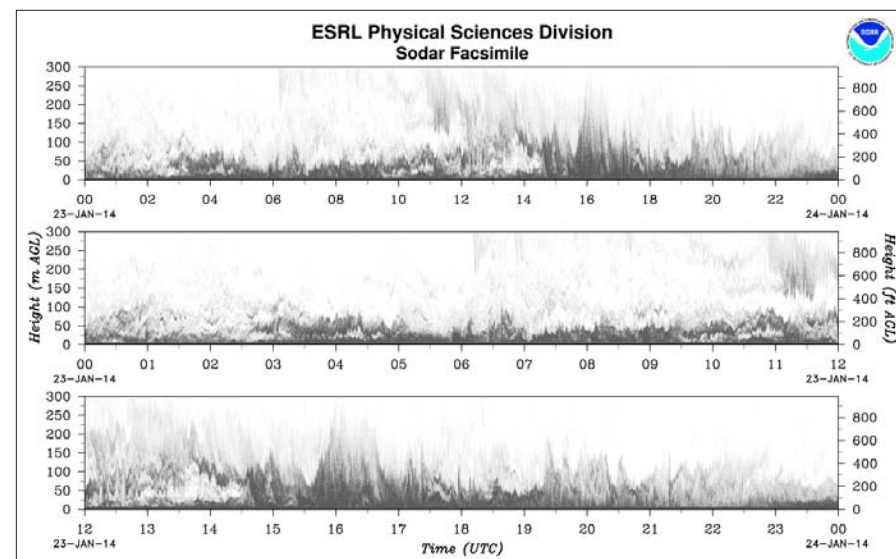
NOAA Theme: Science and Technology Enterprise

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:

During the reporting period, CIRES researchers collected, processed, and distributed observational data from the Uintah Basin Ozone study. These observations included sodar (sonic detection and ranging) reflectivity, surface energy balance fluxes, and 20-meter tower meteorological data, and these data let scientists make comparisons with numerical models to see how well the state boundary layer is simulated. CIRES researchers also helped develop and maintain new graphical products to show detailed sodar time-series plots, which enhanced the ability to detect and visualize the boundary layer (figure below). Finally, we developed and supported new Web interfaces to allow easier user access to the real-time data sets: <http://www.esrl.noaa.gov/psd/data/obs/datadisplay/>



Example of a detailed sodar time-series plot.

Climate Forcing, Feedbacks, and Analysis

CSD-03: Scientific Assessments for Decision Makers

■ CIRES Lead: Christine Ennis ■ NOAA Lead: A.R. Ravishankara

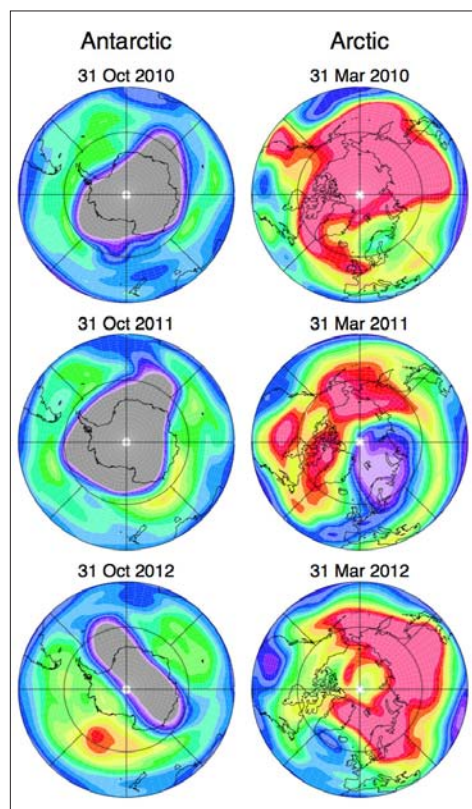
NOAA Theme: Climate Adaptation and Mitigation

Goals & Objectives:

This project addresses adaptation and mitigation.

Accomplishments:

During the past year, CIRES and NOAA scientists made major contributions to the preparation and review of the 2014 state-of-the-science assessment report regarding the stratospheric ozone layer. The document and its underlying five scientific chapters are being prepared (under the auspices of the World Meteorological Organization [WMO] and the United Nations Environment Programme [UNEP]) by the Scientific Assessment Panel of the United Nations Montreal Protocol, an agreement that protects the ozone layer and asks the scientific community to update the state of understanding every four years. A CIRES scientist serves as the coordinating editor for the report, and other CIRES scientists serve as coauthors and reviewers. A major accomplishment this year was the preparation of



Springtime ozone loss in the Arctic and Antarctic during the past four years. The 2014 World Meteorological Organization/United Nations Environment Programme ozone assessment report updates the state of understanding regarding the stratospheric ozone layer, including trends in stratospheric ozone at the poles.

the five scientific chapters of the 2014 report. These chapters underwent a mail review in November 2013 and a face-to-face peer review in April 2014, and were submitted in final form in May 2014.

An important component of the 2014 report is its *Assessment for Decision-Makers*, a document that will describe the policy-relevant scientific findings of the report's five chapters. In June 2014, a major meeting was held to prepare the document, which specifically seeks to address the needs of nations for scientific information that will underpin their decisions about whether to strengthen or broaden the provisions of the Montreal Protocol. The executive summary of the *Assessment for Decision-Makers* was finalized at the June meeting, as were the structure and major elements of the document. The *Assessment for Decision-Makers* will be released to governments and the public in September 2014, with the release of the full 2014 report, including its five scientific chapters, planned for January 2015.

CSD-04: Effects of Emissions on Atmospheric Composition

■ CIRES Lead: Joost de Gouw ■ NOAA Lead: Tom Ryerson

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 the project period, CIRES scientists and colleagues completed a major field study in the U.S. Southeast, Southeast Nexus or SENEX. The study focused on the interactions between biogenic and anthropogenic emissions in the Southeast, the formation of secondary pollutants, and their importance for air quality and climate change. During SENEX, 18 research flights with the NOAA WP-3D aircraft were successfully completed and results were obtained on a variety of topics. Results on atmospheric emissions that are specific to the goals of this project follow.

Emissions of trace gases and fine particles from vegetation, urban areas, power plants, shale gas production regions, agricultural fires and a biofuel refinery were characterized and quantified. Notably, emissions of nitrogen oxides (NO_x) and sulfur dioxide (SO₂) from power plants and of NO_x and volatile organic compounds (VOCs) from urban areas had strongly decreased since earlier studies. The measured mixing ratios of biogenic trace gases correlated with the calculated regional distribution of these trace gases from emissions models. The methane and VOC emissions from three shale gas produc-

tion regions (Haynesville, Fayetteville, Marcellus) were quantified and were found to be a lower, as a percentage of the shale gas production, than the leak rates found from earlier studies in the West (Denver-Julesburg, Uintah). Mixing ratios of nitrous acid (HONO) were measured and the direct emissions from agricultural fires and power plants were quantified. The emissions from a biofuel refinery in Illinois were characterized for the first time. Emissions of NO_x and SO₂ were significant, as this plant uses coal for energy generation. Additional emissions of ethanol and several aldehydes were observed and work is in progress to compare the measured emissions with the National Emissions Inventory of the Environmental Protection Agency.

During the NASA Studies of Emissions and Atmospheric Composition, Clouds, and Climate Coupling by Regional Surveys (SEAC⁴RS) study in August and September of 2013, several CIRES scientists made measurements of trace gases (nitrogen oxides, ozone) and fine particles (black carbon aerosol, particle size distributions) from the NASA DC-8 aircraft. Of specific interest to the goals of this project are the measurements made in the outflow from several wildfires in the western United States, most notably the Rim Fire in the Central Sierra Nevada region, and agricultural fires in the Mississippi Delta.

Analysis of results from previous field missions continued during the project period. Measurements of isocyanic acid (HNCO) made during several different measurement campaigns were analyzed and provided new insights into the emissions



SEENEX flight over Alabama, June 11, 2013. Photo credit: Joost de Gouw/CIRES

and photochemical sources of this compound. Measurements made from a mobile laboratory in an oil and natural gas production region in the Uintah Basin, Utah in 2012 were analyzed during the project period. One analysis focused on the emissions of VOCs from various components of the oil and natural gas production infrastructure, and found that VOC emissions were significantly lower from wells that transport raw gas to a centralized processing plant, as opposed to those that partially process the raw gas on the well pad itself. Another analysis focused on the mass spectrometric observations of hydrogen sulfide and used these to estimate the emission characteristics. In addition, an analysis was made of emissions from U.S. power plant emissions and how these have changed since 1997 as a result of the increased use of natural gas as a fuel.

CSD-05: Laboratory Studies of Fundamental Chemical and Physical Processes

■ CIRES Lead: Ranajit Talukdar ■ NOAA Lead: Jim Burkholder

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:

CIRES scientists worked with NOAA and other colleagues to measure lifetimes, ozone-depletion potentials (ODPs), and global-warming potentials (GWPs) of natural and anthropogenic compounds:

- a) **Bromoform** (CHBr₃) is a short-lived atmospheric trace compound primarily of natural origin that is a source of reactive bromine in both the troposphere and stratosphere. CHBr₃ is removed from the atmosphere primarily via ultraviolet (UV) photolysis and to a lesser extent by reaction with the hydroxyl (OH) radical. Prior to this laboratory study, the UV absorption spectrum of CHBr₃ was highly uncertain. In this study, UV absorption cross sections, $\sigma(\lambda, T)$, for CHBr₃ were measured at wavelengths between 300 and 345 nm at temperatures between 260 and 330 K using cavity ring-down spectroscopy. The photolysis rate in the tropical region obtained with our measured data is 10–15 percent lower (i.e., a longer lifetime) than obtained using currently recommended cross section values. As a result, the calculated ODPs for CHBr₃ are greater than the previously estimated values (Papanastasiou et al. 2014).

- b) **1,2-dichlorohexafluoro-cyclobutane** (1,2-c-C₄F₆C₁₂, R-316c) is a proposed replacement compound. The atmospheric loss processes of the (E)- and (Z)-1,2-dichlorohexafluorocyclobutane isomers were examined in the laboratory to enable an evaluation of their ODPs and GWPs. UV absorption spectra, photolysis quantum yields, photolysis products, infrared absorption spectra, and rate coefficients for the OH, O(1D), and O₃ reactions were measured for each isomer. Local and global annually averaged lifetimes for the (E)- and (Z)-R-316c isomers were calculated, using a two-dimensional atmospheric model, to be 74.6 ± 3 and 114.1 ± 10 years, respectively. Ozone-depletion potentials for (E)- and (Z)-R-316c were calculated using the two-dimensional model, to be relatively high, 0.46 and 0.54, respectively. 100-year time-horizon GWPs of 4160 and 5400 were obtained for (E)- and (Z)-R-316c, respectively. This work showed that both isomers of R-316c are potentially environmentally harmful long-lived ozone depleting substances and potent greenhouse gases (Papadimitriou et al. 2014).
- c) **CFCl₃ (CFC-11)** is the most abundant chlorofluorocarbon (CFC) currently present in the atmosphere and is both an ozone-depleting and a potent greenhouse gas that is removed primarily via UV photolysis in the stratosphere. Modeling stratospheric ozone recovery and climate change requires a thorough understanding of the loss processes (i.e., lifetimes) of CFCs and CFC-11 in particular. In this study, the CFC-11 UV absorption spectrum was measured over a range of wavelength (184.95–230 nm) and temperature (216–296 K) to reduce the uncertainty in its stratospheric photolysis rate. Results include a UV spectrum temperature dependence less than that currently recommended for use in atmospheric models and a lifetime uncertainty that is significantly reduced from that obtained using current UV spectrum recommendations (McGillen et al. 2013).
- d) **Methyl-perfluoroheptene-ethers** (CH₃OC₇F₁₃, MPHE) is a proposed substitute for perfluorinated alkanes, which are persistent greenhouse gases, for use in heat transfer applications. MPHE is not an ozone-depleting substance, but likely is a potent greenhouse gas. Rate coefficients at 296 K for the gas-phase reaction of the OH radical with six key isomers (including stereoisomers and enantiomers) of MPHEs and infrared spectra were measured in this study to evaluate their potential environmental impact. The results from this work were used to estimate atmospheric lifetimes (ranged from days to months), radiative efficiencies, and GWPs of the MPHE isomers. This study highlights the importance of quantifying the atmospheric impact of the individual components in an isomeric mixture (Jubb et al. 2014).

CSD-06: Aerosol Formation, Composition, Properties, and Interactions with Clouds

■ CIRES Lead: Allison McComiskey ■ NOAA Lead: Dan Murphy

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.

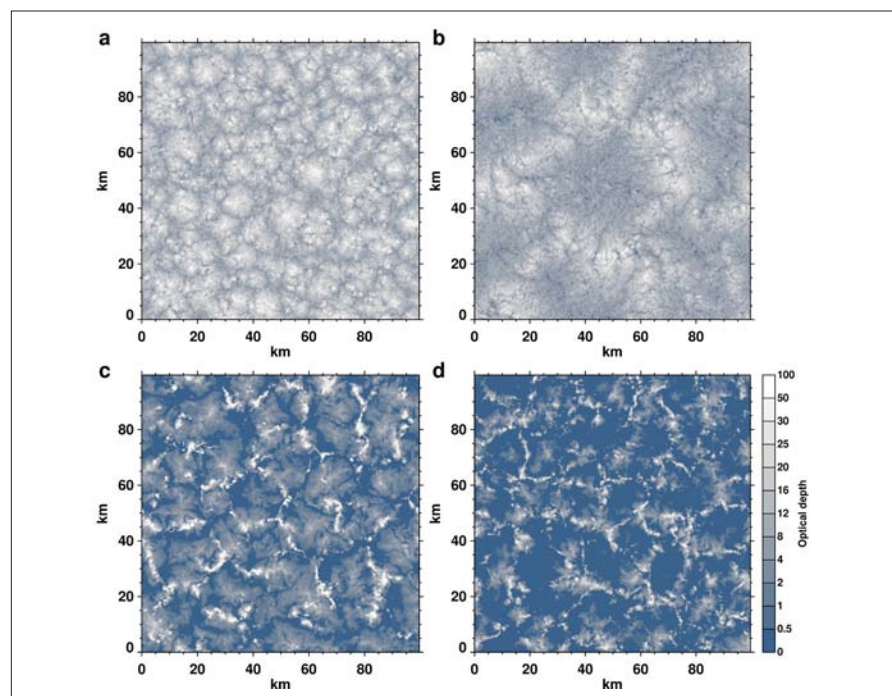
Accomplishments:

During the past year, our team advanced scientific understanding of aerosol impacts on climate through instrument development, laboratory and field work, and modeling at a range of scales. Understanding aerosol sources and their radiative influences requires quantification of chemical composition. The interaction of biogenic organic compounds, and anthropogenically produced sulfate can result in a wide range of aerosol mass, optical, and cloud nucleating properties and thus a range of aerosol radiative forcing on climate. We developed a novel, broadband instrument (360–420 nm) to measure aerosol extinction and hygroscopicity, and we used it in the laboratory to show that absorbing aerosol formed from the reaction of biogenic alkenes with ozone and aged with ammonia at high concentrations. The instrument was also deployed to the U.S. Southeast and used to determine how sulphur dioxide reductions, mandated by the 1990 Clean Air Act amendments, have improved visibility by reducing aerosol mass and aerosol water uptake. Other measurements made in this region focused on the vertical profile of aerosol properties and composition, emissions from small agricultural fires, and factors controlling aerosol optical depth. The abundance and sources of individual organosulfate compounds in atmospheric aerosol have been quantified over several airborne field campaigns. Finally, exploratory model studies supported by cloud measurements show that the formation of secondary organic aerosol (SOA) in clouds is surface-controlled due to oxidant limitation, which will have consequences for parameterizations of cloud SOA formation in climate models.

We continue to develop instruments to support more accurate quantifications of aerosol optical properties. The team designed an Open-Path Cavity Ringdown Aerosol Extinction Spectrometer (OPCRD) to measure aerosol extinction at ambient relative humidity, particularly near clouds where relative humidity is high. During the reporting period, this instrument was successfully tested in a proof-of-concept configuration in the laboratory and installed on the Boulder Atmospheric Observatory tower. We are designing a simple monitoring instrument with a photoacoustic absorption measurement and cavity ringdown extinction measurement, and we are exploring methods for

increasing the sensitivity of our photoacoustic aircraft instrument by optimizing the optical cavity and the acoustic resonator.

Climate models have difficulty representing boundary layer stratocumulus; at the same time these clouds have strong influence on climate sensitivity. Through modeling studies, our team has investigated the drivers of variability in stratocumulus and the relative roles of aerosol and dynamics in a changing climate. Closed cellular circulation capped by stratocumulus clouds with low aerosol loading has been suggested to transform into open cellular circulation with hexagonally arranged shallow cumulus clouds via dynamical feedback associated with outflow produced by precipitation. However, we found that precipitation is not sufficient to trigger the dynamical feedback. The mechanisms responsible for the temporal evolution and spatial distribution of the surface heat fluxes in the closed- and open-cell state (figure below) have also been investigated. In the closed-cell state, the entrainment of dry free-tropospheric air into



Cloud optical depth for various model simulations representing different mechanisms that produce open- and closed-cell stratocumulus states (Kazil et al., 2014).

the boundary layer is implicated, and in the open-cell state, the responsible mechanism is the periodic formation of clouds, rain, and cold and moist pools with elevated wind speed. The response of marine low cloud properties to (large scale) wind speed through its effect on surface fluxes of heat, moisture, and sea spray aerosol has been shown for the first time. Global observations show increases in wind speeds of at least 5-10 percent above 1991-2008, depending on region, and climate simulations project ocean surface wind speed trends for the 21st century in the range of -10 to 10 percent at the locations of large marine stratocumulus decks.

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

■ CIRES Lead: Joshua Schwarz ■ NOAA Lead: Ru-Shan Gao

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:

We prepared a manuscript describing a black carbon (BC) climatology based on data collected in remote regions during 2009-2011, with comparison to global models; the manuscript was published in *Geophysical Research Letters*. We also prepared a manuscript describing the use of a new inlet for sampling interstitial BC within clouds; this was published in *Aerosol Science & Technology*.

In May-July 2013, we deployed a Single Particle Soot Photometer (SP2) on the NOAA WP-3D research aircraft during the Southeast Nexus (SENEX) campaign, acquiring data on BC mass concentration, size distribution, and degree of internal mixing. We were able to make some interesting observations linking power plant emissions of sulphur dioxide to trends in internal mixing state of BC particles. The data were finalized and reported to the SENEX community.

Following SENEX, the SP2 was reconfigured with an additional humidified SP2 for the NASA Studies of Emissions and Atmospheric Composition, Clouds, and Climate Coupling by Regional Surveys (SEAC⁴RS) campaign on the NASA DC8. A month-long collaboration with guest scientist Sho Ohata, University of Tokyo, helped improve data quality. These measurements constrain water uptake by materials internally mixed with BC and hence constrain rates of aging and the fate of BC from different sources.

Of particular interest are trends in water uptake by BC-containing particles in evolving biomass-burning plumes.

A Wideband Integrated Bioaerosol Sensor (WIBS) was acquired in spring of 2013 and used in laboratory and field studies throughout the year. In collaboration with University of Colorado Boulder (CU-Boulder) professor Mark Hernandez, we measured bioaerosol from known fungal populations, supporting the development of a library of known biological materials. Funded by a CIRES Innovative Research Proposal (page 64), we deployed the WIBS on the Boulder Atmospheric Observatory tower for four months in conjunction with filter sampling by CIRES Fellow and CU-Boulder professor Noah Fierer and his group. These data constrain bioaerosol loadings with bacterial and fungal speciation in the Front Range during the transition from fall to winter. Our expertise in WIBS operation/deployment was applied to a blimp mission

that transited the southern United States from Florida to California in the autumn of 2013. The data provide needed context and quantification of bioaerosol loadings and fluorescent signatures.

We are developing a printed optical particle spectrometer (POPS) instrument to provide a low-cost,

lightweight, low-power measurement suitable for small Unmanned Aerial Vehicles (UAVs) and balloon deployments. During the reporting period, we achieved several milestones, including the construction of a working prototype, production of multiple copies, demonstration of full functionality in laboratory conditions, and deployment on a Manta UAV.

We deployed the NOAA ozone instrument O_3-2 on the NASA ER-2 aircraft for the SEAC⁴RS mission. The instrument obtained high-resolution data in the upper troposphere and lower stratosphere that reflect transport and other processes related to the North American monsoon. The data were finalized and presented to the SEAC⁴RS science team.

The recently developed NOAA Water instrument was deployed on the NASA Global Hawk unmanned aircraft as part of the third installment of the NASA Airborne Tropical Tropopause Experiment (ATTREX) campaign in January-March 2014. Science flights from Guam provided extended sampling of the cold western Pacific tropopause region. The measurements of H_2O vapor and cirrus cloud ice water content in the tropical tropopause layer (TTL) constrain our understanding of the microphysical processes of dehydration of air transported to the stratosphere through this important gateway region. The high spatial and temporal resolution in situ data can be compared with larger scale model- and satellite-derived values to investigate the role of small scale processes in TTL dehydration.

We published a manuscript describing the development of a chemical ionization mass spectrometric (CIMS) technique for measuring low mixing ratios of H_2O and the deployment of the NOAA CIMS H_2O instrument on the NASA WB-57F aircraft during NASA's Mid-latitude Airborne Cirrus Properties Experiment (MACPEX) campaign in *Atmospheric Measurement Techniques* in June 2013. A manuscript describing the intercomparison of the water vapor measurements made by multiple instruments during MACPEX was published in the *Journal of Geophysical Research* in February 2014.



Anne Perring (CIRES) at the Boulder Atmospheric Observatory, where she led a study of Front Range bio-aerosols from October 2013 to January 2014.

Photo credit: David Fahey/
NOAA

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

■ CIRES Lead: Anne Jefferson ■ NOAA Lead: John Ogren

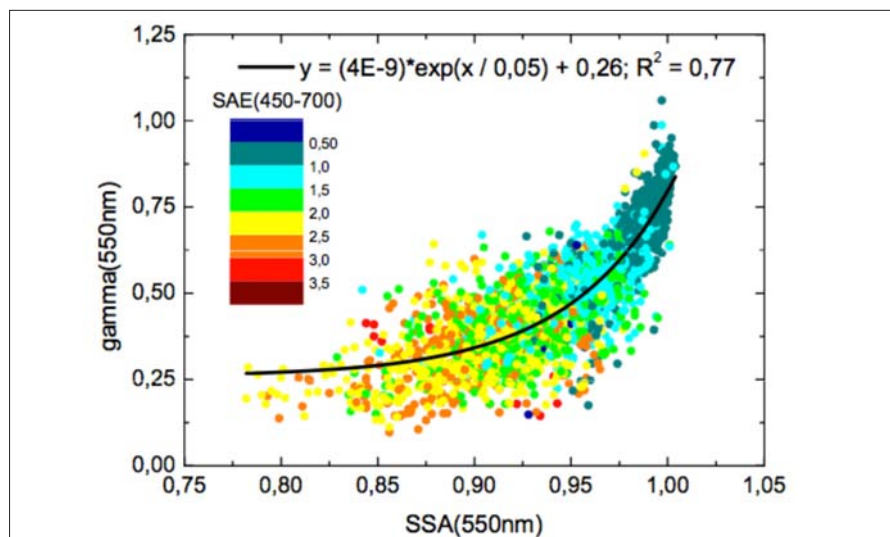
NOAA Theme: Climate Adaptation and Mitigation

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:

We deployed the Aerosol Observing System (AOS) to a Department of Energy site in Amazonia, Brazil as part of the Go-Amazon field campaign in December 2013. The first Intensive Operations Period (IOP), which involved aircraft and surface measurements, took place in February of 2014 and the second IOP is scheduled for September 2014. The goal of the campaign is to examine the role of biogenic and pollution emissions on aerosol and cloud formation in and around the Amazon rainforest near Manaus. Specifically, we will



Aerosol scattering hygroscopic growth fit parameter (γ) in PM_{10} . The color code corresponds to the scattering Angstrom exponent in PM_{10} . An exponential fitting has been added to the plot (black line).

study the environmental impact of urban growth on tropical rainforests. Preliminary results from the AOS show that the aerosol becomes darker with increased loading such that in calculations of direct radiative forcing, the aerosol becomes more warming with higher emissions. There was a strong diurnal signal in the aerosol size, coincident with larger particles being scavenged during afternoon rains.

Long-term measurements from surface monitoring networks provide spatial and temporal variability and trends in aerosol optical properties needed for radiative forcing calculations. Data from four North American surface observatories were analyzed for long-term, seasonal, and diurnal trends and covariance between aerosol properties. At two of the longer-term sites, aerosol scattering and absorption coefficients declined over a 16-year period, coinciding with a reduction in pollution emissions. Aerosol size distributions shifted in this time period to larger sizes, indicating a reduction in sub micron compared to coarse mode aerosol. The manuscript is in preparation and will be submitted in the summer of 2014.

The enhanced scattering from aerosol hygroscopic growth was studied for a surface site in Cape Cod, Massachusetts. A simple model parameterizing the aerosol hygroscopic growth with the aerosol single scatter albedo (scattering to extinction ratio) was developed for the mixed marine/pollution aerosol. Aerosol hygroscopic growth was found to co-vary in with the single scatter albedo in an exponential fit. The paper was accepted for publication in *Atmospheric Chemistry and Physics*. A second paper is in preparation that extends the analysis to include data from eight more measurement sites. The figure at left shows the data and fit equation of the hygroscopic growth fit parameter, γ , to the single scatter albedo. Colors represent different aerosol Angstrom exponents or varying aerosol size. Larger, sea salt particles exhibited higher single scatter albedos and hygroscopic growth.

GMD-04: Studies of Greenhouse Gas Trends and Distributions

■ CIRES Lead: John B. Miller ■ NOAA Lead: Pieter P. Tans

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 continued to determine changes in global abundances for all major long-lived greenhouse gases for

2013 and calculated their influence on radiative forcing. These data are available at <http://www.esrl.noaa.gov/gmd/aggi/>.

We published online two versions of the CarbonTracker data assimilation system, for CO₂ and CH₄, with all source material and results available for public download: <http://carbontracker.noaa.gov>. We published a paper describing the CarbonTracker-CH₄ analysis in *Atmospheric Chemistry and Physics*.

We also recently published the GlobalView-CO₂ 2013 data product. It is available for public download at <http://www.esrl.noaa.gov/gmd/ccgg/globalview/>. This multi-institution international collection of CO₂ observations is the most widely used data product for analyzing changes in global atmospheric CO₂.

We also participated in and led numerous field campaigns to measure greenhouse gas concentrations and emissions at local and regional scales. Ongoing and completed campaigns include: a) Uintah Basin, Utah; Front Range, Colorado; and Barnett, Texas oil and gas production emission studies; b) The Carbon in Arctic Reservoirs Vulnerability Experiment (CARVE), studying CO₂ and CH₄ fluxes over the entire state of Alaska; and c) the Indianapolis Flux Experiment (INFLUX), which aims to determine natural and anthropogenic CO₂ and CH₄ emissions for the city of Indianapolis.

Additional projects include validation of ground and space-based remote sensing of CO₂ and CH₄ using the AirCore sampler and light aircraft in both North and South America.

PSD-02: Diagnosis of Climate Forcing by Ocean Surface Temperatures

■ CIRES Lead: Prashant Sardeshmukh ■ NOAA Lead: Randall Dole

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:

We published a study of 20th century changes in the tropical Pacific Walker Circulation (PWC) using a combination of observational data sets, coupled climate model simulations (Coupled Model Intercomparison Project Phase 5, CMIP5), and additional uncoupled atmospheric model simulations of our own with prescribed observed sea surface temperatures (SSTs) as lower boundary conditions. The CMIP5 simulations show a slight weakening of the PWC over the century, in contrast to a strengthening in the uncoupled simulations and also in the observational 20th reanalysis (20CR) data set. We showed that these results are direct consequences of a weakening zonal SST gradient in the CMIP5 simulations and a strengthening gradient in the uncoupled simulations and observations. We provided further clarification by performing additional uncoupled simulations in which the El Niño Southern Oscillation (ENSO) unrelated and ENSO-related portions of the observed SST changes were prescribed separately as lower boundary conditions. Consistent with the strong role of the zonal SST gradient, the PWC strengthened in the simulations with the ENSO-unrelated SST forcing, which has a strengthening zonal SST gradient. Overall, our results suggest that the PWC strengthened during 20th century global warming, but also that this strengthening was partly masked by a weakening trend associated with ENSO-related PWC variability. We also demonstrated that such a strengthening of a regional overturning atmospheric circulation is not inconsistent with global energy balance constraints associated with global warming.

Publication:

Sandeep, S, F Stordal, PD Sardeshmukh, and GP Compo. 2014. Pacific Walker Circulation variability in coupled and uncoupled models. *Clim. Dynam.* doi: <http://dx.doi.org/10.1007/s00382-014-2135-3>.

Earth System Dynamics, Variability, and Change

GIP-01: Environmental Software Infrastructure and Interoperability Program

■ CIRES Lead: Cecelia DeLuca ■ NOAA Lead: Wade Blake

NOAA Theme: Science and Technology Enterprise

Goals & Objectives:

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

Accomplishments:

This project develops the Earth System Modeling Framework (ESMF), the leading software for building and coupling U.S. climate and weather models. Improvements made in the past year include enhanced grid remapping capabilities and new component-level features such as fault tolerance. We updated the Python version of the software to a new package called ESMPy (Earth System Modeling Python), which is more object-oriented and easier to use. There have been about 5,500 downloads of the ESMF/ESMPy software.

Our team is implementing the National Unified Operational Prediction Capability (NUOPC) layer in collaboration with U.S. weather prediction centers and their research partners. NUOPC simplifies the ESMF interface and increases the interoperability of ESMF applications. This year, our team completed a broad public release of the NUOPC Layer, with many improvements including a “component explorer” that can be used to analyze a component’s compliance status.

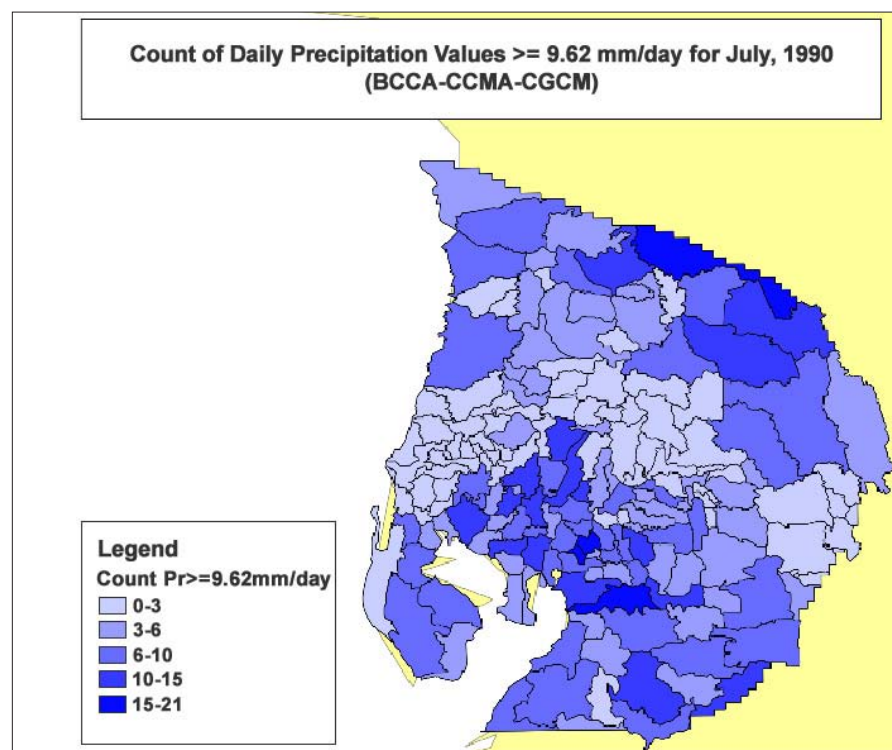
The Earth System Prediction Suite (ESPS) is a set of modeling applications that use ESMF with the NUOPC conventions. Working with partners, our team delivered prototype versions of several coupled applications, including the NOAA Environmental Modeling System (NEMS), the Community Earth System Model (CESM) coupled to the Hybrid Coordinate Ocean Model (HYCOM Ocean), and a NUOPC version of the coupled Model E at the NASA Goddard Institute for Space Studies.

Cupid is a NASA-funded development environment for ESMF-based model code. It parses the model software, displays its component structure, and can generate code needed for NUOPC compliance. The resulting code can be compiled through the Cupid interface and executed locally or on Amazon Web Services. Our team developed an initial prototype and a tutorial. The first public release is expected in early 2015.

Coupled models increasingly span disciplines that have their own native infrastructure, and it has become important to link multiple frameworks. This requires a more formal taxonomy of framework design and implementation choices than has been available. With National Science Foundation (NSF) funding, our team began develop-

ment of an Earth System Description Language (ES-FDL) with European Union collaborators. This is an ontology that describes frameworks. It can be used to understand and compare frameworks, and what the options are for connecting them.

Our project leads development of the Earth System CoG, a NSF-funded Web environment that connects projects to each other and data and metadata services. In the past year, the Earth System Grid Federation (ESGF) and CoG agreed to merge their software, so that CoG will form the front end of the international ESGF data distri-



An example map output from OpenClimateGIS. Here, researchers wanted to understand whether a downscaled climate model did a reasonable job representing the frequency of heavy rain events in Tampa Bay, Florida, watersheds in summertime. This map shows the frequency of rainfalls above the top 10 percent, historically, for the region, in a given month and year. More: <http://cires.colorado.edu/news/press/2014/climateGIS.html>

bution facility. CoG is expected to host the Coupled Model Intercomparison Project (CMIP) phase6 model intercomparison projects and currently hosts about 70 other projects and 400 users. A new project this year is the High Impact Weather Prediction Project (HIWPP), an intercomparison project focused on next generation operational weather prediction.

Earth System Documentation (ES-DOC) is an international collaboration that is developing model metadata and tools for its display, generation, and comparison. This year, our team led development of a questionnaire for collecting model metadata that follows the Common Information Model (CIM) conventions developed for Intergovernmental Panel on Climate Change coupled model experiments.

OpenClimateGIS is a Python library for subsetting, reformatting, and performing computations on climate data. We are currently distributing this software as a beta version, readying it for broader public distribution next year.

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

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:

To more cleanly separate radiatively forced versus natural climate variations during the last century, we completed a study using three distinct types of observational and model simulation data sets for the period 1874-2010:

- 1) **20CR:** A 56-member ensemble of global atmospheric reanalyses at six-hour resolution: the 20th Century Reanalysis (20CR) data set, produced by an international team led by CIRES and NOAA ESRL Physical Sciences Division scientists.
- 2) **AMIP20C:** A 56-member ensemble of uncoupled atmospheric global climate model (GCM) simulations of 1874-2010. We generated the AMIP20C (Atmospheric Model Intercomparison) data using the same National Centers for Environmental Prediction Atmospheric GCM used to produce the 20CRv2 data set, and with identical specifications of time-varying sea surface temperature, sea ice, and radiative forcings.

- 3) **CMIP5:** A multi-model ensemble of 62 coupled climate model simulations (Coupled Model Intercomparison Project Phase 5, CMIP5) of 1874-2010, with observed radiative forcings.

We interpret the long-term variability in the observational 20CR 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 sea surface temperature (SST) variations; and the variability of the multi-model mean responses in the CMIP5 simulations as responses to the radiative-forcing variations.

The most important result from this study is that the observed trends in many circulation variables over the second half (1943-2010) of the record are much weaker or non-existent when examined over the full record (1874-2010). This applies to changes in both the mean near-surface circulation and storminess. The changes in the storminess—measured in terms of changes in the daily root mean squared tendency of sea-level pressure—are especially weak over much of the globe, except at the Southern Hemisphere high latitudes, and are also generally not consistent among our three types of data sets.

PSD-06: Diagnosis and Prediction of Subseasonal Climate Variations

■ CIRES Lead: Prashant Sardeshmukh ■ NOAA Lead: Randall Dole

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:

We recently completed a study that significantly revises the current paradigm of atmospheric equatorial wave dynamics and the Madden-Julian Oscillation (MJO) as free wavelike perturbations to a resting base state that are modified by coupling to tropical convection. The main revision is that the discrepancies between the observed and theoretical Matsuno-Gill equatorial waves are not primarily due to “convective coupling,” but rather due to the spatially varying base state. Convective coupling does affect relatively low frequency waves and the MJO, but the effect is secondary to that of the spatially varying base state even in those cases. These conclusions were derived through an extensive linear inverse modeling (LIM) analysis of tropical atmospheric variations using 30 years of ERA-Interim reanalysis data.

PSD-07: Sensor and Technique Development

■ CIRES Lead: Andrey Grachev ■ NOAA Lead: Chris Fairall

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:

We conducted the High Wind Gas Exchange Experiment (HIWINGS) cruise in the fall of 2013, aboard *research vessel Knorr* (photo below). The cruise was successful and flux data were obtained in two legs: In the Davis Strait and south of the tip of Greenland. Observations were obtained in wind speeds up to 28 meters per second. Archived data are available at ftp://ftp1.esrl.noaa.gov/psd3/cruises/HIWINGS_2013/Knorr/.

We installed the NOAA ESRL Physical Sciences Division W-band radar on the NOAA WP-3D in July 2013, and performed several test flights. Results were analyzed and a short report was written. The radar was deployed on one day during tropical storm Karen. The data were analyzed to infer profiles of sea spray up to 300 m above the ocean. The results were published in *Geophysical Research Letters* (Fairall et al 2014).



Byron Blomquist (University of Hawaii), CIRES' Ludovic Bariteau, Ming-Xi Yang (Plymouth Marine Laboratory), and Amy Simoneau (Woods Hole Oceanographic Institution) on the deck of the *research vessel Knorr* during the High Wind Gas Exchange Experiment (HIWINGS) cruise in the fall of 2013. The researchers are assembled around an instrument package that takes seawater profiles of temperature, pressure, salinity, and density. Photo credit: Claudia María Bagge-Petersen

Publication:

Fairall, CW, S Pezoa, K Moran, and D Wolfe. 2014. An observation of sea spray microphysics by airborne Doppler radar. *Geophys. Res. Lett.* 41. 10.1002/2014GL060062.

PSD-08: Clouds, Aerosols, and Water Vapor Observations and Research

■ CIRES Lead: Matthew Shupe ■ NOAA Lead: Taneil Uttal

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:

CIRES researchers continue to analyze observations from Arctic field stations, both land- and ocean-based, to characterize and understand Arctic cloud processes. A major focus for our group has been the Arctic Summer Cloud Ocean Study (ASCOS, Tjernström et al. 2014) from 2008, which offers a wealth of observations for a number of applications. We have put specific focus on low-level clouds and their role in atmospheric mixing processes (Shupe et al. 2013, Sedlar and Shupe 2014, Sotiropoulou et al. 2014). Beyond ASCOS, CIRES researchers are engaged in many ongoing analyses using observations from ground stations. We have assembled a multiyear analysis of cloud microphysical properties at Eureka, Canada (Cox et al. 2014a), revealing properties that are statistically different from those found at other Arctic stations. Other ongoing studies are examining the relationship between measurements of aerosol properties near the surface with cloud properties aloft, using estimates of vertical mixing processes within the atmosphere.

In support of these observational activities, CIRES researchers promote the development of observational tools and methods for a variety of applications. For example, we have developed a cloud and aerosol lidar and operated it in the field for more than three years, providing insight into cloud properties and ice particle orientation (Neely et al. 2013). Additionally, we have examined detailed scanning radar measurements of precipitating cloud systems to understand how oriented ice crystals affect radar signals as a function of observing angle (Marchand et al. 2013). We have written a paper that highlights the information content available from unmanned aircraft-based dropsonde measurements in the Arctic made from the Global Hawk, a NASA unmanned aircraft. These data were used to provide detailed insight into the boundary layer structure, characterize the dynamics and thermodynamics of the Polar Vortex, and evaluate model products (Intrieri et al. 2014), for example. Finally, CIRES researchers have been engaged in cloud retrievals for many years and have written an overview paper on how the

Department of Energy-funded research has contributed to cloud retrievals during the past 15 years (Shupe et al. 2014).

In addition to these observational efforts, CIRES scientists are engaged in numerous modeling activities related to Arctic clouds and atmospheric structure. We used idealized large-eddy simulations to investigate the relative impact of cloud-top and sub-cloud sources of moisture on cloud microphysical-radiative-dynamical feedbacks in Arctic mixed-phase clouds (Solomon et al. 2014). We also used a cloud-resolving model to demonstrate that changes in cloud condensation nuclei have a reduced impact on precipitation from cold clouds (i.e., ice) relative to warm clouds (Kravitz et al. 2014). CIRES researchers used some of these same modeling tools to participate in a highly-constrained model intercomparison of a cloud case occurring near Barrow, Alaska, demonstrating the importance of accurately representing the ice particle size distribution in mixed-phase clouds (Ovchinnikov et al. 2014). We used ASCOS observations to evaluate multiple global climate models and reanalysis products. We found that while basic meteorological variations are well captured, properties related to clouds, moisture, and radiation continue to have significant issues (de Boer et al. 2014, Wesslen et al. 2014). Reanalysis-derived radiation was compared in more detail with surface-based observations at Summit, Greenland using a wavelet analysis to identify how the reanalysis performs as a function of temporal scales-of-variability (Cox et al. 2014b). Lastly, we used the NOAA 20th Century Reanalysis to compare conditions for major melt events over the Greenland Ice Sheet that occurred in 2012 and 1889, finding remarkably consistent circumstances (Neff et al. 2014).



Researchers atop Arctic sea ice will measure cloud and atmosphere properties by using a tethered balloon during the Arctic Summer Cloud Ocean Study.

Photo credit: Matthew Shupe/CIRES

PSD-09: Air-Sea Interactions

■ CIRES Lead: Andrey Grachev ■ NOAA Lead: Jian-Wen Bao

NOAA Theme: Science and Technology Enterprise

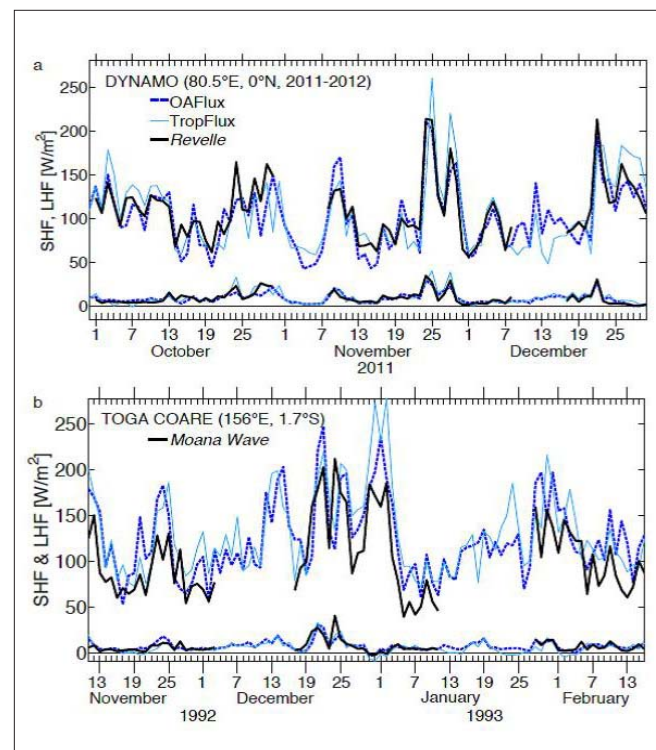
Goals & Objectives:

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:

We obtained new observations by ship during two cruises: the Woods Hole Oceanographic Institute Hawaii Ocean Time-series Station (WHOTS) and High Wind Gas Exchange Experiment (HIWINGS). We also deployed the W-band radar on the German ship *Polarstern* in Cape Town, South Africa. The system captured data during the transit to Bremerhaven, Germany.

We continue to analyze data collected during Dynamics of the Madden-Julian



TropFlux and OAF flux gridded flux products compared with ship observations a) from the Revelle for DYNAMO in 2011 and b) from the Moana Wave for TOGA COARE in 1992-1993 (De Szoek et al. 2014).

Oscillation (DYNAMO), on several fronts. We submitted two articles (see publications below) about air-sea interaction, and we continue to analyze cloud radar to better understand cloud microphysics.

We also focused on implementing and testing the NOAA ESRL sea-spray scheme into the HWRF/GFDL-WW3-POM system (Hurricane-Weather Research and Forecasting model/ Geophysical Fluid Dynamics Laboratory-Wave Watch 3-Princeton Ocean Model). During this implementation work, the National Centers for Environmental Prediction Environmental Modeling Center decided to switch to a new coupler in HWRF, which created some additional technical complications for us to work on. There were three stages in the implementation. First, we tested the sea-spray scheme in the one-way coupler in which the nine-kilometer version of the HWRF/GFDL model was coupled with the WW3 model. In the one-way coupling, the WW3 model was forced by HWRF/GFDL winds at every WW3 time step, but there is no momentum feedback from the WW3 model to HWRF. Second, after the most updated air-sea coupler in the HWRF model was fully tested based on the National Oceanographic Partnership Program development mentioned in the previous year's report, the sea-spray scheme was further tested in the two-way HWRF/GFDL-WW3 coupled system. Now, we are in the third stage of evaluating the performance of the sea-spray scheme in the latest HWRF/GFDL-WW3-POM/HYCOM coupled system.

Publications:

Moum, JA, SP de Szoeke, WD Smyth, JB Edson, HL DeWitt, AJ Moulin, EJ Thompson, CJ Zappa, SA Rutledge, RH Johnson, and CW Fairall. 2014. Air-sea interactions from westerly wind bursts during the November 2011 MJO in the Indian Ocean. *Bull. Am. Meteor. Soc.* To appear.

De Szoeke, SP, JB Edson, JR Marion, CW Fairall, and L Bariteau. 2014. The MJO and air-sea interaction in TOGA COARE and DYNAMO. *J. Clim.* Submitted.

PSD-10: Physical Processes Controlling the Arctic Surface Energy Budget

■ CIRES Lead: Ola Persson ■ NOAA Lead: Janet Intrieri

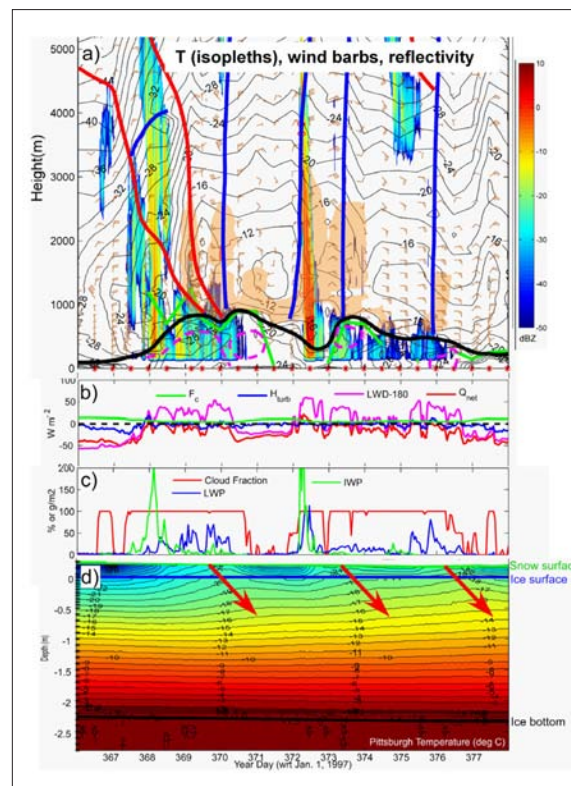
NOAA Theme: Science and Technology Enterprise

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:

Research. We used a multi-pronged collaborative approach to understand interactions between clouds, the atmospheric boundary layer, and surface processes in the Arctic, especially over Arctic sea ice. An early January case from the Surface Heat Budget of the Arctic Ocean (SHEBA) mission demonstrated and quantified the importance of long-distance moisture transport for the existence of supercooled liquid water and significant longwave radiative impacts on the sea-ice surface and the internal ice temperature.



Observations of the synoptic evolution in the lowest 5 km at the SHEBA site for Jan. 1-12, 1998. Shown are a) isotherms, b) energy budget terms, c) cloud fraction, liquid water path, and ice water path, and d) isotherms in the surface snow and the sea ice. A full caption is available in Persson et al., 2013.

We conducted additional analysis of this case to a) understand what may control cloud liquid water in the very tenuous Arctic winter clouds, especially the possible link of water vapor to cloud liquid water; and b) understand confusing model sensitivity to microphysical parameterization resulting in contradictory microphysical and surface radiative sensitivities. We are incorporating these analyses into a manuscript that is nearly ready for submission. Other collaborative research performed for this project (and related grant projects led by other members of our collaborative team) includes analysis of cloud sensitivity to water vapor sources in idealized large eddy simulations (LES) cloud simulations; the evaluation of climate models and reanalysis products over the Arctic sea ice using process diagnostics from the Arctic Summer Cloud Ocean Study (ASCOS) data set; and the observational analysis of vertical mixing and cloud-surface coupling processes also using the ASCOS data set. We began an idealized LES modeling study to examine the impact of large areas of thin ice on wintertime surface energy fluxes, focusing on the contribution of fluxes from the generated mesoscale circulations.

During the autumn of 2013, a small group of scientists from the National Center for Atmospheric Research, the University of Stockholm, CIRES, and other institutions held several meetings to discuss the magnitude of Arctic energy fluxes and budget terms, and the degree to which these are known. Comparing the magnitudes of these terms from the literature reveals problems: the lack of estimates of many terms, a large range of values of terms with estimated terms, the lack of direct measurements of these terms, and the significant difference between existing measurements and estimates from model-based products, such as reanalyses. The group felt it was necessary to carefully examine how these magnitudes were obtained and to estimate error bars. These discussions have produced an improved Arctic energy budget diagram, which is very useful for understanding cloud-atmosphere-surface interactions and the relative importance of the various processes. We expect that further discussions will eventually lead to a publication.

We began making calculations on the surface energy budget at Barrow, Alaska, as part of the National Science Foundation Study of Environmental Arctic Change (SEARCH) grant. This work includes calculating long-term bulk turbulent fluxes and comparing these to recently available covariance fluxes. We designed, but have not yet implemented, a technique to improve editing of wintertime radiative flux measurements. We conducted a surface energy budget analysis for a 2004 Mixed-Phase Arctic Cloud Experiment (MPACE) case. In a focused study, we compared ground energy fluxes estimated from the temporal evolution of soil temperature profiles with surface flux plates at the Eureka site; and we presented results at the fall American Geophysical Union meeting. A poster describing the surface energy fluxes at these terrestrial sites was presented at the European Geophysical Union conference in Vienna.

Field program planning and proposals. The National Science Foundation (NSF) declined to fund our proposal to examine cross-ice edge variability of surface energy fluxes, boundary-layer structure, and cloud structure during the Arctic Clouds in Summer Expedition (ACSE) field program on the Swedish *research vessel Oden*, which began in June 2014. However, because the success of this international measurement effort depended on our participation, funding sources in Sweden became available and we were able to successfully obtain sufficient funds for the field program. ACSE will obtain unique atmospheric and surface in situ and remote sensing data in the marginal ice zone north of Siberia during the summer and autumn of 2014.

The study of key atmosphere-ice-ocean interaction processes near the ice edge, especially the role of waves in ice breakup and formation, is also an objective of the 2015 Office of Naval Research (ONR) Sea State autumn field program. Moreover, we have coordinated with Japanese colleagues to place NOAA ESRL Physical Sciences Division surface flux instrumentation on the Japanese ship *Mirai* near the ice edge in autumn 2014. We participated in planning meetings for ACSE and Sea State, and wrote NSF and NOAA proposals that would fund various analyses of these and other data sets. The NOAA proposal was funded in June 2014; the NSF proposal is still pending.

We continued to work on planning for the international Multidisciplinary drifting Obser-



The research vessel Oden in the Arctic in 2008. Photo credit: Paul Johnston/CIRES

vatory for the Study of Arctic Climate (MOSAiC) field program, primarily on the writing of the science plan and a meeting in Stockholm. MOSAiC has significant surface energy budget components, and the science plan strongly emphasizes the interdisciplinary nature of the processes impacting the energy fluxes to sea ice. In collaboration with Timo Vihma in Finland, we wrote plans and text for a book chapter about the atmospheric boundary layer over sea ice, including surface energy budgets. This chapter will be used in the upcoming third edition of *Sea Ice*, edited by David Thomas. The need for continued improvements in our understanding of the interdisciplinary surface energy flux processes was also emphasized during the NOAA workshop on sea-ice forecasting. Other meetings were held to discuss potentially useful technologies (e.g. hexacopters and deicing energy flux systems).

Publications:

Peer-reviewed

Persson, POG, A Solomon, and M Shupe. 2014. Linking atmospheric synoptic evolution with surface energy fluxes over Arctic sea ice: Observations and modeling of a January case study from SHEBA. *Mon. Wea. Rev.* In preparation.

Persson, POG, and T Vihma. 2015. Chapter 6: The atmosphere over sea ice. In: *Sea Ice*, Third Edition. Edited by DN Thomas. Wiley-Blackwell:London. In preparation.

de Boer, G, MD Shupe, PM Caldwell, SE Bauer, O Persson, JS Boyle, M Kelley, SA Klein, and M Tjernström. 2014. Near-surface meteorology during the Arctic Summer Cloud Ocean Study (ASCOS): Evaluation of reanalyses and global climate models. *Atmos. Chem. Phys.* 14, 427-445. doi:10.5194/acp-14-427-2014.

Tjernström, M, C Leck, C Birch, B Brooks, JI Brooks, L Bäcklin, R Chang, E Granath, M Graus, J Heintzenberg, A Held, A Hind, S de la Rosa Høhn, P Johnston, J Knulst, M Westberg, G de Leeuw, L Di Liberto, M Martin, P Matrai, T Mauritsen, M Müller, S Norris, M Orellana, D Orsini, J Paatero, O Persson, Q Gao, C Rauschenberg, Z Ristovski, J Sedlar, M Shupe, B Sierau, A Sirevaag, S Sjögren, O Stetzer, E Swietlicki, M Szczodrak, P Vaattovaara, N Wahlberg, and C Wheeler. 2012. The Arctic Summer Cloud-Ocean Study (ASCOS): Overview and experimental design. *Atmos. Chem. Phys.* 14:2823-2869. doi:10.5194/acp-14-2823-2014.

Conferences

Persson, O, and A Solomon. 2014. Relative roles of wind forcing and ice dynamics for predicting short-term sea-ice movement as estimated from in situ observations. In: *Geophysical Research Abstracts*. EGU General Assembly 2014; April 27-May 2; Vienna. Vol. 16: EGU2014-16102.

Solomon, A, M Shupe, and O Persson. 2014. The differing impact of local and remote

moisture sources on cloud formation and the surface energy budget at Summit, Greenland. In: *Geophysical Research Abstracts*. EGU General Assembly 2014; April 27-May 2; Vienna. Vol. 16: EGU2014-8033.

Grachev, A, T Uttal, O Persson, R Stone, S Crepinsek, R Albee, A Makshtas, V Kustov, I Repina, and A Artamonov. 2014. Comparison of surface fluxes and boundary-layer measurements at Arctic terrestrial sites. *Geophysical Research Abstracts*, EGU General Assembly 2014; April 27-May 2; Vienna. Vol. 16: EGU2014-9259.

Persson, O, A Solomon, and M Shupe. 2014. Surface energy budget and boundary layer impacts from improving cloud microphysics in Arctic Sc clouds. Poster, DOE Atmospheric System Research PI Meeting; Mar 10-14; Potomac, MD.

PSD-11: Distributions of Raindrop Size

■ CIRES Lead: Christopher Williams ■ NOAA Lead: Rob Cifelli

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:

Rainfall retrieval algorithms often assume a gamma-shaped raindrop size distribution (DSD) with three mathematical parameters: N_w , D_m , and μ . If only two independent measurements are available, as with the dual-frequency precipitation radar (DPR) on the NASA Global Precipitation Mission (GPM) core satellite, then retrieval algorithms are under-constrained and can only estimate two of the three DSD parameters. By analyzing surface disdrometer observations, we identified correlations between the mean D_m and standard deviation S_m of the raindrop mass distribution (Thurai et al. 2014). We then derived relationships that mapped the robust D_m - S_m relationships into D_m - μ relationships, thus reducing the number of free DSD parameters from three to two. The D_m - μ relationship was constructed using two components. The first component is a power-law relationship describing the central, or best-fit, relationship between D_m and μ . And the second component describes the deviations, or error bars, from the best-fit. Together, these two components fit nicely into the probabilistic retrieval algorithm framework used in the NASA GPM satellite program. Probabilistic algorithms require an initial value (aka, first guess) and error bars to allow the algorithm to deviate from this first guess. Details of this analysis are presented in Williams et al. (2014).

In addition to analyzing relationships between DSD parameters, we generated DSD data sets from the Mid-latitude Continental Convective Cloud Experiment (MC3E) and

Tropical Western Pacific—International Cloud Experiment (TWP-ICE), and posted them in NASA, Department of Energy, and NOAA archives. For the NOAA archive, CIRES provided technical support, generating two Web pages hosted through <http://www.esrl.noaa.gov/psd/psd3/boundary/pbl/> (screenshot below). Each Web page includes the project background, links to data and documentation, and sample code to read the netCDF-formatted data. CIRES technical support was reviewed and updated netCDF metadata content to current standards.

Publications:

Thurai, M, CR Williams, and VN Bringi. 2014. Examining the correlations between drop size distribution parameters using data from two side-by-side 2D-video disdrometers. *Atmospheric Res.* 144: 95-110. doi: 10.1016/j.atmosres.2014.01.002.

Williams, CR, VN Bringi, L Carey, V Chandrasekar, P Gatlin, ZS Haddad, R Meneghini, SJ Munchak, SW Nesbitt, WA Petersen, S Tanelli, A Tokay, A Wilson, and D Wolff. 2014. Describing the shape of raindrop size distributions using uncorrelated raindrop mass spectrum parameters. *J. Appl. Meteorol. and Climatol.* 53: 1282-1296. doi: 10.1175/JAMC-D-13-076.1.

Instrument Type	FTP location	Documentation
Surface Meteorology	/surface_met/	PDF
Parsival Disdrometers & Gauges	/parsival_disdrometer/	PDF
S-Band Profiler	/s_band_profiler/	PDF
449-MHz Profiler	/449_mhz_profiler/	PDF
Vertical Air Motion	/omega/	PDF

Screenshot of MC3E data web page (<http://www.esrl.noaa.gov/psd/psd3/boundary/pbl/mc3e/data/>).

PSD-13: Effects of the Tropical Ocean on Weather and Climate

■ CIRES Lead: Leslie Hartten ■ NOAA Lead: Cecile Penland

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:

This year we:

- demonstrated a novel way that wind-profilers can be used to study lower-tropospheric processes in the East Pacific;
- used 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; and
- began newly funded research into the air-sea processes involved in the initial stages of a type of organized convection over the tropical Indian Ocean.

Stratocumulus (Sc) clouds are common over the cold waters of the southeastern Pacific Ocean. Data collected during Pan American Climate Study (PACS) research cruises offer many opportunities to study structural aspects of this Sc-topped marine boundary layer (MBL). During the past year, we strengthened our understanding of gaps in detectable wind-profiler reflectivities, as much as several hundred meters deep and lasting an hour or more, by analyzing data collected during boreal fall cruises in 2000 and 2004. Considering these gaps in terms of the structure-function parameter of the index of refraction, Cn_2 , allows them to be understood as indications of reduced “top-down” buoyancy processes and/or reduced turbulent intensity, both of which have been demonstrated by previous researchers to be associated with decoupling of the Sc-topped MBL. We used ship-based surface observations to obtain a measure of decoupled MBL conditions and compared it with periods with gaps. The results verify that the absence of valid profiler reflectivity in this setting may indicate decoupled conditions (Hartten and Johnston 2014).

The North Atlantic Oscillation (NAO) is a rapidly decorrelating system that strongly affects the climate of the Atlantic Ocean and surrounding continents. Although the NAO itself is basically unpredictable on seasonal timescales, our research during the past two years shows that NAO forcing has a significant impact on north tropical Atlantic (NTA) sea surface temperatures (SSTs) evolving on those timescales. During the past year we

submitted, significantly revised, and resubmitted a manuscript showing that the NAO-generated forcing of SST during boreal winter and spring is responsible for more than half the statistically unpredictable component of SST in the main development region for Atlantic hurricanes during the subsequent summer and fall (Penland and Hartten 2014). Thus, seasonal forecasts of SST in that region might be improved if fast nonlinear NAO dynamics resolved by General Circulation Models could be predicted accurately enough to account for some of what seasonally averaged SSTs “see” as stochastic forcing.

Numerical forecast models have difficulty simulating and forecasting the Madden-Julian Oscillation (MJO), especially in its “initiation” phase over the Indian Ocean, due in part to model deficiencies such as inadequate subgrid parameterizations. During the Dynamics of the MJO (DYNAMO) field campaign (October 2011 to March 2012) a cold pool of air was frequently laid down on the ocean surface during convective rain events. The dramatic changes in air temperature and winds led to large changes in sensible and latent heat fluxes (figure below), but on subgrid scales. Stochastic forcing might be employed in global models to incorporate the effects of these subgrid events, and Linear Inverse Modeling (LIM) can provide an estimate of the stochastic forcing. We have identified the onset of four MJOs during DYNAMO, then applied LIM to a paired index of the MJO (1979–2013) and estimated the stochastic forcing time series during the four events. These very preliminary results suggest that positive convective forcing precedes MJO onset by a week or two, and that this signal may be accompanied by in-phase perturbations of latent heat. We presented our work at two meetings.

Publications:
Peer-reviewed

Hartten, LM, and PE Johnston. 2014. Stratocumulus-topped marine boundary layer

processes revealed by the absence of profiler reflectivity. *J. Appl. Meteor. Climatol.* 53. In press. doi: 10.1175/JAMC-D-12-0308.1.

Penland, C, and LM Hartten. 2014. Stochastic forcing of north tropical Atlantic sea surface temperatures by the North Atlantic Oscillation. *Geophys. Res. Lett.* 41. doi: 10.1002/2014GL059252.

Conferences

Hartten, LM, and PE Johnston. 2014. Using the absence of profiler reflectivity to study stratocumulus-topped marine boundary layer processes. 31st Conference on Hurricanes and Tropical Meteorology. March 30–April 4. San Diego. American Meteorological Society.

Hartten, LM, and C Penland. 2014. Stochastic forcings associated with MJO Initiation during DYNAMO. 31st Conference on Hurricanes and Tropical Meteorology; March 30–April 4. San Diego. American Meteorological Society.

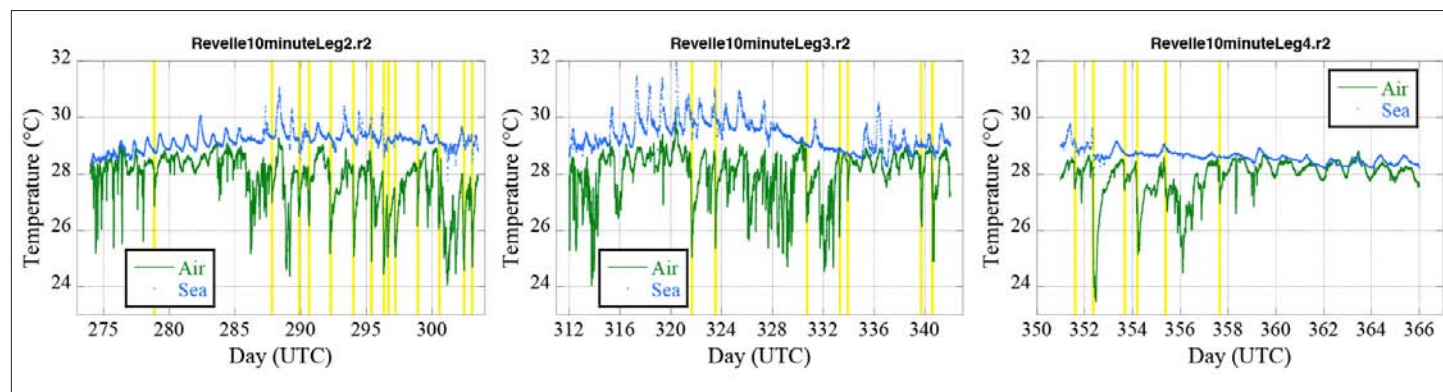
PSD-15: An Assessment of Skill and Reliability of Regional Climate Predictions

■ CIRES Lead: Kathy Pegion ■ NOAA Lead: Robert Webb

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.



Ten-minute air temperature at 10 m and sea surface temperature (SST) measured aboard the research vessel *Revelle* during Leg 2 (left), Leg 3 (center), and Leg 4 (right) of the DYNAMO field campaign. Yellow lines indicate possible atmospheric cold pool events.

Accomplishments:

Below, we present accomplishments in three areas:

Assessment of current skill. We provided a quantitative assessment of the current state-of-the-art skill of seasonal predictions from the National Multi-Model Ensemble (NMME) and National Centers for Environmental Prediction Climate Forecast System, version 2 (NCEP/CFSv2), the operational seasonal prediction model used by NOAA.

This analysis was performed separately for the upper and lower Missouri River Basin (MRB) and for the MRB as a whole. Skill was assessed for the target seasons of Jan-Feb-Mar (JFM) and Apr-May-Jun (AMJ), based on forecasts initialized in December. Three skill metrics were used: correlation, root mean square error (RMSE), and a probabilistic metric such as the Brier Skill Score.

Our results demonstrate that there was no skill in the MRB in predicting precipitation at these lead times as indicated by low correlations, high RMSE, and Brier skill scores worse than using a climatological forecast.

Variations in skill and sources of predictability. The primary source of predictability on monthly/seasonal timescales is the El Niño Southern Oscillation (ENSO). We describe why there is little to no ENSO signal in the Missouri River Basin and demonstrate the skill of the NMME and CFSv2 in predicting precipitation for the phases of ENSO.

Results indicate that the only region with ENSO-related skill is the lower MRB (during El Niño events), which is unfortunate since this is below the lowermost control of the MRB by the U.S. Army Corps of Engineers (USACE).

This analysis will show the skill of precipitation stratified for the warm, cold, and neutral phases of ENSO in the upper, lower, and full Missouri River Basin. Focus will be on the target seasons of JFM, AMJ, and May, and we will assess skill will at lead times of 1-6 months using the NMME and CFSv2, with three skill metrics: correlation, root mean square error, and a probabilistic metric such as the Brier Skill Score.

Report to U.S. Army Corps of Engineers. We provided a draft summary report of these results to the NOAA lead (Robert Webb) on September 4, 2013, which was forwarded to the USACE. It was reported that the USACE was happy with our report. After review by the NOAA lead, some revisions were requested and these changes were made and submitted to the NOAA lead on May 14, 2014.

PSD-16: Understanding and Explaining Role of Extremes in Missouri flooding

■ CIRES Lead: Xiaowei Quan ■ NOAA Lead: Robert Webb

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 informa-



Aerial photo of flooding in Minot, North Dakota. FEMA is supporting the emergency management team in providing disaster assistance to those affected by the flooding. Photo credit: David Valdez/FEMA

tion with others” by providing the credible science that other agencies, state, and local decisions makers, and the private sector require.

Accomplishments:

We provided model output support to NOAA and CIRES scientists for a series of systematic and comprehensive analyses on the cause of the 2011 extreme flood event in the upper Missouri River Basin. Using climate model simulations and historical records of observations since 1898, the research team investigated the potential predictability of such kind of extreme flooding events in that region, assessing the roles of seasonality in local precipitation and land-surface conditions, global ocean surface conditions, and long-term climate change. NOAA and CIRES scientists used the results of our analyses as the core of a special NOAA Climate Assessment Report *Understanding and Explaining Climate Extremes in the Missouri River Basin Associated with the 2011 Flooding* (by Martin Hoerling, Jon Eischeid, and Robin Webb).

PSD-17: Understanding How Tropical SSTs Influence Atmospheric Variability

■ CIRES Lead: Tao Zhang ■ NOAA Lead: Martin Hoerling
 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:

We have made advancements in three key areas this reporting period:

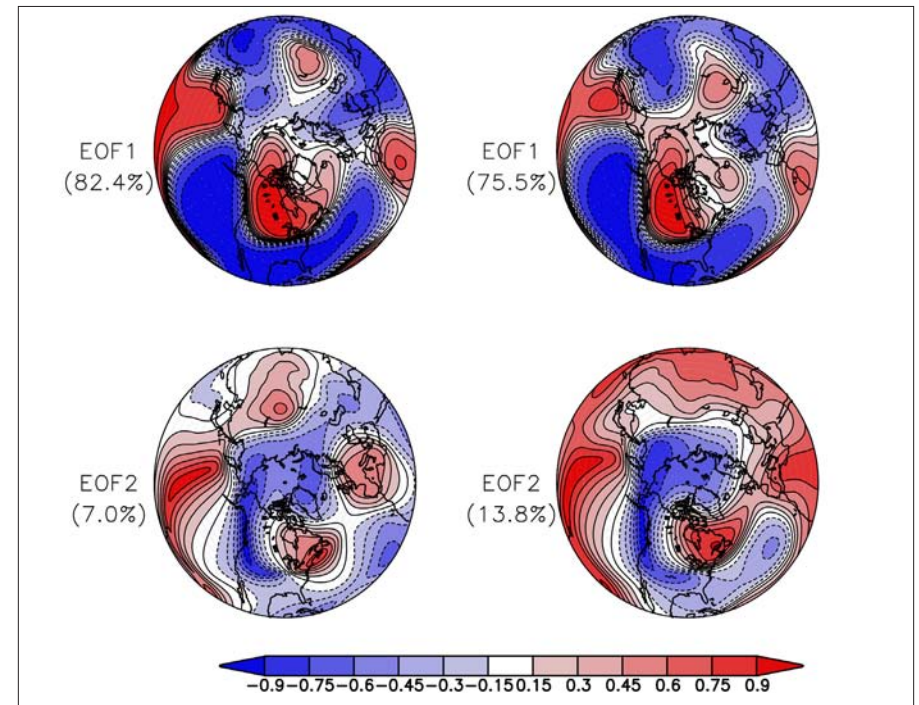
ENSO Teleconnections. We identified a large asymmetric component (El Niño + La Niña) of El Niño–Southern Oscillation (ENSO)-related teleconnections over North America during 1984–2009 that is comparable in strength to the commonly studied symmetric component (El Niño – La Niña). We diagnosed climate reforecasts spanning this period to understand the processes responsible for the observed asymmetry. We confirmed that an asymmetric component is indeed a fundamental property of atmospheric responses to recent ENSO forcing. Each and every composite of a 16-member reforecast ensemble has appreciable asymmetry in tropical Pacific rainfall, upper tropospheric Pacific–North American circulation patterns, and contiguous U.S. surface temperatures. There is considerable sampling variability in the magnitude of this asymmetric component among individual reforecast composites. We argue therefore that the true sea surface temperature boundary-forced signal of ENSO teleconnections is likely composed of a symmetric component having greater magnitude than its asymmetric component, though the latter is an import-

ant property of how ENSO affects North American climate. (Zhang et al. 2014)

Attribution studies. We supported NOAA and CIRES colleagues investigating the causes of the March 2012 record warmth of the central and eastern United States, and attributing the 2012 and 2003–2012 rainfall deficits in eastern Kenya and southern Somalia (Dole et al. 2014, Funk et al 2013).

Numerical experiments. We have completed 50-members Atmospheric Model Intercomparison Project (AMIP) runs with the Global Forecast System model version 2 (GFSv2). This model is the atmospheric component of the CFSv2, driven with specified observed monthly sea surface temperatures, sea ice, and carbon dioxide concentrations for 1979–2012.

We forced a second set, consisting of 50-members, with only SST variations consisting of the leading mode of variability associated with ENSO; and we forced a third set of



Correlation between DJF z500 response and standardized PC time series of EOF from GFSv2 EOF1 SST (left) and EOF1+EoF2 SST (right) run (50 runs ensemble).

50-members with SST variations consisting of the first two modes of variability associated with ENSO.

The modes are derived from an empirical orthogonal function (EOF) analysis of the covariance matrix of monthly global SST variations for 1979-2012. The linear trend in the SSTs at each grid point over the period of analysis is removed prior to performing the EOF analysis.

We have conducted the real-time update for these experiments and the results from these simulations have contributed to several studies.

Publications:

Zhang, T, J Perlwitz, and MP Hoerling. 2014. What is responsible for the strong observed asymmetry in teleconnections between El Niño and La Niña? *Geophys. Res. Lett.* 41:1019-1025. doi:10.1002/2013GL058964.

PSD-18: Linking Changes in Climate to Water Resources Management Outcomes

■ CIRES Lead: Jon Eischeid ■ NOAA Lead: Martin Hoerling

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:

NOAA PSD has requested that CIRES delay moving forward on this project until the partner water resource management agencies helping to support the activity provide NOAA and CIRES with the necessary information to ensure the analyses described in the work plan address the appropriate questions.

Management and Exploitation of Geophysical Data

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

■ CIRES Lead: David Neufeld ■ NOAA Lead: Kelly Prendergast

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 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 continued to



Scientists gather around a fresh dredging catch of calcareous ooze and potential bedrock from the continental shelf during a multiagency cruise aboard the Coast Guard research vessel Healy in 2012. CIRES researchers in NGDC are supporting the Extended Continental Shelf project with data storage, management, evaluation, and other tools. Photo credit: US Coast Guard

build on their collaborative Agile software development process this past year. As a result, the team produced a variety of new and enhanced software systems. The software 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 (ECF) project.

The NGDC Extract (NEXT) data extract system provides a general data access service for data managers with a simple and scalable retrieval architecture. This past year, we expanded the system to support the NOAA Deep Space Climate Observatory (DSCOVR) satellite program and trackline data sets. The previous approach required us to create 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.

Consistent with last year's goal, we began work on a new project to provide a common data ingest system for NGDC. This system standardizes the process of bringing new data into the center archives and is also highly customizable to accommodate data set-specific processing. The team's quick development and deployment of this system has enabled the center to support ingest of DSCOVR and Enlil forecast model data from the Space Weather Prediction Center, and marine water-level tide gauge data from the NOAA Center for Operational Oceanographic Products and Services.

The Enterprise Metadata Management Architecture (EMMA) is a system of tools and services to assist metadata management and reuse, standardize documentation using International Standards Organization (ISO) formats, and enable discovery of scientific data. The tools include conversion of metadata from formats such as NcML (network common data form markup language), FGDC (federal geographic data committee), SOS (special ordered sets), and WMS (web map service) into ISO documentation standards. Metadata are hosted and displayed using web-accessible folders (WAFs) with dynamic custom views, and are discoverable through ESRI Geoportal using 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. A new metadata editor framework (code-named Chameleon) provides a way for non-programmers to build forms to make metadata collection easier, and can be customized for different data sets and users. The National Ocean Service has used this framework to build three editors, and more organizations are expressing interest in using it. The EMMA team also provides training and guidance to NGDC and many other organizations throughout NOAA

and beyond on the implementation of ISO metadata documentation standards and usage of the EMMA tools.

Lastly, in collaboration with State Department, the U.S. Geological Survey, and NGDC, CIRES researchers extended the ECS catalog software to support handling seismic data and initiated the development of a more user-friendly interface. This software provides production tools for a multi-agency collaboration whose goals are to determine and define the extent of the U.S. continental shelf beyond 200 nautical miles (nm). The ECS project team is using this software to assemble a boundary extension submission to the United Nations, to track data sets, conduct analysis and documentation, and to support other aspects 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

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 the cost of data access through increased use of partnerships and integration of systems that leverage the value of data.

Accomplishments:

Both national and international organizations contribute to and retrieve marine geophysical and geological data from the NGDC interactive databases. NGDC provides long-term archiving, stewardship, and delivery of data to scientists and the public by utilizing standards-compliant metadata, spatially enabled databases, robotic tape archive, and standards-based Web services. Since June 2013, 121 multibeam swath sonar surveys (180,481 nautical miles) and 197 trackline (single-beam bathymetry, magnetics, gravity, subbottom, and seismic reflection) surveys (835,711 nautical miles) conducted throughout all of the world's oceans have been added to NGDC's global marine geophysical archives by federal and CIRES data managers in NGDC. Data managers spent half of 2013 working with CIRES programmers on redesigning the Marine Trackline Geophysical Data Request Page. Users are now able to request a variety of data sets (new and legacy, digital and analog) from a single page (left figure below).

Water column sonar data, the most recent data set archived at NGDC, image the entire water volume between the ship and the seafloor and enable three-dimensional mapping of fish schools and plankton blooms, large-scale mapping of natural gas seeps, and remote monitoring of undersea oil spills. In partnership with and supported by NOAA Fisheries, we developed a pipeline for data to flow from the data providers to the newly established database. We archived and made available approximately 5 TB of water column sonar data. We built a Web map and data access service (http://maps.ngdc.noaa.gov/viewers/water_column_sonar/, right figure below) to enable researchers and the public worldwide to query, discover, and extract data.

Data Available	Survey ID	Institution	Ship	Year	Date Added	Types	Select
▶	EX1105	NOAA CE	Okeanos Explorer	2011	2013-03-12	15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 100 101 102 103 104 105 106 107 108 109 110 111 112 113 114 115 116 117 118 119 120 121 122 123 124 125 126 127 128 129 130 131 132 133 134 135 136 137 138 139 140 141 142 143 144 145 146 147 148 149 150 151 152 153 154 155 156 157 158 159 160 161 162 163 164 165 166 167 168 169 170 171 172 173 174 175 176 177 178 179 180 181 182 183 184 185 186 187 188 189 190 191 192 193 194 195 196 197 198 199 200 201 202 203 204 205 206 207 208 209 210 211 212 213 214 215 216 217 218 219 220 221 222 223 224 225 226 227 228 229 230 231 232 233 234 235 236 237 238 239 240 241 242 243 244 245 246 247 248 249 250 251 252 253 254 255 256 257 258 259 260 261 262 263 264 265 266 267 268 269 270 271 272 273 274 275 276 277 278 279 280 281 282 283 284 285 286 287 288 289 290 291 292 293 294 295 296 297 298 299 300 301 302 303 304 305 306 307 308 309 310 311 312 313 314 315 316 317 318 319 320 321 322 323 324 325 326 327 328 329 330 331 332 333 334 335 336 337 338 339 340 341 342 343 344 345 346 347 348 349 350 351 352 353 354 355 356 357 358 359 360 361 362 363 364 365 366 367 368 369 370 371 372 373 374 375 376 377 378 379 380 381 382 383 384 385 386 387 388 389 390 391 392 393 394 395 396 397 398 399 400 401 402 403 404 405 406 407 408 409 410 411 412 413 414 415 416 417 418 419 420 421 422 423 424 425 426 427 428 429 430 431 432 433 434 435 436 437 438 439 440 441 442 443 444 445 446 447 448 449 450 451 452 453 454 455 456 457 458 459 460 461 462 463 464 465 466 467 468 469 470 471 472 473 474 475 476 477 478 479 480 481 482 483 484 485 486 487 488 489 490 491 492 493 494 495 496 497 498 499 500 501 502 503 504 505 506 507 508 509 510 511 512 513 514 515 516 517 518 519 520 521 522 523 524 525 526 527 528 529 530 531 532 533 534 535 536 537 538 539 540 541 542 543 544 545 546 547 548 549 550 551 552 553 554 555 556 557 558 559 560 561 562 563 564 565 566 567 568 569 570 571 572 573 574 575 576 577 578 579 580 581 582 583 584 585 586 587 588 589 590 591 592 593 594 595 596 597 598 599 600 601 602 603 604 605 606 607 608 609 610 611 612 613 614 615 616 617 618 619 620 621 622 623 624 625 626 627 628 629 630 631 632 633 634 635 636 637 638 639 640 641 642 643 644 645 646 647 648 649 650 651 652 653 654 655 656 657 658 659 660 661 662 663 664 665 666 667 668 669 670 671 672 673 674 675 676 677 678 679 680 681 682 683 684 685 686 687 688 689 690 691 692 693 694 695 696 697 698 699 700 701 702 703 704 705 706 707 708 709 710 711 712 713 714 715 716 717 718 719 720 721 722 723 724 725 726 727 728 729 730 731 732 733 734 735 736 737 738 739 740 741 742 743 744 745 746 747 748 749 750 751 752 753 754 755 756 757 758 759 760 761 762 763 764 765 766 767 768 769 770 771 772 773 774 775 776 777 778 779 780 781 782 783 784 785 786 787 788 789 790 791 792 793 794 795 796 797 798 799 800 801 802 803 804 805 806 807 808 809 810 811 812 813 814 815 816 817 818 819 820 821 822 823 824 825 826 827 828 829 830 831 832 833 834 835 836 837 838 839 840 841 842 843 844 845 846 847 848 849 850 851 852 853 854 855 856 857 858 859 860 861 862 863 864 865 866 867 868 869 870 871 872 873 874 875 876 877 878 879 880 881 882 883 884 885 886 887 888 889 890 891 892 893 894 895 896 897 898 899 900 901 902 903 904 905 906 907 908 909 910 911 912 913 914 915 916 917 918 919 920 921 922 923 924 925 926 927 928 929 930 931 932 933 934 935 936 937 938 939 940 941 942 943 944 945 946 947 948 949 950 951 952 953 954 955 956 957 958 959 960 961 962 963 964 965 966 967 968 969 970 971 972 973 974 975 976 977 978 979 980 981 982 983 984 985 986 987 988 989 990 991 992 993 994 995 996 997 998 999 1000	▶
▶	EX1202_1	NOAA	Okeanos Explorer	2012	2012-07-04	15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 100 101 102 103 104 105 106 107 108 109 110 111 112 113 114 115 116 117 118 119 120 121 122 123 124 125 126 127 128 129 130 131 132 133 134 135 136 137 138 139 140 141 142 143 144 145 146 147 148 149 150 151 152 153 154 155 156 157 158 159 160 161 162 163 164 165 166 167 168 169 170 171 172 173 174 175 176 177 178 179 180 181 182 183 184 185 186 187 188 189 190 191 192 193 194 195 196 197 198 199 200 201 202 203 204 205 206 207 208 209 210 211 212 213 214 215 216 217 218 219 220 221 222 223 224 225 226 227 228 229 230 231 232 233 234 235 236 237 238 239 240 241 242 243 244 245 246 247 248 249 250 251 252 253 254 255 256 257 258 259 260 261 262 263 264 265 266 267 268 269 270 271 272 273 274 275 276 277 278 279 280 281 282 283 284 285 286 287 288 289 290 291 292 293 294 295 296 297 298 299 300 301 302 303 304 305 306 307 308 309 310 311 312 313 314 315 316 317 318 319 320 321 322 323 324 325 326 327 328 329 330 331 332 333 334 335 336 337 338 339 340 341 342 343 344 345 346 347 348 349 350 351 352 353 354 355 356 357 358 359 360 361 362 363 364 365 366 367 368 369 370 371 372 373 374 375 376 377 378 379 380 381 382 383 384 385 386 387 388 389 390 391 392 393 394 395 396 397 398 399 400 401 402 403 404 405 406 407 408 409 410 411 412 413 414 415 416 417 418 419 420 421 422 423 424 425 426 427 428 429 430 431 432 433 434 435 436 437 438 439 440 441 442 443 444 445 446 447 448 449 450 451 452 453 454 455 456 457 458 459 460 461 462 463 464 465 466 467 468 469 470 471 472 473 474 475 476 477 478 479 480 481 482 483 484 485 486 487 488 489 490 491 492 493 494 495 496 497 498 499 500 501 502 503 504 505 506 507 508 509 510 511 512 513 514 515 516 517 518 519 520 521 522 523 524 525 526 527 528 529 530 531 532 533 534 535 536 537 538 539 540 541 542 543 544 545 546 547 548 549 550 551 552 553 554 555 556 557 558 559 560 561 562 563 564 565 566 567 568 569 570 571 572 573 574 575 576 577 578 579 580 581 582 583 584 585 586 587 588 589 590 591 592 593 594 595 596 597 598 599 600 601 602 603 604 605 606 607 608 609 610 611 612 613 614 615 616 617 618 619 620 621 622 623 624 625 626 627 628 629 630 631 632 633 634 635 636 637 638 639 640 641 642 643 644 645 646 647 648 649 650 651 652 653 654 655 656 657 658 659 660 661 662 663 664 665 666 667 668 669 670 671 672 673 674 675 676 677 678 679 680 681 682 683 684 685 686 687 688 689 690 691 692 693 694 695 696 697 698 699 700 701 702 703 704 705 706 707 708 709 710 711 712 713 714 715 716 717 718 719 720 721 722 723 724 725 726 727 728 729 730 731 732 733 734 735 736 737 738 739 740 741 742 743 744 745 746 747 748 749 750 751 752 753 754 755 756 757 758 759 760 761 762 763 764 765 766 767 768 769 770 771 772 773 774 775 776 777 778 779 780 781 782 783 784 785 786 787 788 789 790 791 792 793 794 795 796 797 798 799 800 801 802 803 804 805 806 807 808 809 810 811 812 813 814 815 816 817 818 819 820 821 822 823 824 825 826 827 828 829 830 831 832 833 834 835 836 837 838 839 840 841 842 843 844 845 846 847 848 849 850 851 852 853 854 855 856 857 858 859 860 861 862 863 864 865 866 867 868 869 870 871 872 873 874 875 876 877 878 879 880 881 882 883 884 885 886 887 888 889 890 891 892 893 894 895 896 897 898 899 900 901 902 903 904 905 906 907 908 909 910 911 912 913 914 915 916 917 918 919 920 921 922 923 924 925 926 927 928 929 930 931 932 933 934 935 936 937 938 939 940 941 942 943 944 945 946 947 948 949 950 951 952 953 954 955 956 957 958 959 960 961 962 963 964 965 966 967 968 969 970 971 972 973 974 975 976 977 978 979 980 981 982 983 984 985 986 987 988 989 990 991 992 993 994 995 996 997 998 999 1000	▶
▶	EX1202_2	NOAA	Okeanos Explorer	2012	2012-07-04	15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 100 101 102 103 104 105 106 107 108 109 110 111 112 113 114 115 116 117 118 119 120 121 122 123 124 125 126 127 128 129 130 131 132 133 134 135 136 137 138 139 140 141 142 143 144 145 146 147 148 149 150 151 152 153 154 155 156 157 158 159 160 161 162 163 164 165 166 167 168 169 170 171 172 173 174 175 176 177 178 179 180 181 182 183 184 185 186 187 188 189 190 191 192 193 194 195 196 197 198 199 200 201 202 203 204 205 206 207 208 209 210 211 212 213 214 215 216 217 218 219 220 221 222 223 224 225 226 227 228 229 230 231 232 233 234 235 236 237 238 239 240 241 242 243 244 245 246 247 248 249 250 251 252 253 254 255 256 257 258 259 260 261 262 263 264 265 266 267 268 269 270 271 272 273 274 275 276 277 278 279 280 281 282 283 284 285 286 287 288 289 290 291 292 293 294 295 296 297 298 299 300 301 302 303 304 305 306 307 308 309 310 311 312 313 314 315 316 317 318 319 320 321 322 323 324 325 326 327 328 329 330 331 332 333 334 335 336 337 338 339 340 341 342 343 344 345 346 347 348 349 350 351 352 353 354 355 356 357 358 359 360 361 362 363 364 365 366 367 368 369 370 371 372 373 374 375 376 377 378 379 380 381 382 383 384 385 386 387 388 389 390 391 392 393 394 395 396 397 398 399 400 401 402 403 404 405 406 407 408 409 410 411 412 413 414 415 416 417 418 419 420 421 422 423 424 425 426 427 428 429 430 431 432 433 434 435 436 437 438 439 440 441 442 443 444 445 446 447 448 449 450 451 452 453 454 455 456 457 458 459 460 461 462 463 464 465 466 467 468 469 470 471 472 473 474 475 476 477 478 479 480 481 482 483 484 485 486 487 488 489 490 491 492 493 494 495 496 497 498 499 500 501 502 503 504 505 506 507 508 509 510 511 512 513 514 515 516 517 518 519 520 521 522 523 524 525 526 527 528 529 530 531 532 533 534 535 536 537 538 539 540 541 542 543 544 545 546 547 548 549 550 551 552 553 554 555 556 557 558 559 560 561 562 563 564 565 566 567 568 569 570 571 572 573 574 575 576 577 578 579 580 581 582 583 584 585 586 587 588 589 590 591 592 593 594 595 596 597 598 599 600 601 602 603 604 605 606 607 608 609 610 611 612 613 614 615 616 617 618 619 620 621 622 623 624 625 626 627 628 629 630 631 632 633 634 635 636 637 638 639 640 641 642 643 644 645 646 647 648 649 650 651 652 653 654 655 656 657 658 659 660 661 662 663 664 665 666 667 668 669 670 671 672 673 674 675 676 677 678 679 680 681 682 683 684 685 686 687 688 689 690 691 692 693 694 695 696 697 698 699 700 701 702 703 704 705 706 707 708 709 710 711 712 713 714 715 716 717 718 719 720 721 722 723 724 725 726 727 728 729 730 731 732 733 734 735 736 737 738 739 740 741 742 743 744 745 746 747 748 749 750 751 752 753 754 755 756 757 758 759 760 761 762 763 764 765 766 767 768 769 770 771 772 773 774 775 776 777 778 779 780 781 782 783 784 785 786 787 788 789 790 791 792 793 794 795 796 797 798 799 800 801 802 803 804 805 806 807 808 809 810 811 812 813 814 815 816 817 818 819 820 821 822 823 824 825 826 827 828 829 830 831 832 833 834 835 836 837 838 839 8	

Marine geophysical data archived at and delivered by NGDC currently support 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 federal staff in NGDC have continued to focus their efforts on improving the design and implementation of the ECS database, now referred to as the ECS Information Management System (IMS). The IMS is a complex data system built to manage the extremely large volumes of ECS data at NGDC and to track the exacting provenance and quality requirements needed under international law.

We have continued to collaborate with scientists and data experts from several U.S. federal agencies and academic science data centers 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 U.S. ECS project and the IOCM program. Staff members 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 Web page, <http://www.ngdc.noaa.gov/mgg/ecs/cruises.html>. CIRES and federal staff in NGDC collaborated to enhance data discovery and data access for the IOCM program by publishing more than 2,000 cruise-level metadata records for multibeam bathymetry data to Web-accessible folders. These records have also been harvested by other data discovery websites (e.g., data.gov) to further expand their accessibility.

NGDC-03: Improved Geomagnetic Data Integration and Earth Reference Models

■ CIRES Lead: Arnaud Chulliat ■ NOAA Lead: Susan McLean

NOAA Theme: Science and Technology Enterprise

Goals & Objectives:

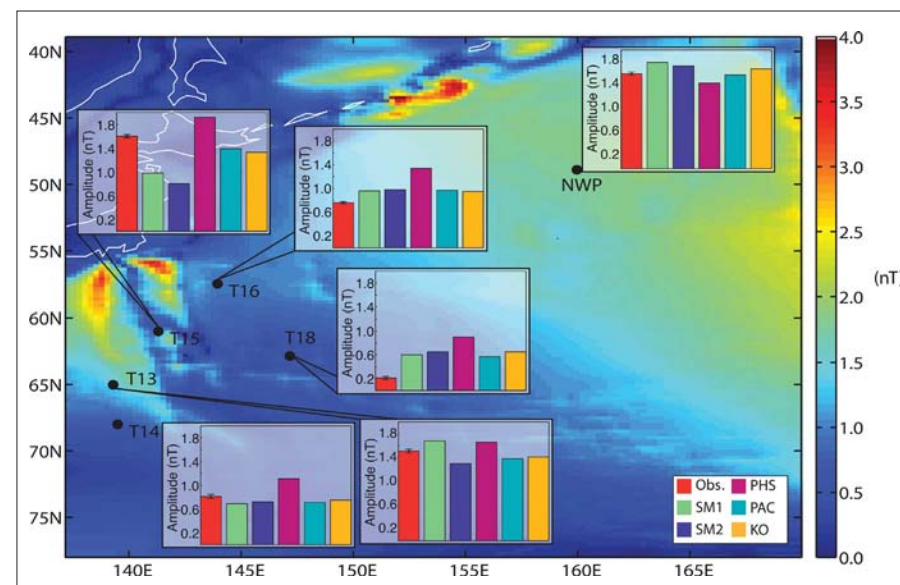
This project will increase the volume and diversity of geomagnetic data that are integrated into improved, higher-resolution geomagnetic reference models of Earth, which are increasingly important for navigation.

Accomplishments:

Our team developed new algorithms for the calibration and processing of the magnetic field measurements made by the Defense Meteorological Satellite Program (DMSP) satellites. This effort was motivated by the need to fill the gap in high-quality satellite magnetic measurements between the end of the German CHAMP satellite mission in September 2010 and the launch of the European Space Agency (ESA) Swarm satellite mission in November 2013. Thanks to the newly developed algorithms, our team could produce a valuable geomagnetic field model from DMSP data covering

2010-2013; this model is available at www.geomag.org/models/dmsp.html. Upcoming operational models—such as the World Magnetic Model (WMM) 2015 and research into the Earth's core processes at the origin of the geomagnetic secular variation—will benefit from this new data set.

Our team also developed algorithms for the validation of the first measurements of the ESA Swarm satellite mission. Swarm is the latest and most sophisticated satellite mission providing high-quality vector measurements of the Earth's magnetic field. It comprises three satellites in near-polar orbit slowly drifting in local time: two of them are flying side-by-side at about 460 km altitude (initially) to allow gradient measurements of the crustal magnetic field anomalies, and the third satellite is flying at a slightly higher altitude (initially 530 km) and in a different orbital plane. Our team participated in an international effort to scientifically validate the first magnetic data provided by Swarm, by comparing them to geomagnetic models and independent data sets such as the Defense Meteorological Satellite Program (DMSP) and ground obser-



Nighttime observed versus predicted amplitudes for the M2 tidal mode at various ocean-bottom stations in the Pacific and for various upper-mantle conductivity models, with the predicted (SM1) M2 amplitudes shown in the background. From Schnepf, N.R. et al., Tidal signals in ocean-bottom magnetic measurements of the Northwestern Pacific: observation versus prediction, *Geophys. J. Int.*, 198, 1096-1110, 2014.

variations. Swarm magnetic data from the first six months of the mission were found to be of excellent quality and ready to be used in the preparation of the various geomagnetic models to be released in the coming year, including the World Magnetic Model 2015 and the International Geomagnetic Reference Field (IGRF) model.

Other noteworthy scientific results obtained by our team over the past year include: a better understanding of the interplanetary electric field effect on, and the longitudinal and seasonal variability of, the equatorial electric field in the ionosphere; the discovery of a standing wave of period six years in the Earth's core magnetic field over the past decade; and the improvement of numerical models of tidal magnetic fields and their comparison with ocean-bottom magnetic measurements (figure on page 104).

To meet increasing demand for accurate geomagnetic referencing by the industry, our team produces the High Definition Geomagnetic Model (HDGM), a global geomagnetic model describing long-wavelength crustal magnetic anomalies, on a yearly basis. We released the latest HDGM in April 2014. It includes DMSP data for the first time and comes with a simple error model integrated into the software.

Our team has also made great strides in ingesting new ship and airborne geomagnetic field observations into the Geophysical Data Search System (GEODAS) trackline database, adding more than 55 million data points to the database. These new data will form the basis of future improvements of high-definition crustal magnetic field models.

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

■ CIRES Lead: Kelly Carignan ■ NOAA Lead: Susan McLean

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.

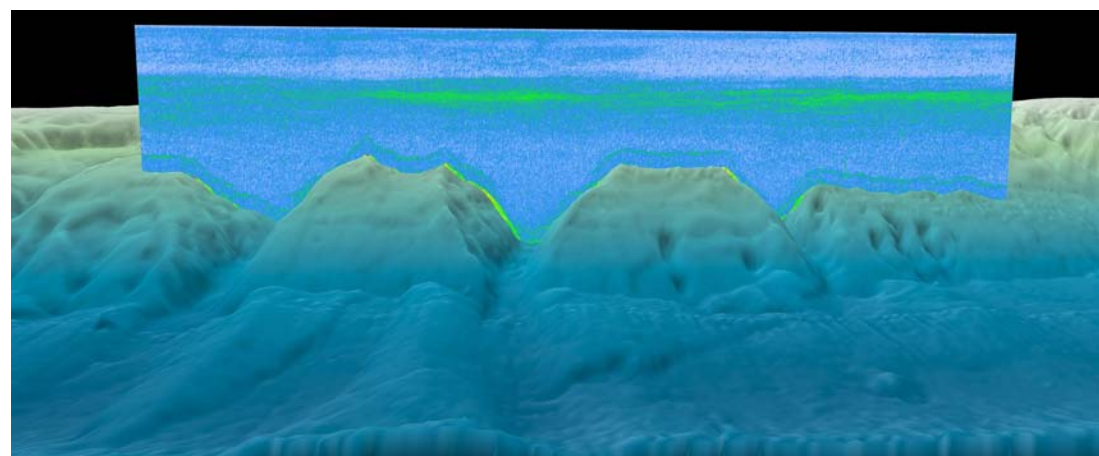
Accomplishments:

CIRES staff at NGDC developed three new digital elevation models (DEMs) and updated four existing DEMs supporting NOAA's Tsunami Program and the National Tsunami Hazard Mitigation Program. Updating existing DEMs with recently collected high-resolution lidar-based elevation data improves the accuracy of the models, resulting in better forecasts and warnings for coastal hazards. We archived more than three terabytes of new lidar data at NGDC this year, supporting long-term data storage needs for many NOAA agencies as well as DEM development. During this time, CIRES staff at NGDC worked with data provider, NOAA's Coastal Service Center, to

deliver International Organization for Standardization-compliant metadata to NGDC with each new submission of data. Additionally, CIRES staff contributed insight to the interagency National Coastal Mapping Strategy, particularly as it relates to coastal lidar data validation, documentation and long-term archive and maintenance.

Our scientific research into DEM development includes: establishing standardized robust procedures for 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. CIRES staff met with NOAA and the U.S. Geological Survey to discuss coordination and collaboration regarding Hurricane Sandy DEM development. CIRES staff at NGDC submitted a document to NOAA Integrated Ocean and Coastal Mapping Program outlining the procedures for the development of a framework of consistent, continually updated, integrated, bathymetric-topographic DEMs. To that end, we began development of a tiling scheme to guide data development and future data dissemination, and began data development. We completed draft versions of offshore bathymetric tiles, and continue to develop high-resolution integrated topo-bathy tiles.

CIRES staff collaborated with NOAA's Coastal Service Center to develop high-resolution DEMs of the shore-zone along the U.S. Great Lakes. These DEMs will be used in an online lake-level change viewer allowing users to visualize potential impacts from changes in lake levels and strategize plans for communities. Providing this information



A vertical image of water column sonar data captures a layer of plankton, shown as bright green, above the seafloor. National Geophysical Data Center (2014): doi: 10.7289/V5HT2M7C.

to planners and local agencies will benefit the community by reducing the economic and environmental impacts associated with lake-level changes.

A crucial element to plan for many coastal natural hazards impacts is water-level data. CIRES staff at NGDC ingest, process, and archive tide gauge data and deep-ocean-bottom pressure recorder (BPR) data from several NOAA agencies. These data are then made available via online tools for researchers and modelers. Improvements to the automated data processing technology enabled accessibility to new features and accounted for quality issues and segments with significant data quality disturbances observed in recently retrieved BPRs and in the records from tide gauges along the East Coast and the Gulf of Mexico. The NOAA Center for Tsunami Research customized and implemented our tidal analysis code for operational processing and de-tiding of real-time Deep-ocean Assessment and Reporting of Tsunami (DART®) data from the Pacific Basin. Following the Solomon Islands tsunami event on February 6, 2013 and the East Coast meteotsunami on June 13, 2013, NGDC compiled all available tide gauge and DART data where the event registered; published a review of historical tsunamis in the Solomon Islands region; and (for the February 6 earthquake and tsunami) described the data collected and processed.

Water column sonar data, archived and distributed at NGDC, provide valuable information for fisheries management by mapping the volume of water between the ship and the seafloor. Collected on NOAA Fisheries, Office of Exploration and Research, and University-National Oceanographic Laboratory System survey vessels, these data are used for three-dimensional mapping of fish schools and other marine organisms, large-scale mapping of natural gas seeps, and remote monitoring of undersea oil spills. Within the past year, nearly five terabytes of data and associated metadata have been ingested into a newly developed data pipeline and database. We also made the software packaging tool—used by each data provider to easily submit their metadata in an ISO-compliant format—more robust. Online data extraction tools and Web map services were developed at NGDC to ensure all archived data are publicly accessible and able to be queried, discovered, and extracted.

NGDC-05: Enhanced Stewardship of Space Weather Data

■ CIRES Lead: Justin Mabie ■ NOAA Lead: William Denig

NOAA Theme: Science and Technology Enterprise

Goals & Objectives:

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

Accomplishments:

Data ingest has continued. The AP index (maximum amplitude Potsdammer or planetary) has been re-launched and updated. All metadata holdings were converted from Federal Geographic Data Committee to International Organization for Standardization compliance. Using the binary reader, an echo location algorithm has been developed that can track ionospheric irregularities. The NASA Dynamo II mission was successfully supported and antenna repairs were made at the Wallops facility Vertically Incident Pulsed Ionospheric Radar (VIPIR). Experiments were also conducted to measure the Ionospheric response to 3 orbital rocket launches.



The log periodic transmitting antenna at Wallops Island, Virginia, after an unusual late spring snowstorm. The antenna is 250x250 ft square, 120 ft tall and contains a mile of wire. It is normally not possible to photograph the complexity of the wires in this antenna because they are difficult to see at distances large enough to capture the entire antenna.

NGDC-07: Remote Sensing of Anthropogenic Signals

■ CIRES Lead: Kimberly Baugh ■ NOAA Lead: Chris Elvidge

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:

During the past year, CIRES staff collaborated with NOAA scientists to complete development on version 2 of the Visible Infrared Imaging Radiometer Suite (VIIRS) Nightfire algorithm. Nightfire version 2 improved upon the capabilities of version 1 by incorporating a midwave infrared detection system using VIIRS nighttime data from bands M12 and M13. Version 2 also incorporates dual Planck curve fitting, which



Nighttime lights composite showing the East Coast of the United States generated using cloud-free VIIRS Day-Night Band data from January 2013. Image credit: NASA

removed the reliance on reliable local background statistics for the midwave channels.

The VIIRS Nightfire algorithm has been incorporated into software that generates cloud-free composites of nighttime data. Historically, these composites have been made using Defense Meteorological Satellite Program (DMSP) Operational Linescan System (OLS) data, but this year CIRES staff have started producing composites using VIIRS nighttime data. The increased spectral bands available in VIIRS data allow for not only nighttime lights composites, but for the generation of nighttime combustion source composites from the Nightfire algorithm. During the reporting period, CIRES staff completed three monthly cloud-free composites of nighttime lights and Nightfire combustion source detections. Production of monthly composites and algorithm refinement will continue through 2015.

CIRES staff also worked on developing a preliminary calibration for estimating flared gas volumes using VIIRS Nightfire composites. We obtained a preliminary calibration coefficient by regressing known flared gas volumes for regional areas against the same areas on the VIIRS Nightfire composites. We then used this coefficient to obtain preliminary country-level estimates of gas flaring volumes for 2012.

NGDC-08: Development of Space Environment Data Algorithms and Products

■ CIRES Lead: James Manley ■ NOAA Lead: William Denig

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:

CIRES staff in the National Geophysical Data Center (NGDC) Solar and Terrestrial Physics (STP) division performed the Satellite Sensor Systems Engineer responsibilities for NOAA's GOES-R satellite. CIRES staff acted as STP's primary technical interface to NOAA's GOES-R and Deep Space Climate Observatory (DSCOVR) programs for space weather sensors and associated space environmental data and ground processing algorithms, including identification of system-level issues affecting the quality of environmental products.

We provided extensive technical feedback during discussions of GOES-R's multiple data acquisition interfaces, e.g. what data must be available via these mechanisms, how NOAA/NGDC will ingest the data and how NOAA/NGDC will successfully accomplish tasks using them. We evaluated issues affecting multiple system components (i.e. multiple instruments), and attempted to identify potential solutions.

We helped plan activities related to calibration and validation, a ground processing algorithm and post-launch testing (PLT); and we delivered PLT and Post-Launch Product Test (PLPT) descriptions.

In other work related to GOES-R and DSCOVR, we:

- Prepared and reviewed technical documentation and specifications for space sensor data interfaces between NGDC/STP and the DSCOVR mission, the GOES-R program, and the NOAA Space Weather Prediction Center (SWPC).
- Developed requirements for NGDC's new Satellite Product Analysis and Distribution Enterprise System (SPADES), which will control the acquisition, processing, distribution and archive of NOAA space weather satellite data including from DSCOVR and GOES-R.
- Created the initial drafts for all of the Solar Ultra-Violet Imager (SUVI) Phase III Product Algorithm Theoretical Basis Documents (ATBDs), and assisted in the further refinement of the SUVI Phase III algorithm requirements. This was necessary to clarify developer responsibilities.
- Successfully completed the Critical Design Review for all Phase III algorithms. This review included the proposed final algorithm design and theoretical basis for each Phase III product.
- Continued refinement of the development algorithms for all the SUVI Phase III products (Coronal Hole Boundaries, Bright Region Locations and Flare Locations) progressing towards the maturity necessary for delivery.
- Completed review of revised Space Environment In Situ Suite (SEISS) Flight Model 1 ground calibration results and started review of Flight Model 2 results.
- Completed the processing and release of the 2006-2010 (pre-operational) GOES 13-15 Magnetospheric Electron Detector and Magnetospheric Proton Detector fluxes.
- Completed the magnetopause location product review and preliminary design review, and helped identify improvements to the magnetopause location product website.
- Developed GOES-R magnetometer contractor support documents, contributed to identifying the impacts of the ground processing frozen baseline on GOES-R magnetometer data quality and the resolution of GOES-R magnetometer issues.
- Participated in the GOES-R magnetometer delta-Critical Design Review.
- Participated in Extreme Ultraviolet and X-ray Irradiance Sensor instrument calibration and validation testing and assisted in resolving issues to ensure NOAA objectives are met.
- Participated in the "Inter-calibration and Validation of Solar Extreme Ultraviolet Spectral Irradiance Measurements," sponsored by the Belgian Solar-Terrestrial Centre of Excellence. This project will help improve the understanding of the GOES Extreme Ultraviolet Sensor (EUVS), and X-Ray Sensor (XRS) measurements which will be used to validate the GOES-R Extreme Ultraviolet/X-Ray Irradiance Sensor (EXIS) instruments.

NGDC-09: Enhanced Ionosonde Data Access and Stewardship

■ CIRES Lead: Terry Bullett ■ NOAA Lead: Rob Redmon

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:

In the ionosonde data stewardship arena, we completed the transition of ionosonde data from an obsolete tape library to the a one. Such media translations are essential to assure that the historical data can still be used and not become unreadable due to technological obsolescence. The project has still not been authorized to place data into NOAA's Comprehensive Large Array-data Stewardship System (CLASS), so this is projected into next year.

For this project, we collected more than 2TB of data from more than 60 instruments around the world. Hundreds of users access these data every month, including users from other government agencies. We collected and stored off-line an additional 40 TB of research-quality data from Vertical Incidence Pulsed Ionospheric Radar (VIPIR) instruments.

In addition to routine data collection and dissemination, we provided advanced support in several specific areas. One involved a NASA sounding rocket experiment to study winds and electrical currents in the daytime ionosphere. Another supported a research effort to track the propagation of wave energy from deep ocean waves through the atmosphere and into the ionosphere. We have collected excellent data sets.

Our progress on the VIPIR for Antarctica is on track. The large antenna components have been delivered, and we have provided technical advice and on-site assistance to ionosonde users in Ethiopia, Peru and Bolivia.

NGDC-10: Enhanced CORS Data Access and Stewardship

■ CIRES Lead: Francine Coloma ■ NOAA Lead: William Denig

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:

In collaboration with National Geodetic Survey (NGS), we completed reconciliation of data holdings between the primary NGS Continuously Operating Reference Stations

(CORS) facility in Silver Spring, Maryland, and a parallel facility in Boulder, Colorado.

We also migrated all historical CORS data from the local NGDC tape archive system into the Comprehensive Large Array-data Stewardship System (CLASS) archive system. This project received a NOAA award during the reporting period. On November 15, 2013, NOAA/NESDIS Assistant Administrator Mary Kizca presented the team with a U.S. Department of Commerce Certificate of Appreciation for “migrating NGDC’s initial data set to the CLASS Archive.”

We also archived new satellite signals from a Russian constellation. NGS transitioned from being a single satellite navigation system (solely operating on GPS signals) to becoming a Global Navigation Satellite System (GNSS) operation, by including the Russian GLONASS signals. This project involved successful coordination among NGS, NGDC, and CLASS offices, and then implemented the archive of the new GNSS signals.

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

■ CIRES Lead: Carrie Morrill ■ NOAA Lead: David M. Anderson

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:

There is large uncertainty surrounding future hydroclimate changes in a warming world, and the paleoclimate record offers a longer-term perspective on non-linearities and extreme events. To maximize the use of information contained in the paleoclimate record, our team archived more than 90 new data sets on past hydrologic changes.

These data sets cover phenomena as diverse as the intertropical convergence zone, streamflow in the mid-latitudes, precipitation in the Arctic and lake levels in North America (such as Owens Lake, below). They document time scales ranging from annual to millennial. We also made progress in developing a consistent methodology for naming variables in paleoclimate data sets. Our new ruleset is designed to accommodate the heterogeneity of paleoclimate data while providing more complete information on attributes such as analytical technique and statistical processing. It will enable users to identify more easily and accurately which measurements are comparable, which is essential for developing synthesis products derived from multiple paleoclimate proxy types. We began to develop such a synthesis product of lake-level changes at the Last Glacial Maximum, which we are using to test the skill of climate models in reproducing past hydrologic changes and to test several hypotheses about how greenhouse gas concentrations alter regional moisture patterns.

The paleoclimate record offers a critical independent test of the skill of climate models in simulating conditions outside the realm of the short instrumental record. To support paleoclimate model-data comparisons, we assembled and archived model results from the third phase of the Paleoclimate Modelling Intercomparison Project. One



NGDC’s database of lake-level changes includes information about California’s Owens Lake. Photo credit: G. Thomas/Creative Commons

of these data sets comprised simulations of the 8.2 ka event, a period during which reduced salinity in the North Atlantic had global climatic consequences, and which represents a scenario that could recur in the future due to global warming. This data set indicates that climate models may not be sensitive enough to this type of event. We also created and archived a data product of sea surface temperature changes since the Last Glacial Maximum 21,000 years ago. Temperature changes since the Last Glacial Maximum help to quantify climate sensitivity to atmospheric greenhouse gas concentrations and are an important target for the new generation of transient simulations being produced by climate models.

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

■ CIRES Lead: Scott Woodruff ■ NOAA Lead: Jay Lawrimore

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:

We continued long-term work transiting legacy International Comprehensive Ocean-Atmosphere Data Set (ICOADS) activities and infrastructure—including the project’s central website—from NOAA’s Earth System Research Laboratory to the agency’s National Climatic Data Center (NCDC).

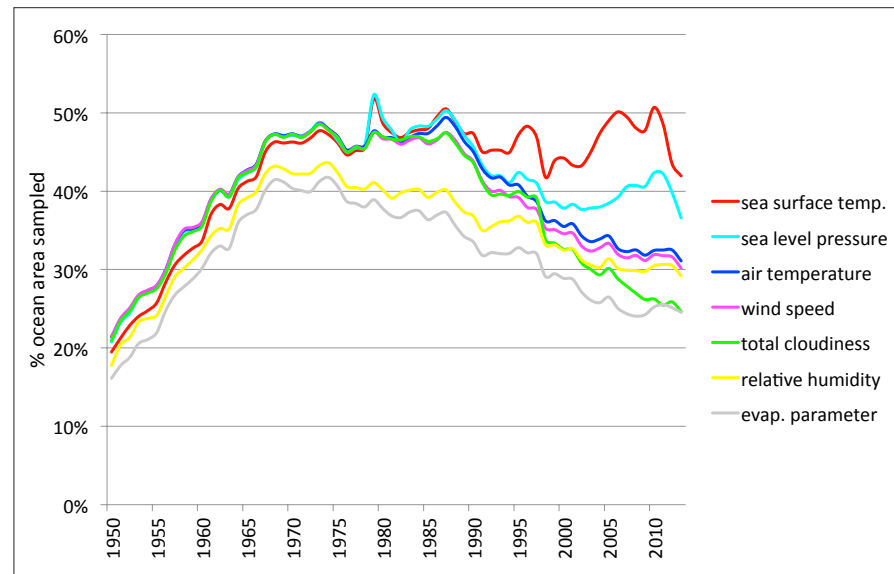
Following April 2013 agreements reached at “EarthTemp Network SST-ICOADS Exchange of Visiting Scientists” meetings, held in Southampton and Exeter, UK, we developed and advanced, among the eight signatory organizations, a letter of intent to “Enhance Support for the International Comprehensive Ocean-Atmosphere Data Set (ICOADS) Program through International Partnership.” In addition, we drafted the Terms of Reference for a new ICOADS Steering Committee, which recently started operating under the letter of intent.

We continued preparations for the next major delayed-mode update, Release 3.0 (R3.0)—now planned for completion around late 2015—including development of a detailed preliminary workplan. This involved ongoing discussions with our international partners to help coordinate planned contributions and deliverables.

As a critical element of the R3.0 workplan, we continued to refine and implement the next version of the International Maritime Meteorological Archive format, which, together with its access software, will enhance ICOADS data stewardship and access, and is also serving as a key foundation for the ICOADS Value-Added Database (IVAD) project.

Also, as an important development closely related to the overall R3.0 workplan, we continued implementation of our new merged Global Telecommunication System (GTS) product. This product combines GTS data from NCDC with data from NOAA’s National Centers for Environmental Prediction. Once fully operational, it 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.

Woodruff is a core member and past chairperson of the Expert Team on Marine Climatology (of the Joint World Meteorological Organization [WMO]/Intergovernmental Oceanographic Commission [IOC] Technical Commission for Oceanography and Marine Meteorology [JCOMM]). As such, and because he is involved in related task teams and working groups, Woodruff participated in a range of international meetings and had new or continuing involvement on various international publications and reports, including reviewing selected chapters in a new Joint Technical Commission for Oceanography and Marine Meteorology (JCOMM) Data Architecture Consultant Report. Lastly, as a scientific organizing committee member, Woodruff was heavily involved with advance planning and preparations for the upcoming Fourth JCOMM



Percentage global ocean and coastal area (1950-2010) sampled in Release 2.5 based on area-weighted 2° boxes (smoothed) for sea surface temperature. Full caption: http://icoads.noaa.gov/index_fig3.html

Workshop on Advances in Marine Climatology (CLIMAR-IV; 9-12 June 2014) workshop, and First IVAD (13 June 2014) Workshop, both held in Asheville, NC.

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

■ CIRES Lead: Florence Fetterer ■ NOAA Lead: Eric Kihn

NOAA Theme: Science and Technology Enterprise

Goals & Objectives:

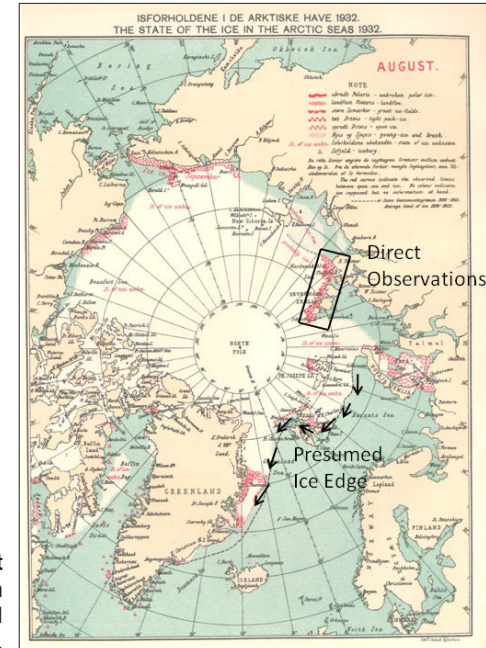
This project will ensure availability of data on polar ice and glaciers for research purposes.

Accomplishments:

- We published two new data collections and updated several others. Most notably:
- We published the Multisensor Analyzed Sea Ice Extent (MAISE) Daily 4-km Arctic Sea Ice Extent product archive back to 2006. MASIE is updated every day but previously, only the last 4 weeks were made available to users. MAISE is second only to the Sea Ice Index in terms of number of users.
- We made several updates to the Global Lake and River Ice Phenology Database, spanning 1889 through 2012, and added one new lake to its inventory.
- We added Submarine Arctic Science Program (SCICEX) submarine bathymetry and ice draft data from 2011 to the inventory.

- We published the Unified Sea Ice Thickness climate data record from 1947-2012. This is a collection of observations of Arctic sea-ice draft, freeboard and thickness.

More information can be found at <http://nsidc.org/noaa/news.html>



Arctic sea-ice chart from the Danish Meteorological Institute.

Regional Sciences and Applications

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

■ CIRES Lead: Christoph Senff ■ NOAA Lead: Alan Brewer

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 characterize the distribution and transport of ozone, quantify greenhouse gas emissions, and investigate ocean plankton layers.

We analyzed data sets collected with the Tunable Optical Profiler for Aerosol and Ozone (TOPAZ) ozone lidar during the 2013 Uintah Basin Wintertime Ozone Study (UBWOS) and the Las Vegas Ozone Study (LVOS) experiments and presented first results from these studies at several conferences.

The UBWOS data revealed that the high wintertime ozone values observed in the Uintah Basin in Utah were confined to a shallow layer only a few hundred meters deep. The lidar observations showed that there was no long-range transport of ozone into the Uintah Basin and thus supported the notion that the high ozone concentrations are primarily due to emissions associated with oil and gas extraction in the basin.

At LVOS, the ozone lidar data documented several cases where ozone that originated in the lower stratosphere was transported to the surface, resulting in elevated ground-level ozone concentrations. On two occasions, this stratosphere-to-troposphere transport of ozone caused exceedances of the 8-hour ozone standard in the Las Vegas area.

We also deployed the TOPAZ lidar to Houston, Texas as part of the Deriving Information on Surface conditions from Column and Vertically Resolved Observations Relevant to Air Quality (DiscoverAQ) study. TOPAZ characterized the vertical distribution and temporal evolution of ozone, which in Houston is primarily driven by the land-sea breeze circulation.

We deployed two of our Doppler wind lidars, the High Resolution Doppler Lidar (HRDL) and the Halo Lidar to the Texas Flux (TXFLUX) study near Dallas, Texas and the Indianapolis Flux (INFLUX) campaign in Indianapolis, Indiana. TXFLUX and INFLUX were aimed at testing and improving methods to quantify greenhouse gas emissions from oil and gas fields and a metropolitan area, respectively. HRDL

at TXFLUX provided continuous and real-time wind speed and direction profiles. These observations were used to plan the flights of the research aircraft making the greenhouse gas measurements and to validate models used for forecasting air pollution transport. Boundary layer height measurements made with HRDL will be key for quantifying greenhouse gas fluxes.

The autonomous Halo Lidar has been deployed at INFLUX for almost a year now to provide wind speed and direction profiles and estimates of boundary-layer heights. These observations, together with in situ measurements of greenhouse gas concentrations, have been used in inverse model simulations to create a greenhouse gas inventory for the Indianapolis area.

We collaborated with the U.S. Naval Research Laboratory on a project to study ocean plankton layers in East Sound, Washington. Plankton layers are likely to play an important role in controlling many biological and biogeochemical processes in the oceans. For this study, we modified our oceanographic lidar instrument to combine hyperspectral imaging techniques with the lidar observations. This hybrid instrument was flown on a small aircraft over East Sound. Using its data, we successfully identified plankton layers and mapped out their horizontal and vertical extent.



TOPAZ ozone lidar (and other instrumentation) at the LaPorte Airport ground site during DiscoverAQ 2013 with the NASA P3B research aircraft performing a missed approach. Photo credit: Scott Sandberg/NOAA

PSD-05: Prediction of Extreme Regional Precipitation and Flooding

■ CIRES Lead: Allen White ■ NOAA Lead: Marty Ralph

NOAA Theme: Climate Adaptation and Mitigation

Goals & Objectives:

This project specifically addresses regional climate predictions.

Accomplishments:

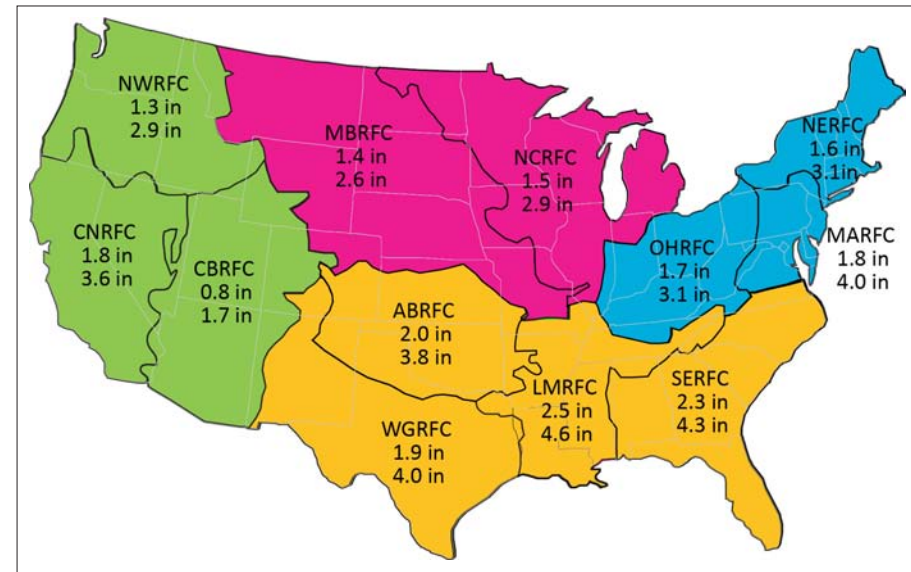
We completed a study that quantified the performance of National Weather Service (NWS) Weather Prediction Center (WPC) extreme precipitation forecasts as a function of NWS River Forecast Center region (figure at right). The results of this study have been summarized in a manuscript entitled “Extreme quantitative precipitation forecast performance at the Weather Prediction Center from 2001 to 2011” and accepted for publication in the journal *Weather and Forecasting*. In addition, we have written a draft manuscript, “Assessing the utility of the NOAA Reforecast data set for atmospheric river quantitative precipitation forecasting along the western U.S. Coast.” This manuscript expands upon the use of the NOAA reforecast database for better precipitation forecasts from eight cases used during the Atmospheric River Retrospective Forecasting Experiment (ARRFEX) to a broader sample of atmospheric-river events since 1979. Finally, we compared high-resolution ensemble forecasts from the Hydrometeorology Testbed (HMT) to coarser operational ensemble forecasts for eight atmospheric river events along the U.S. West Coast.

Another related accomplishment was associated with an effort to perform a physical validation of Weather Research and Forecasting (WRF) model simulations of major precipitation events impacting northern California, with an emphasis on the representation of cloud and precipitation microphysics. Examination of one precipitation event over the coastal mountains north of San Francisco indicates that while horizontal water vapor transport is well simulated, precipitation forecasts are low by as much as a factor of 3-4. This is especially true when the observed orographic precipitation is shallow and dominated by warm rain processes. Output from simulations using the microphysics scheme employed in NWS operations produces precipitation forecasts that are closest to the observations, only about 15 percent low. However, the analysis reveals that this result is obtained in association with a factor of two under-prediction of rain-water content and a 50 percent over-prediction of rain fall speed.

We also accomplished goals related to the hydrological component of this project. The Hydrology Laboratory-Research Distributed Hydrologic Model (HL-RDHM) was first calibrated for the Russian and Napa river watersheds of northern California, which led to demonstrable improvements in simulation accuracy. Then, various ra-

dar-rainfall products were used as input to HL-RDHM as a means to assess the best radar-rainfall algorithms. Radar data and model output imagery were animated in a synchronous manner to facilitate the analysis.

Finally, we accomplished improvements in data display and management components of this project. After obtaining feedback from end-users, we implemented online new real-time and historical data displays for HMT (<http://www.esrl.noaa.gov/psd/data/obs/datadisplay/>) to replace the legacy displays. This enhancement included the added feature of metadata displays for each field site. We also supported the wireless communication infrastructure for data acquisition by configuring additional wireless routers and through migration to a new Web server computer for data management and display.



Proposed regional precipitation thresholds for evaluating extreme Weather Prediction Center QPF performance. These thresholds were calculated by River Forecast Center (RFC) region for daily precipitation amounts using 32-km gridded Stage IV QPE data. In each RFC region, the upper number is the threshold of the top 1.0% (99th percentile) of precipitation events and the bottom number the threshold of the top 0.1% (99.9th percentile) of precipitation events during the period from 2001-2011 in inches. RFC regions are color-coded into four broad U.S. geographical regions.

Scientific Outreach and Education

GSD-02: Science Education and Outreach (SOS)

■ CIRES Lead: Elizabeth Russell ■ NOAA Lead: John Schneider

NOAA Theme: NOAA 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, which includes NOAA's Science On a Sphere® (SOS) and the Data Visualizations and Games group (DVG, formerly NOAA's Fragile Earth Studios) have reached significant milestones this past year, 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.

During the last year, the SOS team celebrated its 100th installation, and by the end of the year counted 111 SOSs. Of the 13 installations last year, the SOS team installed six and SOS distributors installed seven. The traveling SOS also made appearances during the year at the American Geophysical Union fall meeting in San Francisco, Southern Hills Middle School in Boulder (photo), the World Science Festival in New York City, and the Our Ocean U.S. Department of State Conference in Washington DC.

The technical SOS team grew, with two new CIRES employees joining the group. This allowed two software updates, in December 2013 and June 2014. Both of these releases included new features that users have requested such as flexible data formats and usage statistics.

Another major accomplishment for the year was the first annual SOS Teachers Workshop, "The Sphere Next Door—Integrating SOS into Your Teaching." Eleven teachers from across Colorado attended the workshop. This workshop resulted in a reworking of Eighth Grade Science Day SOS presentations and integration of SOS content in classrooms. In addition, we held a half-day teacher workshop focused on the fall 2013 Boulder floods.

The content library continues to grow. A CIRES intern helped create several new SOS data sets related to climate change and health and wrote a new program using them. In addition, CIRES' Shilpi Gupta, from the SOS tech team, was awarded a CIRES Innovative Research Proposal award (page 64) that brought together artists and scientists to create two new movies for SOS.

At the beginning of June 2014, the SOS Users Collaborative Network assembled

for their sixth workshop. Building upon lessons learned, the planning committee, which included CIRES staff, put together a packed three-day agenda with the theme "Welcome to the Anthropocene." The SOS team together gave 12 talks during the workshop, on topics ranging from technical updates to teacher workshops and data evaluation.

The Data Visualizations and Games group continued work on the TerraViz data visualization tool and the back-end NOAA Earth Information Services (NEIS) core. TerraViz was selected as the visualization component of a two-year, next generation forecast improvement project called the High Impact Weather Prediction Program (HIWPP), comprised of a dozen different groups at NOAA. TerraViz was presented at a number of major conferences, including AMS, Unite, and the SOS Users Workshop, and was shown at an in-depth meeting with top NOAA management as a possible NOAA-wide visualization tool. The SOS team and other groups in ESRL's Global Systems Division used TerraViz in international presentations including in Israel, Taiwan, and Canada.

New features added to TerraViz and NEIS include the ability to load large-scale (100s of gigabytes) real-time and historical model runs; new two- and three-dimensional



CIRES' Hilary Peddicord demonstrates Science On a Sphere® to students using a portable system set up at Southern Hills Middle School. Photo credit: David Oonk/CIRES

visualization options including images, contours, vectors, barbs, and particle trails; a full redesign of the graphical user interface (GUI) in jQuery/HTML, in collaboration with the Climate Program Office; an “SOS Explorer” curated mode for TerraViz with a simplified GUI and curated data set list; volumetric rendering demos for cloud data; and other features to support meteorologists. DVG created an initial implementation of TerraViz for the Oculus Rift VR platform, and upgraded the program for display on next-generation 4,000-pixel-resolution screens and projectors.

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

■ CIRES Lead: Florence Fetterer ■ NOAA Lead: Eric Kihn

NOAA Theme: NOAA 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:

We changed the baseline period for trends and anomalies from 21 to 30 years, as explained below.

When the Sea Ice Index was first published online in 2002, we used a baseline period of 1979-2000 for calculating means and medians. In July 2013, we changed the product to use a 30-year baseline period (1981-2010). This new normal, by including the first decade of the 21st century with its record low extent years, changed the scale on the extent trend plots so the overall loss of ice looked less anomalous than before the change, and each month’s median extent line generally moved further north in the Arctic (in Antarctica, the position of the median extent line did not change much).

A 30-year period is the standard used by organizations such as the World Meteorological Organization (WMO) and NOAA for climatologies and climate normals. Thirty years is deemed a sufficiently long time to average out most interannual variability but short enough to clearly show longer-term climate trends. These maxims about climate normals come from the world of weather and climate. Sea ice responds to climate forcing differently, and the assumptions behind the use of 30-year normals for meteorology may not hold true for sea ice.

The large audience of interested non-scientist as well as scientist users was informed of the change, and some of its implications, through NSIDC data news messages (e.g. <http://nsidc.org/the-drift/data-update/the-sea-ice-index-now-has-a-30-year-baseline/>). A website explains the change in simple language and with illustrations: http://nsidc.org/data/seaice_index/baseline-change.html. We presented a poster on this change to a “new normal” at the IN-STAAR Arctic Workshop and at the CIRES Rendezvous.

NSIDC-02: Update and Maintain Education Resources for the Cryosphere

■ CIRES Lead: Florence Fetterer ■ NOAA Lead: Eric Kihn

NOAA Theme: NOAA Engagement Enterprise

Goals & Objectives:

This project brings unique reference materials to educators and researchers.

Accomplishments:

Our data publication efforts included a data set of image and shapefiles that provide estimates of Arctic sea ice extent and concentration from 1901 to 1956. These data came from a collection of historic, hand-drawn sea ice charts at the Danish Meteorological Institute (DMI). The original DMI charts are based on compiled observations of ice conditions reported by a variable network of national organizations, shore-based observers, scientific expeditions, and ships. These were used to create sea ice extent and concentration fields for each summer month by manual, subjective interpretation of scanned versions of the charts.

As reported last year, the Roger G. Barry Archives and Resource Center (ARC) analog archive is at risk due to inadequate funding and resulting insufficient institutional support.



Arapaho Glacier
Location: Colorado, USA
Coordinates: 40.02° N, 105.65° W
Glacier Type: Alpine
Current Size: 0.16 sq km
Retreat : 52% in 20th Century

These photos show Arapaho Glacier in 1898, photographed by Junius Henderson, and in 2004, photographed by J. Van de Grift. Junius Henderson was one of the first to explore Arapaho glacier and took many photos of it from 1902 to 1922.

Located above Boulder, CO, USA in the Southern Rocky Mountains, Arapaho glacier is a typical alpine glacier with an elevation of 12,434 feet (3,790 meters). It is the largest glacier in Colorado, but it is tiny by world standards.

Arapaho Glacier serves as a water source for the city of Boulder. Many glaciers around the world are important water sources for communities which adds another level of complexity to the necessity of glaciers. Because Arapaho Glacier provides water to the city of Boulder, it is very closely monitored. A study done in 2010 by Haugen and Scambos et al. states, “Arapaho Glacier may disappear in as few as 65 years.”

An example of a fact sheet those adopting a glacier receive, along with a “certificate of adoption.”

Fundraising efforts continued (<https://nsidc.org/rocs/support.html>), and the Adopt-a-Glacier site received considerable use, functioning as a contribution to our education mission as well as to our fundraising. The figure on page 115 is an example of a fact sheet those adopting a glacier get, along with a “certificate of adoption.” Funds raised this way amount to less than \$10,000. While helpful, this will not be enough to create the endowment needed to maintain an archivist position at NSIDC and to support the archive. Allaina Wallace, NSIDC’s archivist until she resigned in February 2014, laid the groundwork for us to work with the CU library system on a Council on Library and Information Resources (CLIR) Cataloging Hidden Special Collections and Archives grant proposal. The pre-proposal was met with approval and we will submit a full proposal in July. If successful, this will allow us to move the archive to main campus, and will allow University of Colorado Boulder Libraries to hire an archivist for the collection. The loss of NSIDC’s archivist was shared with our users in a 20 February news item (<http://nsidc.org/noaa/news.html>).

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

■ CIRES Lead: Catherine Smith ■ NOAA Lead: Randall Dole

NOAA Theme: Climate Adaptation and Mitigation

Goals & Objectives:

This project addresses regional use of climate information.

Accomplishments:

We developed several experimental tools to make climate data more accessible. One is the “Climate Change Web Portal,” where users can easily compare maps and time-series gener-

At the “Climate Change Web Portal,” users can easily compare maps and time series generated from different climate models and climate scenarios. Time series, such as the one shown here, include the spread of the forecasts in addition to the means.

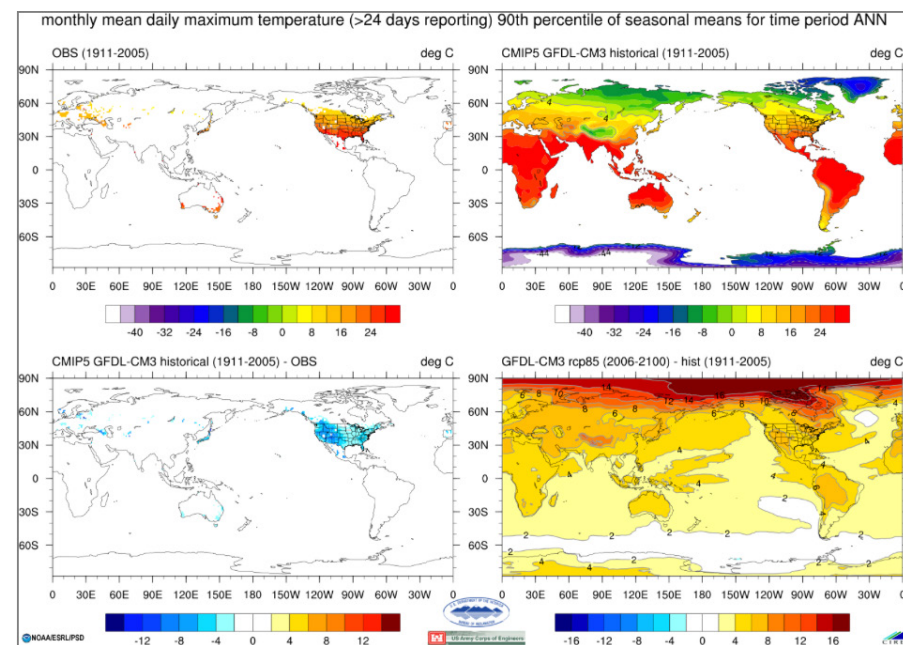
ated from different climate models and climate scenarios. Available products include means, anomalies, and statistics such as the trend and the 10th/90th percentiles. Time series include the spread of the forecasts in addition to the means (<http://www.esrl.noaa.gov/psd/ipcc/>).

A second set of Web tools helps people assess climate-related extremes. It includes tools users can use to compare one climate scenario versus another, and which users can use to compare selected variables from different reanalysis (<http://www.esrl.noaa.gov/psd/repository/alias/facts/>).

A third tool Web tool allows a user to download a set of plots for a specific location and date. Data are taken from several reanalysis data sets so users can examine both current and historic climate events.

We also provided a Web tool that allows users to plot vertical profiles and other vertical products including transects, skew-T, and time-height plots, at <http://www.esrl.noaa.gov/psd/map/profiles/>. Users select a location and date, and an optional second location or date, and a product is returned from one of the reanalysis data sets.

We have added the COBE2 SST/ICE (Centennial in situ Observation-Based Estimates-2 Sea Surface Temperature/Sea Ice) data set to our available data sets.



Space Weather Understanding and Prediction

NGDC-06: Satellite Anomaly Information Support

■ CIRES Lead: Juan Rodriguez ■ NOAA Lead: Bill Denig

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. The CIRES effort in this period included development of new tools, validation of environmental data, and improvements and additions to existing data.

The social media-driven auroral observing platform called PeEP (People Empowered Products), a collaborative effort with Cornell University, neared completion. We released a demonstration of the product in action at <http://auror.ae> at the end of 2013, just in time for some of the last major auroral displays of the Northern Hemisphere's winter (image). The product is fully functional, apart from a few aspects of the display that need to be polished.

We completed our validation of the relative accuracy of the Geostationary Operational Environmental Satellite (GOES) 8-15 solar proton data. Solar energetic particles (SEPs) consist of ions (protons, helium nuclei, and heavier ions), electrons, and energetic neutral atoms emitted by the Sun in association with solar flares and coronal mass ejections. SEPs have attracted scientific interest since their discovery in ground-level cosmic ray measurements in 1942, and NOAA has continuously monitored SEPs at geostationary orbit since the 1970s as an important aspect of space weather. SEPs pose a radiation hazard to robotic and human space flight, and to aircraft passengers and crews at high latitudes. SEPs also precipitate into the upper atmosphere, causing absorption of radio waves in the polar cap.

The level of agreement among various SEP measurements has received much attention for scientific reasons and because of the societal need for consistent space weather observations. Our validation effort was important because these observations are used to derive NOAA alerts involving human safety. We published a research paper in the AGU journal *Space Weather* in January (Rodriguez et al., Intercalibration of GOES 8–15 solar proton detectors, *Space Weather*, 12, 92–109) which demonstrates that SEP observations at geostationary orbit can be intercalibrated precisely, regardless of their look direction, when the dynamic pressure exerted on the Earth's magnetosphere by

the solar wind is greater than 10 nPa. As a result of this analysis, we now know that solar proton measurements by multiple GOES satellites since 1997 agree to 20 percent or better, even before the intercalibration correction coefficients are applied. The paper

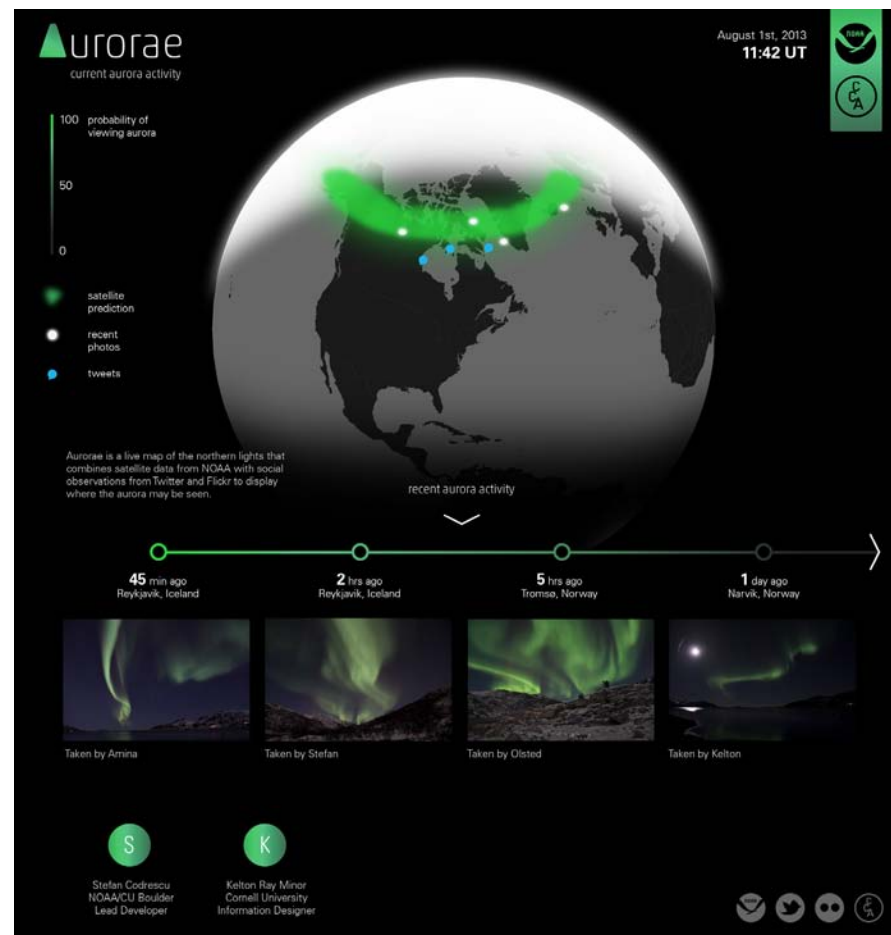


Image from the social media-driven auroral observing platform called PeEP (People Empowered Products).

was highlighted in *Eos Transactions* of the AGU on April 29, 2014, under “Research Spotlight” (p. 148).

Inspired by these results, we organized and led a workshop on April 11, 2014, in Boulder, Colorado on the intercalibration of solar energetic particle measurements, in collaboration with the Space Weather Prediction Center (SWPC) and following the annual Space Weather Workshop. Our mini-workshop included contributions from several universities, NASA, the European Space Agency, the World Meteorological Organization, Russia, China and Japan. We successfully met our goals of (1) discussing intercalibration of SEP measurements, (2) fostering new cooperative intercalibration efforts, and (3) recommending a path forward for establishing a set of intercalibration guidelines, a necessary step in achieving a consistent international scale for solar radiation storm alerts.

For decades, NGDC has archived the real-time GOES charged particle measurements processed by SWPC. Now, we have started to add new products and quality measures to the suite of GOES charged particle data. The first new product is the set of pitch angles for the MAGnetospheric Electron Detector (MAGED) and the MAGnetospheric Proton Detector (MAGPD) on GOES-13, -14 and -15. Pitch angles, the angles between charged particle velocities and the Earth’s magnetic field, are essential quantities for proper scientific interpretation of radiation belt measurements. The public may now access pitch angle data at NGDC, complete back to January 2011 and updated every 24 hours. This new data set is also being copied and made available by the NASA Space Physics Data Facility.

SWPC-01: Space Weather Information Technology and Data Systems

■ CIRES Lead: David Stone ■ NOAA Lead: Steven Hill

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:

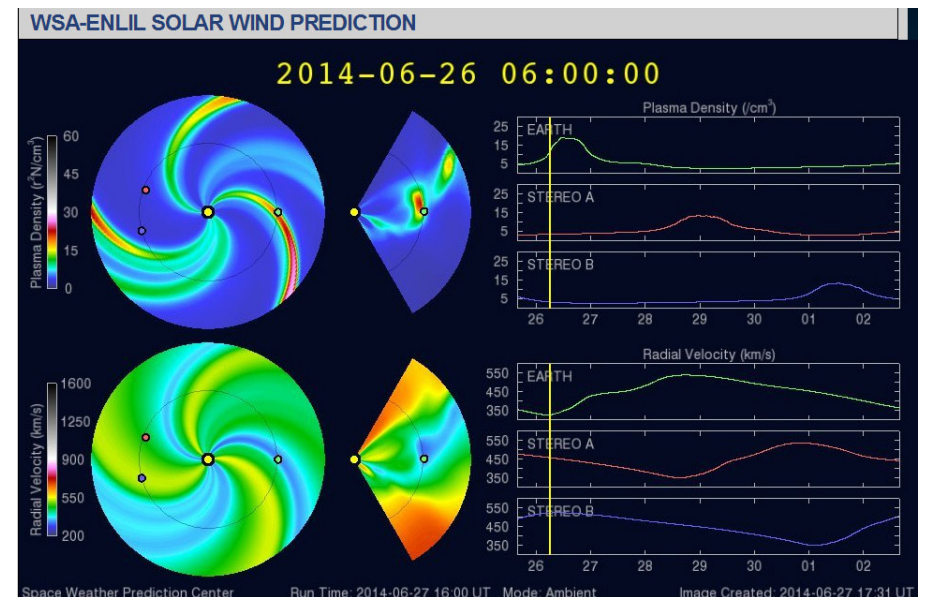
We implemented an upgrade to the Wang-Sheeley-Argge (WSA-Enlil) model (image) that brought significant improvements to the system. Upgrades included perfecting the system Coronal Mass Ejection (CME) Analysis Tool (CAT) and improving the model to account for slow temporal change in the solar corona outflow through which CMEs transit en route to Earth. The importance of the work was demonstrated by the publishing of a CAT development paper being published in the American Geophysical Union (AGU) *Space Weather Journal*.

CIRES staff successfully managed a half-dozen developers through the beta release of the Space Weather Prediction Center’s (SWPC) new public website. We coordinated walk-through tours of the site here with the lab and with the National Geophysical Data Center (NGDC) for feedback. The site now averages almost 10,000 sessions and 6,000 visitors per month.

We supervised the transition and validation of WSA-Enlil, the Product Subscription Service (PSS), the Space Weather Data Store (SWDS), and Geosynchronous Operational Environmental Satellite (GOES) Preprocessor system to the Alternate Processing Site for continuity of Operations (COOP).

We also transitioned the Space Environment Anomalies Expert System Real-Time (SEAESRT) model into operations to successfully support satellite operators in analyzing geostationary satellite charging hazards. Three new plots were released to the alpha website to facilitate diagnosis of satellite anomalies.

CIRES staff led the transition to operations effort of the Direct Mag Kp application, along with implementing several important improvements to Kp calculation and persistence. And we sponsored the introduction of Git as a distributed revision control and source code management system. This involved transitioning all the team’s Subversion software code repositories, simplifying code control, improving reliabil-



Significant improvements were made to the Wang-Sheeley-Argge model.

ity, decreasing the repository size and significantly improving team code reviews. To further improved team interactions and ease of use, we integrated Git with our project management software by acquiring the Stash plugin and training the team in its use.

We provided timely operational support for the following critical systems and maintained a high customer satisfaction:

- Advanced Composition Explorer (ACE) processor
- GOES processor and preprocessor
- WSA-Enlil
- Air Force and Institute for Science and Engineering Simulation (ISES) Message Decoder (AIMED) processor
- Polar Orbiting Environmental Satellite (POES) processor
- Microsoft SQL Server Space Weather Data Store (SWDS)

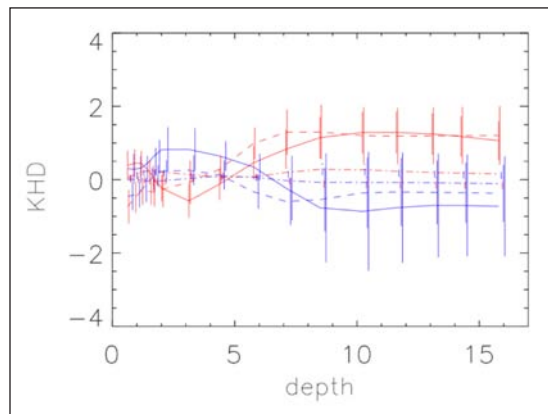
SWPC-02: Enhancement of Prediction Capacity for Solar Disturbances in the Geospace Environment

■ CIRES Lead: Alysha Reinard ■ NOAA Lead: Vic Pizzo

NOAA Theme: Weather-Ready Nation

Goals & Objectives:

This project will advance preparedness for solar storms affecting communication, transportation, and other U.S. infrastructure.



The KHD values of active regions on the Sun's northern (red) and southern (blue) hemispheres clearly have opposite signs, particularly deep below the solar surface.

Accomplishments:

We determined that separating active regions based on their hemisphere of origin produced an opposite sign in the subsurface helicity. The figure bottom left shows kinetic helicity density (KHD) from active regions in the northern (red) and southern (blue) hemispheres. The KHD values clearly have opposite signs, particularly deep below the solar surface. The effects of nearby active regions had little to no effect on the flare productivity of an active region.

SWPC-03: Analysis of the Role of the Upper Atmosphere in Space Weather Phenomena

■ CIRES Lead: Timothy Fuller-Rowell ■ NOAA Lead: Rodney Viereck

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 year we have examined the impact on the ionosphere of the spectrum of neutral atmosphere waves from the lower atmosphere. The waves, including inertial gravity waves, are generated self-consistently in the Whole Atmosphere Model (WAM), and propagate from a range of lower atmosphere sources including convective storm complexes and geostrophic adjustment of tropospheric and stratospheric jets.

We used the WAM neutral atmosphere wave field to drive the Global Ionosphere Plasmasphere (GIP) model, and the ionospheric response compared to observations

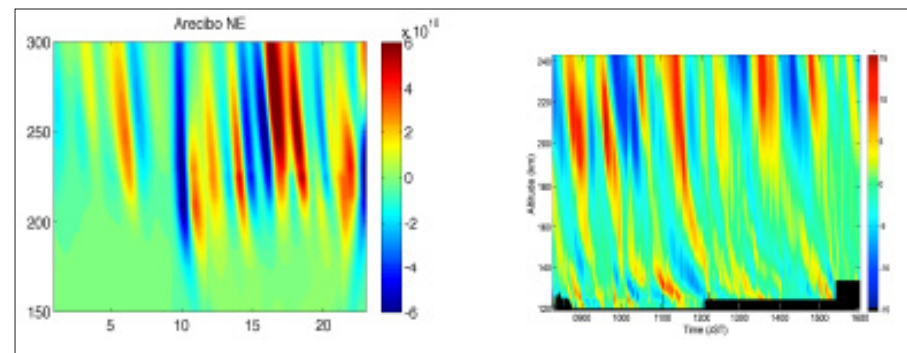


Figure 1. Comparison of the impact of lower atmosphere gravity waves on the ionosphere at Arecibo, Puerto Rico, as modeled by WAM-GIP on the left, and as observed by the incoherent scatter radar on the right.

from the Arecibo Incoherent Scatter Radar (ISR) observations. Comparisons of the observed and modeled perturbations in plasma density at the site are compared in figure 1. The perturbations are typically 15 to 20 percent, and the wave periods and vertical structure are well modeled by WAM-GIP. The impact of the waves on the ionosphere is expected to have a space weather consequence because of the reflection of high-frequency radio waves off the bottom-side ionosphere. The ionospheric tilts will change the propagation paths and the likelihood that the communication signals will reach their desired target.

This year we have also examined the impact of atmospheric tidal wave variability. In addition to modeling part of the spectrum of gravity waves from the lower atmosphere, WAM models the spectrum of tidal waves. These waves can have a range of wave numbers and tidal harmonics (e.g., 24, 12, 8, 6 hours, etc.), and can propagate both eastward and westward. Two such waves, the diurnal eastward propagating wave numbers 2 and 3 (DE2 and DE3), have been shown to be particularly important in creating structure in the thermosphere and ionosphere. We chose a period in September to analyze the impact of these two tidal modes on the ionosphere. These particular tidal modes are associated with latent heat release by tropical convective storms.

The tidal waves drive winds in the lower thermosphere dynamo region. Through the electrodynamic solver in GIP, we can model the electric fields and equatorial vertical plasma drift. The electric fields drive plasma transport and can cause substantial changes in plasma concentrations in the ionosphere, affecting space weather. The top panels of figure 2 show the change in the amplitude of the DE2 (right) and DE3 (left) tidal modes as a function of latitude during September at an altitude of 115 km. Note the amplitude of both modes exhibit a high degree of variability from day to day. We then used the tidal fields for each hour to drive the electrostatic dynamo in the GIP model for each day.

The impact on the vertical plasma drift as a function of longitude and local time is shown in the lower panels of figure 2 for 10 days in September. Note that on days when the DE3 mode is strong (e.g., September 16) a four-peak longitude structure is evident on the dayside ionosphere. The four peaks are a natural consequence of the wave 3 moving eastward diurnally in the longitude frame. Also note that on days when the DE2 mode is particularly strong (e.g., September 22) a three-peak longitude structure is evident. The simulations and analysis enable the space weather impact of the tidal wave field from the lower atmosphere to be quantified.

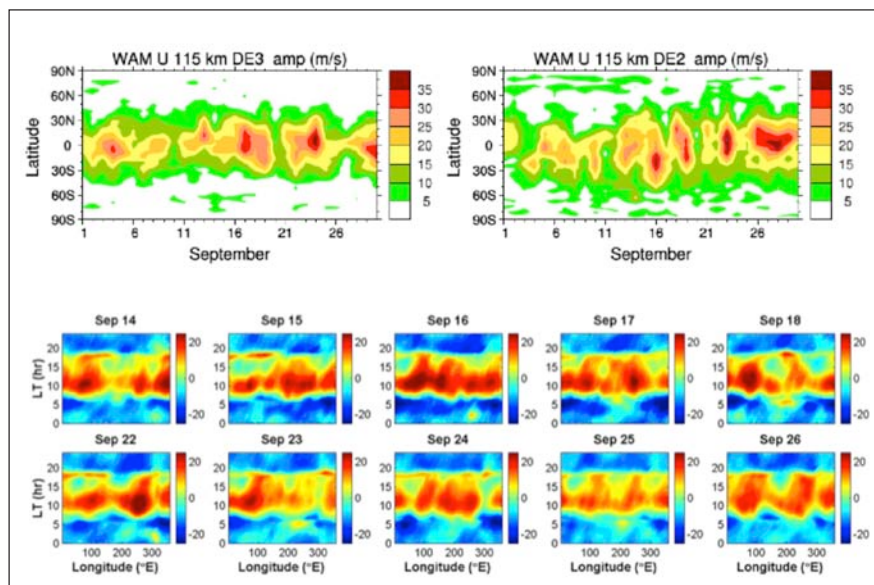


Figure 2. In the upper panels, the variation in the amplitude of the DE3 (left) and DE2 (right) tidal modes are shown at 115 km altitude in September, as a function of latitude and day, from the WAM whole atmosphere model. In the lower panels, equatorial vertical plasma drift is shown for ten days in September, illustrating the influence of the changing magnitude of the tidal models. Increase in amplitude of DE3 drives four peaks in longitude on the Earth's dayside ionosphere; DE3 on the other hand drives three peaks in longitude.

Stratospheric Processes and Trends

CSD-09: Stratospheric Radiative and Chemical Processes That Affect Climate

■ CIRES Lead: Sean Davis ■ NOAA Lead: Karen Rosenlof

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 in the stratospheric ozone layer, in that region of the atmosphere.

Accomplishments:

During the past year, this project made several advances in understanding the interactions of stratospheric composition, stratospheric circulation variability, and climate.

One major theme of this project is to better quantify the climate response to stratospheric ozone depletion. However, it is critical to have well-validated ozone data sets before using such data sets to model the climate response to ozone depletion. Towards this end, we intercompared and validated several ozone data sets we created, in conjunction with the international SI²N (SPARC/IO₃C/IGACO-O₃/NDACC) activity on “Past changes in the distribution of vertical ozone.” Specifically, we updated and evaluated our Stratospheric Water Vapor and OzOne Satellite Homogenized (SWOOSH) data set and the Binary DataBase of Profiles (BDBP). One key aspect of the SI²N activity was quantifying the uncertainty associated with past changes in ozone. We presented validation and preliminary comparisons between our data sets and other data sets at several meetings (Wang et al. 2013; Davis et al. 2013; Hassler et al. 2013; Davis et al. 2014; Hassler et al. 2014; Hassler 2014). Overall, our data sets compare favorably with other data sets participating in the activity (Tummon et al. in prep; Harris et al. in prep; Hassler et al. 2014).

We used the BDBP and the IPCC ozone data set as input to the National Center for Atmospheric Research climate model to study the climate impact from stratospheric ozone depletion since ~1980. We found that our BDBP ozone data set caused a significantly stronger climate response than IPCC data. These results suggest that the IPCC models may have underestimated the climate response from stratospheric ozone depletion (Young et al. in preparation).

In addition to the model runs, we also investigated the possibility that zonal asymmetries in ozone depletion have played a role in enhancing the climate response to ozone depletion. Several existing studies have tackled this issue at a conceptual level, but none of these studies have demonstrated this using observational data. Our initial observationally based

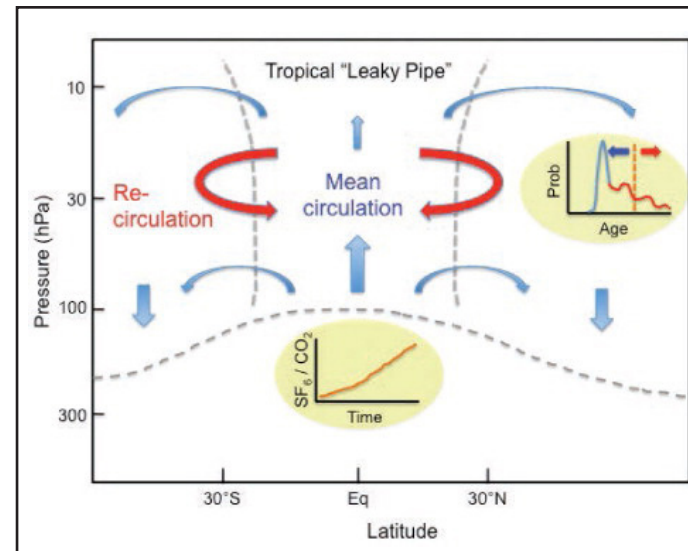
simulations show that zonally asymmetric ozone depletion enhances the climate response, but not as strongly as in previous work (Davis, 2013).

In addition to the ozone-related research, we made significant contributions to quantifying and understanding the role of stratospheric water vapor in the climate system.

Using climate models and the SWOOSH water vapor data, we helped to identify and quantify a stratospheric water vapor feedback to climate that is non-negligible and roughly the size of the ice-albedo feedback (Dessler et al. 2014). We also collaborated in a project that established an important role for stratospheric water vapor in driving lower stratospheric temperature trends (Maycock et al., 2014).

Finally, we also collaborated with Dale Hurst from the ESRL Global Monitoring Division to intercompare the Boulder Frostpoint Hygrometer (FPH) data with Aura Microwave Limb Sounder (MLS) satellite measurements. This work showed that the Aura MLS measurements agree to within the uncertainties with the Boulder FPH record (Hurst et al. 2014). This validation was necessary to have confidence in the use of Aura MLS measurements for global-scale studies of stratospheric water vapor.

In addition to the water vapor and ozone studies, we also studied variability and long-term change in the stratospheric circulation. Climate models predict that the stratospheric



A schematic with the main components of the stratospheric circulation. Full caption in the *Bulletin of the American Meteorological Society*, doi: 10.1175/BAMS-D-12-00153.1

circulation will speed in response to climate change. Several previous studies have pointed to a discrepancy between model-predicted increases in stratospheric circulation and observations, which do not show a speeding of the circulation. Our study presents a new analysis of the observational data to better explain the discrepancy (Ray et al. submitted). Another study outlines a strategy for future observations to measure radiatively active gases and monitor future stratospheric circulation changes (Moore et al. 2014).

Presentations

Hassler, B. The joint SPARC/IO3C/IGACO-O3/NDACC Initiative on Past Trends in the Vertical Distribution of Ozone. 2014 Ozone Mangers meeting. May 14-16, 2014; Geneva, Switzerland.

Davis, SM, and KH Rosenlof. The Stratospheric Water Vapor and OzOne Satellite Homogenized (SWOOSH) data set. NOAA Global Monitoring Division Annual Conference. May 21, 2014; Boulder, Colorado.

Hassler, B, N Harris, KH Rosenlof, J Staehelin, R Stolarski, I Petropavlovskikh and F Tummon. Past Changes in the Vertical Distribution of Ozone: The SI2N Activity and Its Outcome. NOAA Global Monitoring Division Annual Conference. May 21, 2014; Boulder, Colorado. (presented by K. Rosenlof)

Published

Hurst, DF, A Lambert, WG Read, SM Davis, KH Rosenlof, EG Hall, et al. 2014. Validation of Aura Microwave Limb Sounder stratospheric water vapor measurements by the NOAA frost point hygrometer. *Journal of Geophysical Research-Atmospheres* 119(3), 1612–1625. doi:10.1002/2013JD020757.

Maycock, AC, MM Joshi, KP Shine, SM Davis, and KH Rosenlof. 2014. The potential impact of changes in lower stratospheric water vapour on stratospheric temperatures over the past 30 years. *Quarterly Journal of the Royal Meteorological Society*. doi:10.1002/qj.2287.

Moore, FL, EA Ray, KH Rosenlof, JW Elkins, P Tans, A Karion, and C Sweeney (n.d.). A Cost-Effective Trace Gas Measurement Program for Long-Term Monitoring of the Stratospheric Circulation. *BAMS*, doi: 10.1175/BAMS-D-12-00153.1.

Several other papers have been submitted or are in preparation.

GMD-02: Analysis of the Causes of Ozone Depletion

■ CIRES Lead: Irina Petropavlovskikh ■ NOAA Lead: Russ Schnell

NOAA Theme: Climate Adaptation and Mitigation

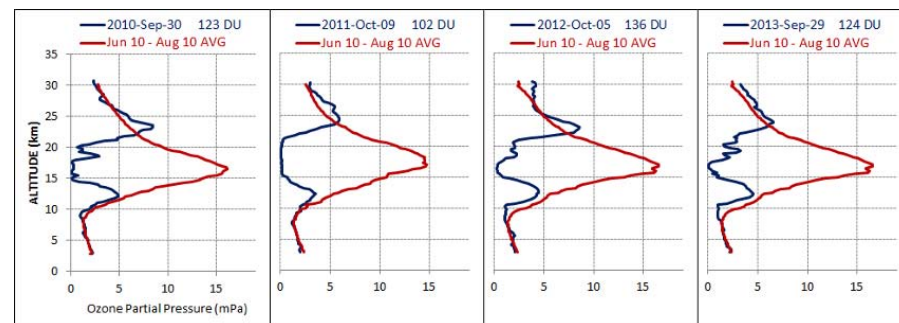
Goals & Objectives:

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:

In collaboration with federal colleagues, CIRES scientists in the ESRL Global Monitoring Division continued monitoring of stratospheric and tropospheric ozone variability at 15 stations worldwide. We collected more than 10,000 ozone column measurements from Dobson instruments at 17 stations, with six stations producing Umkehr ozone profiles. The data are archived at NOAA ESRL GMD (<ftp://ftp.cmdl.noaa.gov/ozwv/>) and are also regularly submitted to the World Meteorological Organization (WMO) World Ozone and Ultraviolet Radiation Data Centre (WOUDC) in Canada, and Network for the Detection of Atmospheric Composition Change (NDACC) centers.

We continued validation activities of ozone profiles and total column from the Ozone Mapping and Profiler Suite (OMPS) instrument aboard the NASA/NOAA National Polar-orbiting Partnership (NPP) satellite. As a result, several software programs were written that assist with data conversion and comparisons of satellite and ground-based profiles. We wrote and published the first validation paper (Flynn et al. 2014).



The South Pole minimum ozone profiles and date measured from 2010–2013. The charts also include the normal ozone profile observed several weeks before ozone begins dropping over the South Pole in late winter. The charts show altitude above sea level in kilometers with ozone amount in the horizontal axis (http://www.esrl.noaa.gov/gmd/dv/spo_oz/spmin.html).

Ozonesonde launches at 15 stations are supported through the NOAA OAR Health of Atmosphere program and NSF and NASA Southern Hemisphere ADditional Ozonesondes (SHADOZ). During the reporting period, we conducted 182 launches for the SHADOZ program and 250 for NOAA and NSF programs combined. All NOAA-funded data are timely processed and placed on the NOAA ftp site for public distribution. SHADOZ data are reported from the NASA website (<http://croc.gsfc.nasa.gov/shadoz/>).

Our work to reprocess ozonesonde records at several long-term NOAA stations continued through 2013 and 2014. Our approach was to correct the instrumental artifacts (change of the sonde types in time series and the pump pressure corrections). We conducted the processing in accordance with the directives to homogenize time series of ozonesonde data for trend analysis in the upcoming 2014 WMO Ozone assessment. We accomplished this in the spring of 2014 and will submit data to the NDACC in 2014.

For the second year in a row, Antarctic spring in 2013 was unusually warm and did not last long enough to produce significant ozone depletion at NOAA South Pole station. The record-low ozone measured at South Pole station was ranked 18th, with the ozone column as low as 124 DU (2012 was ranked 24th, with 136 DU). The vortex shifted off the South Pole station sooner in 2013 than previously observed in the 50-year-long record and thus the recovery of the spring depletion was faster than in previous years. South Pole personnel will continue monitoring ozone depletion in Antarctica.

A good portion of 2013 was dedicated to the 2014 WMO Ozone assessment. Several papers published in 2013 and 2014 analyze ozone profile time series taken by Dobson and ozone sonde methods. One paper reported no significant recovery in stratospheric ozone above Antarctic Syowa station (Miyagawa et al. 2013) and another paper found a recent decline in stratospheric ozone over Boulder. Both papers concluded that dynamical variability of the atmosphere masks the small expected chemical recovery of ozone.

Flynn, L., Long, C., Wu, X. Evans, R. Petropavlovskikh, I. McConville, G. Yu, W. Zhang, Z. Niu, J. Beach, E. Hao, Y. Niu, J. Pan, C. Sen, B. Novicki, M. Zhou, S. Seftor, C., 2014: Performance of the ozone mapping and profiler suite (OMPS) products. *J. Geophys. Res.*, doi: 10.1002/2013JD020467.

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

■ CIRES Lead: Fred Moore ■ NOAA Lead: James W. Elkins

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:

Our work and accomplishments are tied to long-term global observations derived from two surface networks: a flask sampling program (flask collected daily to weekly) and an hourly in situ program. We also obtain results from light aircraft profiles conducted at about 20 locations, mostly over North America. Results from these programs feed into the calculations of NOAA's Annual Greenhouse Gas Index (AGGI) and the Ozone Depleting Gas Index (ODGI). These data are integral to the United Nations Environment Programme's (UNEP)/World Meteorological Organization (WMO)



CIRES researcher Fred Moore with the SkyWisp unmanned aircraft. Photo credit: NOAA

2014 Scientific Assessment of Ozone Depletion report, which was finalized this year. This year was also highlighted by a substantial push to expand both our instrumentation and the platforms used to take data. We constructed a new gas chromatograph mass spectrometer (GCMS) named Perseus, now in its final stages of development and testing. We have scheduled stability, accuracy, and comparison tests with the legacy M2 and M3 instruments. The increased throughput, higher precision and accuracy, and the addition of new and more volatile compounds will greatly improve our flask data set.

Regular low-altitude airborne flask measurements and periodic higher-altitude, mission-oriented measurements complement these surface observations. For example, during this reporting period we completed the NASA Airborne Tropical Tropopause Experiment (ATTREX-3) campaign, based primarily out of Guam, which focused on the tropical convective processes near the warm pool. These processes define transport of water vapor and the ozone depleting gas into the tropical tropopause layer and the stratosphere. Our airborne programs help define the process that connects the surface network measurements to the atmosphere as a whole. By themselves, each set of results addresses specific aspects of atmospheric chemistry (source and sinks), transport, feedback mechanisms, etc. However, because these data sets conform to a common in-house standards program, they represent a much more powerful tool when combined with the surface observations, and they are especially well-suited to three-dimensional model analysis. This combined data set continues to aid emissions studies and global-local process oriented studies. The publications below highlight some of these studies.

As stated earlier, our year was highlighted by a substantial push to expand both our instrumentation and the platforms used to collect data. We added a second ozone photometer to our in situ gas chromatograph. We submitted a new NASA proposal, the Atmospheric Tomography Mission (AToM)—Imaging the Chemistry of the Global Atmosphere, to put our in situ GCMS instruments (PANTHER and UCATS) on the DC-8 aircraft. This will generate a chemistry-oriented extension of the global-scale observations from 2009-2011, made during HIPPO, the HIAPER (High-Performance Instrumented Airborne Platform for Environmental Research) Pole to Pole Observation. We also moved forward on our small unmanned aerial vehicle (UAV) program with improvements to SkyWisp (photo on page 123), a UAV glider return vehicle dropped from 32 km, and new work on the 3D Robotics Aero electric powered plane, which uses an open source software based Pix Hawk auto-pilot.

Hall, B.D., A. Engel, J. Mühle, J. W. Elkins, F. Artuso, E. Atlas, M. Aydin, D. Blake, E-G. Brunke, S. Chiavarini, P. J. Fraser, J. Happell, P. B. Krummel, I. Levin, M. Loewenstein, M. Maione, S. A. Montzka, S. O'Doherty, S. Reimann, G. Rhoderick, E. S. Saltzman, H. E. Scheel, L. P. Steele, M. K. Vollmer, R. F. Weiss, D. Worthy, Y. Yokouchi, Results from the International Halocarbons in Air Comparison Experiment (IHALACE), *Atmos. Meas. Tech.*, 7, 496-490, 2014. (Submitted in 2013).

GMD-06: Monitor Water Vapor in the Upper Troposphere and Lower Stratosphere

■ CIRES Lead: Dale Hurst ■ NOAA Lead: Russ Schnell

NOAA Theme: Climate adaptation and mitigation

Goals & Objectives:

This project is a new one, constituting an amendment to the CIRES workplan. It makes use of balloon-borne frost point hygrometer measurements from three monitoring sites to detect inter-annual and longer-term trends in upper troposphere/lower stratosphere (UTLS) water vapor. The goal is to improve our understanding of what drives water vapor changes in the UTLS and how these changes influence climate.

Accomplishments:

Monthly soundings of the balloon-borne NOAA frost point hygrometer (FPH) continued at the three monitoring sites (Boulder, Colorado; Hilo, Hawaii; Lauder, New Zealand) to extend the long-term UTLS water vapor records. The Boulder record, the



CIRES' Patrick Cullis releases a high-altitude balloon, which carries ozone-measurement equipment up to 20 miles high in the atmosphere, from a monitoring site in Boulder, Colorado. Photo credit: David Oonk/CIRES

longest continuous UTLS water vapor data set in existence, entered its 35th year. In 2013 CIRES personnel operated the FPH during an international water vapor measurement inter-comparison (AquaVIT-2) conducted at the 84 m³ AIDA environmental chamber in Karlsruhe, Germany. Results from this laboratory-based comparison of more than 20 different water vapor sensors are pending. In February 2014 CIRES personnel performed water vapor soundings from the island of Guam as part of the NASA-funded Airborne Tropical Tropopause Experiment (ATTREX). The campaign was designed to study the important tropical tropopause region of the atmosphere that influences the composition of the stratosphere, with a focus on processes controlling stratospheric humidity.

Three papers utilizing NOAA FPH data were published in the *Journal of Geophysical Research: Atmospheres* during this reporting period. One paper quantitatively compared FPH stratospheric measurements with water vapor retrievals from the Aura Microwave Limb Sounder (MLS) during 2004-2012. The comparison utilized MLS profiles coincident in time and space with the FPH soundings at Boulder, Hilo and Lauder. Agreement between FPH and MLS measurements was shown to be excellent (better

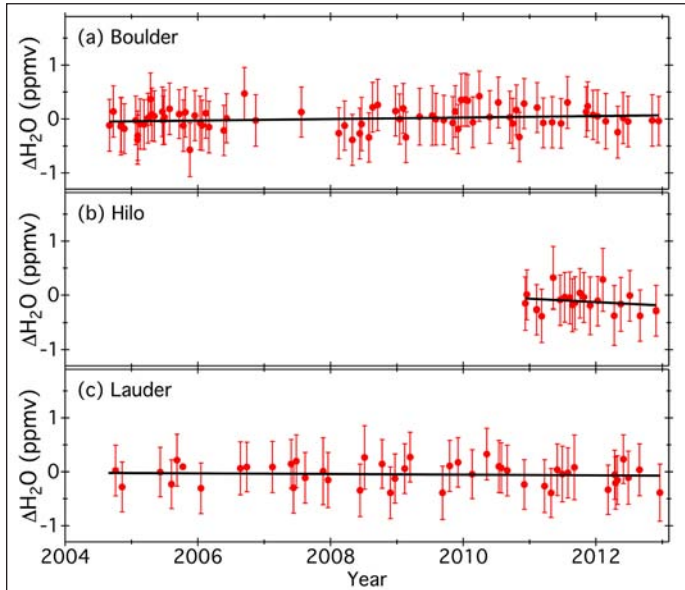
than 1 percent) from 68 to 26 hPa over all three sites. Comparisons at 83 and 100 hPa revealed a 2-10 percent high (wet) bias in MLS retrievals relative to the FPH measurements in the lowermost stratosphere. These discrepancies have important implications for radiative transfer and climate models. Instrumental drift was examined by linearly fitting the time series of FPH-MLS differences at each MLS retrieval pressure (figure below). None of the fit slopes depicted statistically significant trends although the FPH record at Hilo was too short to detect anything but very large trends.

Publications

Hurst, D. F., A. Lambert, W. G. Read, S. M. Davis, K. H. Rosenlof, E. G. Hall, A. F. Jordan, and S. J. Oltmans (2014) Validation of Aura Microwave Limb Sounder stratospheric water vapor measurements by the NOAA frost point hygrometer, *J. Geophys. Res. Atmos.*, 119, doi:10.1002/2013JD020757.

Kunz et al, 2013.

Fueglistaler et al, 2013.



Differences between NOAA FPH and Aura MLS measurements of water vapor at 46 hPa show no significant drifts between the two instruments during 2004-2012 (2010-2012 for Hilo).

Systems and Prediction Models Development

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

■ CIRES Lead: Gary Hodges ■ NOAA Lead: Joseph Michalsky

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.

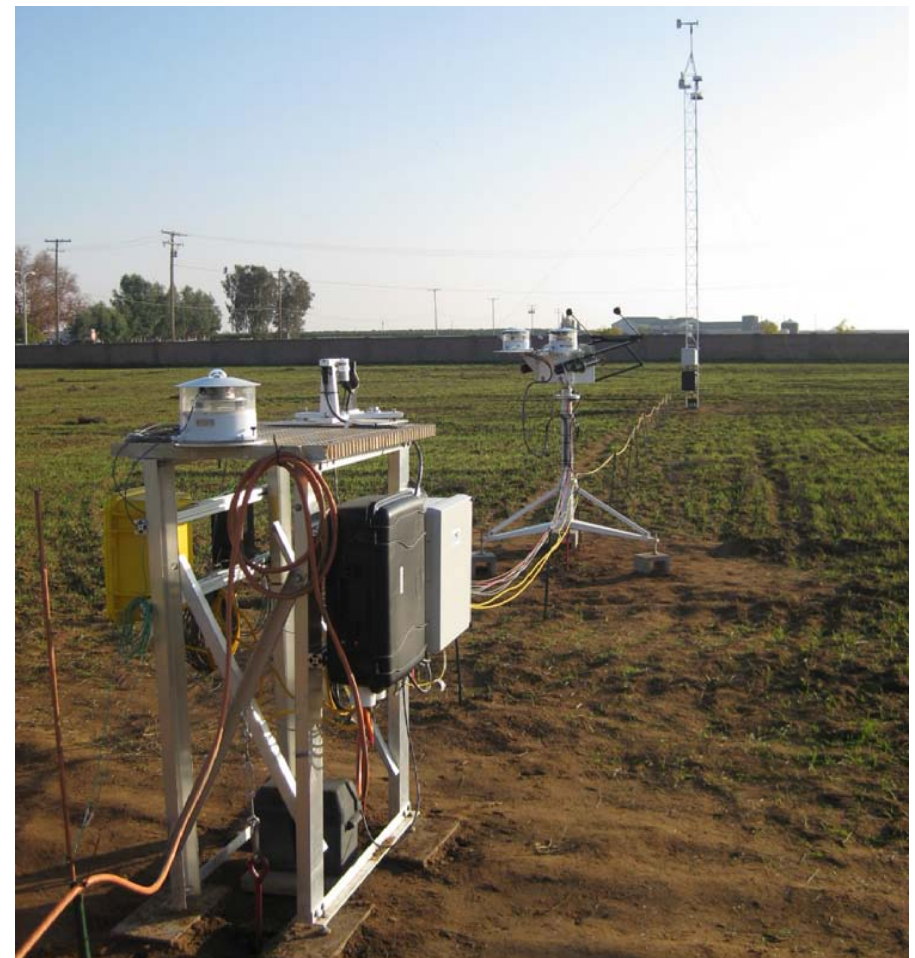
Accomplishments:

During the past year we have kept the Surface Radiation (SURFRAD) network operating with minimal problems and minimal lost data through regular site maintenance, preventative measures, and infrastructure and equipment improvements. Many of the preventative measures and infrastructure improvements are of the important, but mundane, variety. Tasks such as tightening bolts, pest control, and replacing degraded signal wires don't make for compelling reports, but are crucial for keeping the SURFRAD network operating at such a high level. One site component worth mentioning is the data logger. This year we have begun the replacement of the site data loggers with an upgraded model. The new logger has a more current design and it also offers design features that we will take advantage of in the near future. The new loggers have the potential for a large amount of local data storage with a storage module addition. The old logger only held about 10 days of data, and this limitation at times results in data loss when a site's communication is down for an extended period. The new loggers also offer an improvement in communications, discussed below.

The suite of SURFRAD instruments remains the same, but we have begun a significant upgrade of two of those systems. We are now in the process of redesigning and upgrading the internal components of the Total Sky Imagers (TSIs). The redesign simplifies the component layout and greatly eases the task of replacing failed components. The upgrade allows us to remotely align the instrument as necessary without the need of coordinating with a local person. Another important added feature is the ability to connect a GPS antenna directly to the unit for automated setting of location information and accurate time keeping. As funding allows, we are also replacing our Multi-Filter Rotating Shadowband Radiometers (MFRSRs) with a newer model. The new MFRSRs replace the 615 nm channel with a 1625 nm channel. The new channel, further into the infrared, will help us better define coarse mode particles in the atmosphere and will improve cloud retrievals and surface spectral albedo measurements. The instrument shading feature (the shadowband)—long the most difficult aspect of

configuring a MFRSR in the field—has been significantly improved.

Perhaps the most important change currently underway at all seven SURFRAD sites is the transition from copper phone line communication to wireless broadband using cell phone technology. The move to wireless broadband is very exciting. At many sites



Galveston, Texas, SURFRAD station. Photo credit: NOAA/CIRES

the ancient copper phone lines have been a consistent source of headaches for us and for our local site contacts. Bad phone lines are by far the most common cause of lost data. Moving to wireless broadband will also allow us to collect data in near real-time. Real-time data are coveted by many researchers, especially those working on renewable energy projects. The new data loggers described above have the ability to add a communication module that allows broadband speeds for downloading data.

We now have two mobile SURFRAD stations that have been deployed to a number of different locations for two primary purposes. Our first mobile station has been associated with a national air quality research project known as Deriving Information on Surface conditions from Column and Vertically Resolved Observations Relevant to Air Quality (DISCOVER-AQ). Last summer the station was located on the shore of Galveston Bay, Texas (photo on page 126), and this summer it is being deployed near Erie, Colorado. The second mobile station is being set up for deployment at a large photovoltaic array near Alamosa, Colorado, to support renewable energy research.

GSD-01: Improve Weather Information Systems

■ CIRES Lead: Leon Benjamin ■ NOAA Lead: Gregory Pratt

NOAA Theme: NOAA Engagement Enterprise

Goals & Objectives:

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

Accomplishments:

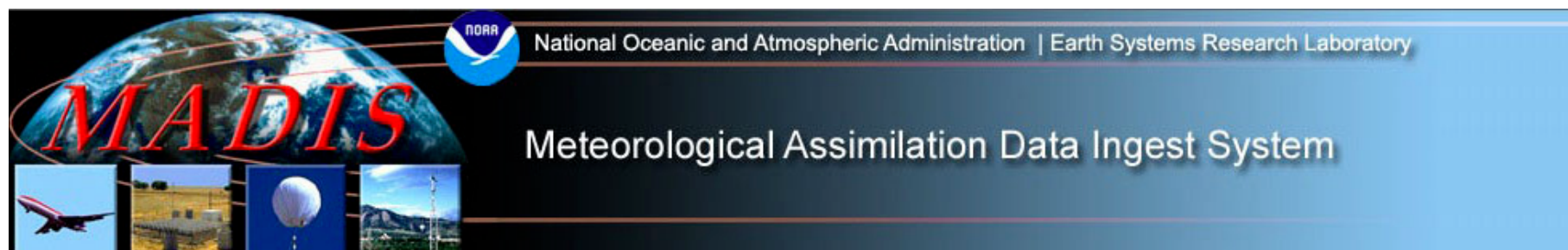
MADIS and AWIPS II. Meteorological Assimilation Data Ingest System (MADIS) has been scheduled for final operating capability at NOAA's National Weather Service (NWS). MADIS is a conduit for providing NWS operations with non-NWS meteorological data and quality control algorithms, for use by the greater meteorological community. MADIS Final Operating Capability (FOC) at NWS is scheduled for December 31,

2015. MADIS has run its processing on the Weather and Climate Operational Super-computer Systems (WCOSS) successfully for the last year. MADIS on-boarded its ingest to the NWS Integrated Dissemination Program (IDP), and acceptance is scheduled for July 2015. The MADIS real-time processing and distribution are in the on-boarding process, with acceptance scheduled for the fall of 2015.

During the last year, MADIS added 1,500 new surface sites, four data providers, 20,000 more surface records an hour, and 40,000 more surface and upper-air records per hour. The new data providers include the National Estuarine Research Reserve System (NERRSSNOW) and miscellaneous providers in Alaska. MADIS also added more than 200 new data users and serviced more than 1 million data requests a day.

MADIS successfully installed the Advanced Weather Interactive Processing System II (AWIPS II) Data Provider Agent (DPA), which would be a direct way to feed MADIS to the weather forecast office. We are in the process of evaluating the DPA performance and capabilities. This reporting season, we also ported FX-Collaborate software to AWIPS II and developed an AWIPS II collaboration prototype.

Prototype Hazard Services in AWIPS II. The Hazard Services Project is creating the capability for timely and accurate issuance of hazard information and effective communication of this information in a digital world—the foundation of the NWS Weather-Ready Nation goal. In the second generation of AWIPS, the issuance of hydrological and meteorological watches, warnings, and advisories is handled by three separate hazard generation applications, each of which has a different user interface and process. Hazard Services is an AWIPS II extended project, which will provide one common interface and process for issuing hazard products while preserving the efficiency of the existing applications. It will also foster communication among all stakeholders, including partners external to NWS, such as emergency managers. Hazard Services will streamline NWS watch, warning, and advisory operations, allowing NWS 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 2013-2014, we completed the Production Version Two (PV2) “Hazard Services Road Show.” We completed a one day demonstration and test drive of the PV2 software at the National Weather Service forecast offices in Grand Junction, Pueblo, and Boulder, Colorado; Cheyenne, Wyoming; Goodland, Kansas; and Burlington, Vermont. We also completed numerous re-factoring of the code to improve performance, reduce maintenance, and create better separation of concerns. We completed version PV3 and got the Hazard Services tool into a testbed in Nebraska.

The Ensemble Tool. The Ensemble Tool is an Ensemble-based Numerical Weather Prediction (NWP) visualization and manipulation capability on the NWS AWIPS workstation. Computer model forecasts are the basis for modern weather forecasting. All models are imperfect, but multiple models, i.e., an ensemble of models, can be statistically processed into a single forecast that, over many forecasts, will perform better than any of the individual predictor models. Furthermore, the spread in the ensemble solutions is an indicator of the forecast uncertainty, and can be used to estimate event probabilities, such as the chance that today’s maximum temperature will exceed 90° F. And finally, a variety of forecast solutions gives the forecaster fully-described alternative scenarios, for example, what the conditions will be like if the cold front does, or does not, pass through the forecast area.

We worked with the NWS Regional Science Service Division chiefs to develop requirements for the ensemble tool, and successfully demonstrated prototype software for NWS. The NWS requested that we advance the prototype to the AWIPS II baseline.

GSD-03: Improving Numerical Weather Prediction

■ CIRES Lead: Curtis Alexander ■ NOAA Lead: Georg Grell

NOAA Theme: Science and Technology Enterprise

Goals & Objectives:

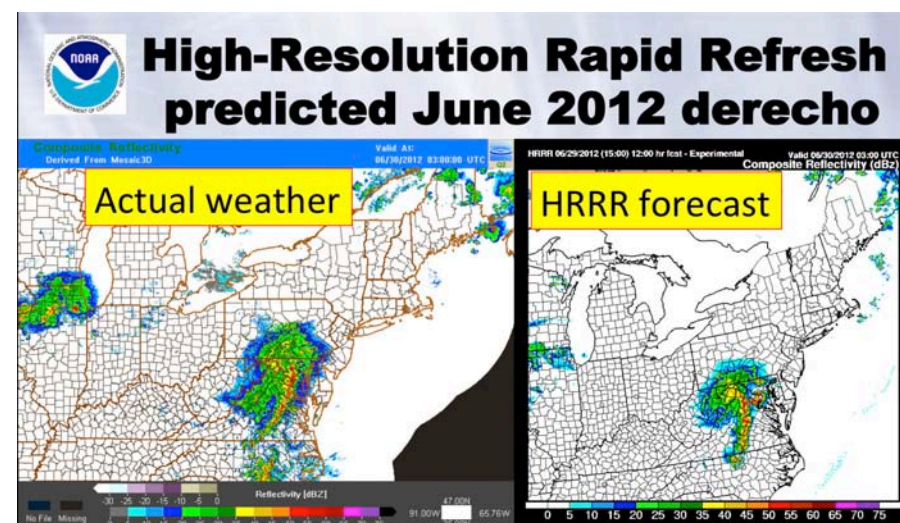
This project focuses on improvements in numerical weather prediction by use of models through improved model design and implementation and optimal use of new and existing observations.

Accomplishments:

The second, more advanced, version of the Rapid Refresh (RAP) model from ESRL was implemented operationally at the National Centers for Environmental Prediction (NCEP) on 25 February 2014. This version of the RAP includes the Advanced Weather Research and Forecasting model (WRF-ARW) version 3.4.1 as the code base. Additional enhancements in the RAP version 2 include weather (flow) dependent

data-assimilation using a hybrid Global Forecast System (GFS) 80-member ensemble Kalman filter and 3-D variational background error covariance estimate. Model physics improvements in version 2 include the adoption of a nine-level Rapid Update Cycle (RUC) land surface model with shallower near-surface levels to reduce the thermal inertia and improve forecasts of 2-m temperatures and dewpoints and 10-m winds. The planetary boundary layer scheme is changed from Mellor-Yamada-Janjic (MYJ) to an enhanced version of the Mellor-Yamada-Nakanishi-Niino (MYNN) scheme.

Development of the third version of the RAP model continued into April 2014 with our real-time experimental model runs at ESRL. This development includes the update to the WRF-ARW version 3.5.1 code base along with many physics changes including a new Grell-Freitas convective parameterization scheme with scale-aware activation including shallow convection. The shortwave and longwave radiation schemes are changed to a more advanced Global Rapid Radiative Transfer Model (RRTMG) that uses a statistical model for sub-grid scale cloud variability. Seasonally varying Moderate Resolution Imaging Spectroradiometer (MODIS) vegetation fraction and leaf area index are added to improve prediction of sensible and latent heat fluxes. The MYNN



The HRRR forecast model was the only NOAA model to capture, in advance, the June 29, 2012, derecho event. On the left is an animation of the HRRR forecast beginning at 11 a.m. eastern time that day, made available by NOAA in the early afternoon. On the right is the actual radar of the storm, which shows that the HRRR forecast closely aligned with what occurred. Image credit: NOAA

boundary layer scheme is enhanced through radiative feedback coupling with the shallow cumulus convective parameterization. Data assimilation changes include an introduction of cycled satellite radiance bias correction for a tighter fit to higher atmospheric observations.

The ESRL High-Resolution Rapid Refresh (HRRR) real-time experimental 3-km model remains a foundational component of the 2010–2014 Consolidated Storm Prediction for Aviation (CoSPA) forecast system used for convective weather guidance in both tactical and strategic flight planning. The National Weather Service, including the Storm Prediction Center, extensively uses the HRRR for severe-weather prediction. Use of HRRR forecasts in the renewable energy industry for wind and solar forecasts are having an increased emphasis.

An initial version of the HRRR model, including 3-km radar and conventional data assimilation, has been transferred to NCEP in preparation for the first operational implementation later in 2014. Development of a second version of the HRRR model continued into April 2014 with our real-time experimental model runs at ESRL. This development includes the update to WRF-ARW version 3.5.1 code base and addition of 6th order diffusion to reduce grid-scale noise. Additional model physics changes to the radiation, boundary layer and land surface model include those made in the parent RAP version 3 model along with the same hybrid data-assimilation in Gridpoint Statistical Interpolation (GSI).

Additional products were derived from the ESRL HRRR forecasts including a real-time mesoscale analysis (RTMA) using short-term (one to two hour) forecasts as a background when assimilating surface observations for estimating the current state of surface weather conditions across the coterminous U.S. every fifteen minutes. A multi-year HRRR model climatology was established to estimate the regional, diurnal, and seasonal availability of wind and solar resources across the United States at a 3-km scale along with estimates of short-term (six-hour) precipitation and associated reflectivity. Initial work to extend a limited number of daily HRRR model runs from fifteen to 48 hours was completed on a National Renewable Energy Laboratory high performance computer. Finally, the hourly HRRR model runs are being used in a time-lagged ensemble to estimate the likelihood of convection in the form of probabilities that are being evaluated in real-time at the Aviation Weather Center.

GSD-05: Development of High-Performance Computing Systems

■ CIRES Lead: Craig Tierney ■ NOAA Lead: Forrest Hobbs

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:

Over the past year, our team has extended several tools and methodologies that the National Oceanic and Atmospheric Administration (NOAA) relies on for efficient use of their High Performance Computing (HPC) systems. Our accomplishments this year include continued development and use of the Rocoto Workflow Management System



A high-performance computing system at NOAA's Earth System Research Laboratory. Photo credit: Will von Dauster/NOAA

and improvements in workflow management to support deadline driven science within NOAA's HPC environment.

During the past year, we have added many enhancements to the Rocoto Workflow Management System and expanded its user base. Version 1.1, released in September, added key capabilities that facilitate the expression of workflow requirements. ESRL's Global Systems Division and the Developmental Testbed Center (DTC) have relied on Rocoto for automation of large retrospective and real-time workflows on NOAA's and National Center for Atmospheric Research's (NCAR) HPC systems for several years. In the past year, Rocoto has also been adopted by researchers at NOAA's National Center for Environmental Prediction (NCEP) Environmental Modeling Center (EMC) for automating the High Resolution Rapid Refresh (HRRR), Hurricane Weather Research Forecast (HWRF), and Non-hydrostatic Mesoscale Model (NMMB) modeling systems on the National Weather Service's Weather and Climate Operational Supercomputing System (WCOS). Researchers at the Atlantic Oceanographic and Meteorological Laboratory (AOML) Hurricane Research Division (HRD) have also adopted Rocoto for use on clusters at the University of Miami and the University of Wisconsin, to run Observing System Simulation Experiments (OSSEs). The adoption of Rocoto by EMC and HRD researchers is significant because it means that Rocoto is providing a key functionality in NOAA modeling efforts that transition research into operations.

One of the major projects we support is NOAA's Hurricane Forecast Improvement Project (HFIP). During their real-time experiment season, typically June through November, it is required that their hurricane forecasts complete by specific deadlines (so that the National Hurricane Center can evaluate next-generation hurricane forecasts in real time). To meet programmatic requirements, these systems must not be underutilized during this season, and traditional research and development (R&D) simulations must continue. To meet these requirements, we have developed novel methods to support deadline-driven science on traditional R&D HPC systems. The system relies on several different future reservation methods, dynamic support of multiple hurricane scenarios, and extended user control to support over 150 reservations and more than 10,000 jobs per day. With this system, more than 20 different projects simultaneously generate daily hurricane forecasts and deliver their results on time to the NHC for evaluation alongside the traditional R&D workload.

GSD-06: Verification Techniques for Evaluation of Aviation Weather Forecasts

■ CIRES Lead: Matthew Wandishin ■ NOAA Lead: Jennifer Mahoney

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:

CIRES scientists in the ESRL Global Systems Division continue to support aviation weather forecasting and verification techniques. During this reporting period, we released the next version of the Integrated Support for Impacted air-Traffic Environments (INSITE) Web-based application, providing convective weather forecast guidance to aviation weather forecasters.

Our team also completed evaluation of the latest version (1.1) of the Current Icing Potential (CIP) and Forecast Icing Potential (FIP) products.

We completed most of the evaluation of the latest version of the Graphical Turbulence Guidance (GTG) product; evaluation of the GTG nowcast product has been delayed by the FAA.

We completed preparation for the evaluation of Icing Product Alaska (IPA), including the identification of available observation platforms, e.g., polar orbiting satellites, and development of techniques for using those data.

The National Weather Service is switching to Multi-Radar Multi-Sensor (MRMS) as the operation national radar mosaic product. In support of this effort, we completed preparation for evaluation of Corridor Integrated Weather System (CIWS) and MRMS.



An American Airlines aircraft is de-iced at Syracuse Hancock International Airport, New York. CIRES and other scientists in NOAA's Global Systems Division support improved aviation weather forecasts.

Photo credit: Phillip Capper/Creative Commons

We enhanced the Event-based Verification and Evaluation of NWS gridded products Tool (EVENT) to include the High-Resolution Rapid Refresh (HRRR) model forecasts and to allow switching from CIWS- to MRMS-based thunderstorm observations.

We completed research into several kinds of new verification techniques:

- approaches to event-based (as opposed to fixed time intervals) verification;
- extending our constraint-based techniques from the en-route to the terminal domain for aviation; and
- investigating the use of dual-polarization radar data in the verification of forecasts of in-flight icing and forecasts of convective initiation.

The FAA postponed a planned Consolidated Storm Prediction for Aviation winter weather evaluation; CIRES work in this arena is therefore postponed, too.

GSD-07: Testbed Center for Numerical Prediction Developmental

■ CIRES Lead: Ligia Bernardet ■ NOAA Lead: Zoltan Toth

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:

The Hurricane Weather Research and Forecast (HWRF) model and the Gridpoint Statistical Interpolator (GSI) codes continued to be used both in NOAA operations and in the research and development communities. GSI is also being transitioned to the Air Force Weather Agency (AFWA). To that effect, CIRES and collaborators 1) maintained the community and operational codes synchronized to prevent divergence, 2) helped community users test and commit their code to the repository, 3) hosted developers committee meetings, and 4) supported users by maintaining Web portals with data sets and documentation, and by staffing a help desk. Additionally, tests were conducted to evaluate new code developments, making them potentially available for implementation at the NOAA National Centers for Environmental Prediction and at AFWA. In particular, HWRF was tested with the Rapid Radiative Transfer Model (RRTMG) and the Thompson microphysical parameterization, and results were contrasted against the control (operational) configuration.

Publications and conferences:

Bernardet, L., V. Tallapragada, S. Bao, S. Trahan, Y. Kwon, Q. Liu, M. Tong, M. Biswas, T. Brown, D. Stark, L. Carson, R. Yablonsky, E. Uhlhorn, S. Gopalakrishnan, X. Zhang, T. Marchok, B. Kuo and R. Gall, 2014: Community Support and Transition of Research to Operations for the Hurricane Weather Research and Forecast (HWRF) Model. Accepted by the Bull. *Atmos. Meteor. Soc.*, pending minor reviews.

Bernardet, Ligia, V. Tallapragada, Y. Kwon, S. Trahan, M. Tong, Q. Liu, M. Biswas, C. Holt, T. Brown, X. Zhang, S. Gopalakrishnan, R. Yablonsky, T. Marchok, and L. Carson, 2014: Hurricane WRF: 2014 operational implementation and community support. 15th Annual WRF Users' Workshop, June 24-26, Boulder, Colorado.

Shao, H., M. Hu, D. Stark, K. Newman, C. Zhou, and L. Bernardet, 2014: DTC data assimilation system community support and testing: 2014 annual update. 15th Annual WRF Users' Workshop, June 24-26, Boulder, Colorado.

Zhou, C., H. Shao, and L. Bernardet, 2014: Testing and evaluation of the GSI-Hybrid data assimilation and its applications for high-resolution tropical storm forecasts. 15th Annual WRF Users' Workshop, June 24-26, Boulder, Colorado.



Participants of the Hurricane Weather Research and Forecasting (HWRF) model tutorial, co-organized and taught by CIRES/NOAA staff in January 2014 at the NOAA Center for Weather and Climate Prediction in College Park, Maryland.

Biswas, M., C. Holt, G. Thompson, Y. Kwon, L. Bernardet, and V. Tallapragada, 2014: Impact of Thompson microphysics and RRTMG radiation on hurricane forecasts with HWRF. 15th Annual WRF Users' Workshop, June 24-26, Boulder, Colorado.

Newman, K. M., M. Hu and H. Shao: Testing and Evaluation of GSI Background Error Sensitivity for Regional Applications. 18th Conf. on Integrated Observing and Assimilation Systems for the Atmos., Oceans, and Land Surface (IOAS-AOLS). Amer. Meteor. Soc., 12.4.

Shao, H., M. Hu, D. Stark, K. M. Newman, and C. Zhou, 2014: Provide supports for Community Researchers to Use Operational Gridpoint Statistical Interpolation (GSI) System. 18th Conf. on Integrated Observing and Assimilation Systems for the Atmos., Oceans, and Land Surface (IOAS-AOLS). Amer. Meteor. Soc., Atlanta, GA. 12.3.

PSD-12: Analysis of the Causes of Extreme Events

■ CIRES Lead: Judith Perlwitz ■ NOAA Lead: Randall Dole

NOAA Theme: Weather-Ready Nation

Goals & Objectives:

This project will promote more accurate forecasting of extreme events.

Accomplishments:

Our research during the last year focused on the link between Arctic sea ice loss and mid-latitude weather and climate extremes. Arctic temperature has risen dramatically since 1979, with a common supposition being that sea ice decline has principally caused Arctic tropospheric warming (and 1000-500 hPa thickness increase) including a pronounced thickness increase over the far North Atlantic region. Using climate simulations, we quantify the magnitude of Arctic (60°-90°N) warming resulting from various factors. Sea ice decline caused much of near-surface Arctic warming, but contributed only about 20 percent to deep tropospheric warming. It is shown that the Arctic troposphere warmed primarily due to remote, rather than in situ, forcings since 1979. A recent decadal internal fluctuation in sea surface temperatures (SSTs) and a long-term warming of SSTs mainly outside the polar cap contributed about 25 percent and 34 percent to the observed deep tropospheric warming, respectively. Unforced random atmospheric variability may have contributed up to 25 percent of the magnitude of observed Arctic tropospheric warming, possibly exceeding impacts from sea ice loss.

Results further indicate that pronounced tropospheric thickness increases over the far North Atlantic region including a reduction in westerly flow over the mid-latitudes were mainly a large amplitude expression of internal atmosphere-ocean variability.

This regional feature of climate trends since 1979 was thus mostly unrelated to effects of sea ice loss. An implication of this study's results is that the Arctic troposphere has been mainly responding to rather than forcing mid-latitude weather and climate. We submitted a manuscript on this study to *J. Climate*.

PSD-14: Forecasts for Wind Energy

■ CIRES Lead: Laura Bianco ■ NOAA Lead: James Wilczak

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:

As introduced in the previous report, to quantify the impact of assimilation of the additional Wind Forecast Improvement Project (WFIP) observations only, data denial (DD) experiments were run with the Rapid Refresh (RAP) model. In these experiments, we ran control simulations that did not assimilate any of the special WFIP



Turbines at the National Renewable Energy Laboratory's National Wind Technology Center. Photo credit: Will von Dauster/NOAA

observations. We compared those results to those of experimental simulations that did assimilate the WFIP observations. In total, we ran six DD episodes, each 7-12 days long, spanning all four seasons of the year.

Using conventional statistical analysis, the experimental simulations were found to improve the average mean absolute error power forecast skill at all forecast hours. This improvement ranged from 8 percent at forecast hour 1 to 3 percent at forecast hour 6 in the North Study Area (NSA, in the upper Great Plains, including North Dakota, South Dakota, Nebraska, Minnesota, and Iowa); and from 6 percent at forecast hour 1 to 1 percent at forecast hour 6 in the South Study Area (SSA, centered in west Texas). Positive forecast skill improvement remained until the last forecast hour 15 in both study areas, but at levels less than 2 percent.

We investigated the dependence of the forecast percent improvement on season, verification time of day, and observed power. Although the magnitude of improvement varied considerably between the six DD episodes, we found no clear seasonal trends across both study areas. This suggests that the variability was more related to sampling issues than to meteorological characteristics of the different seasons. In contrast, we found that forecast improvement depended strongly on the hour of the day that forecast was verified. In the NSA, the largest improvements were observed during the daytime hours, with considerably smaller improvements during the nighttime hours. In the SSA, the diurnal variation of the improvement was less clear, with a suggestion

of two maxima, one in the early daytime hours and the second in the night. In terms of dependence on the observed power, the power forecast improvement had, at most, a small variation, with slightly larger improvement for larger observed power. We investigated the improvement caused by the assimilation of new data in several other ways, all described in a report submitted to the Department of Energy. Also, we submitted a paper about the WFIP experiment to the *Bulletin of the American Meteorological Society* in April 2014.

We developed a ramp tool and metric to: (1) identify ramp events in a time series and (2) score the skill of a model at forecasting ramp events. We studied the skill of the RAP model at forecasting ramp events using this ramp tool and metric developed for WFIP, using data from six DD episodes for which 15-minute model output was available. We found that assimilation of the special WFIP observations improve the RAP ramp forecast skill, averaged over the first nine forecast hours, by more than 10 percent in the NSA, but only 3.5 percent in the SSA. A manuscript regarding the ramp tool and metric is almost ready to be submitted for publication.

In summary, it is clear that significant improvements to hub-height wind forecasts and ramp event forecasts have been achieved during WFIP by assimilating additional observations into the model. Results were documented and papers will likely be published soon.

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Publications by the Numbers

CIRES scientists and faculty published at least 603 peer-reviewed papers during calendar year 2013. Below, we tabulate publications by first author affiliation. CIRES scientists and faculty published many additional non-refereed publications in 2013, 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	2013
CIRES Lead Author	177	165	188	141	130	110	158	137	238	186	189
NOAA Lead Author	31	56	20	81	73	99	79	63	41	30	44
Other Lead Author	183	134	145	289	264	385	342	312	293	312	370
Total	391	355	353	511	467	594	579	512	572	528	603

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Commonly used abbreviations

CSD	NOAA ESRL Chemical Sciences Division
CU-Boulder	University of Colorado Boulder
ESRL	NOAA Earth System Research Laboratory
GMD	NOAA ESRL Global Monitoring Division
GSD	NOAA ESRL Global Systems Division
NGDC	National Geophysical Data Center
NOAA	National Oceanic and Atmospheric Administration
OAR	NOAA Office of Oceanic and Atmospheric Research
PSD	NOAA ESRL Physical Sciences Division

personnel demographics

CIRES Personnel Breakdown 2013–2014¹

Category	Total CIRES personnel	NOAA-supported CIRES personnel	Highest degree earned by NOAA-supported personnel		
			B.S.	M.S.	Ph.D.
Faculty	18	0			
Research Scientist	207	118	1	1	116
Visiting Scientist	32	3	0	0	3
Postdoctoral Researcher	37	12	0	0	12
Associate Scientist	276	144	68	68	8
Administrative	33	29	21	6	2
TOTAL > 50% NOAA Support		306	90	75	141
Undergraduate Students	76	55	0	0	0
Graduate Students	111	6	6	0	0
Received < 50% NOAA Support		71	11	24	36
Total CIRES Personnel	790				

¹Includes CIRES employees receiving NOAA funding anytime between June 2013 and May 2014

CIRES Personnel in NOAA Boulder Laboratories²

OAR ESRL³	258
ESRL Director's Office (9)	
Chemical Sciences Division (80)	
Global Monitoring Division (46)	
Global Systems Division (48)	
Physical Sciences Division (75)	
NESDIS NGDC⁴	45
NWS SWPC⁵	17
TOTAL	320

²Counted on May 1, 2014

³NOAA Office of Oceanic and Atmospheric Research's Earth System Research Laboratory

⁴NOAA Environmental Satellite, Data, and Information Service's National Geophysical Data Center

⁵NOAA National Weather Service's Space Weather Prediction Center

active NOAA awards

NOAA Cooperative Agreements

Record number	Description	Time frame
NA12OAR4320137	Current Cooperative Agreement	September 2012– August 2017
NA10OAR4320142	Old Cooperative Agreement	June 2010– September 2013

Other NOAA Awards

Record number	Description	Time frame	Total funding
NA10OAR4310112	Maximizing the potential of tropical climate proxies through integrated climate-proxy forward modeling	August 2010–July 2014	\$64,291
NA09OAR4310063	Exploring the dynamics of high latitude carbon balance	September 2009–August 2014	\$326,260
NA12OAR4310142	Climate Literacy and Energy Awareness Network (CLEAN) core activities	September 2012–August 2014	\$81,529
NA13OAR4310210	Climate.gov follow-up evaluation: A study of the four NOAA audiences	September 2013–August 2014	\$79,907
NA12NWS4680005	HFIP using Global Forecast System forecast system to generate tropical cyclone forecast products	January 2012–December 2014	\$133,220
NA12OAR4310136	Building climate science into land and water conservation planning and decision-making in the American Southwest	January 2013–December 2014	\$162,098
NA12OAR4310136	Subcontr to 1549744: University of Arizona	January 2013–December 2014	\$36,680
NA14NWS4830004	Ensemble-variational data assimilation and prediction	February 2014–January 2015	\$201,929
NA14NWS4830007	FY2014 HFIP physics package experiment	February 2014–January 2015	\$58,949
NA14OAR4830066	Extreme precipitation and flooding from atmospheric rivers: CIRES labor contribution	February 2014–January 2015	\$301,616
NA13OAR4310063	Collaborative research: influence of NO _x and NO ₃ on SOA formation: analysis of real-time field observations	August 2013–July 2015	\$382,151
NA13OAR4310079	Improving Carbon Tracker by incorporating constraints from atmospheric O ₂ measurements and ocean biogeochemical tracer data	August 2013–July 2015	\$125,415
NA13OAR4310082	Improving Carbon Tracker flux estimates for North America using carbonyl sulfide (OCSs)	August 2013–July 2015	\$307,488
NA13OAR4310085	Quantifying observational variability and inverse model biases of planetary boundary layer depths and their impact on the calculation of carbon fluxes in carbontracker	August 2013–July 2015	\$79,476
NA10OAR4310214	Western Water Assessment	September 2010–August 2015	\$4,245,000
NA13OAR4310074	Quantification of fossil fuel CO ₂ by source sector using multi-species trace gas measurements in the INFLUX experiment	September 2013–August 2015	\$111,786
NA13NES4830008	Seamless digital elevation models for Sandy-impacted areas	October 2013–September 2015	\$282,317

Other NOAA Awards (continued)

Record number	Description	Time frame	Total funding
NA14NWS4830002	Stochastic physics	February 2014–January 2016	\$280,000
NA14NWS4830003	Lower boundary ensemble initial perturbations in GFS	February 2014–January 2016	\$280,000
NA14NWS4830005	Multi-model post processing	February 2014–January 2016	\$340,000
NA14OAR4830105	Establishment of a NOAA laboratory activity for observing system simulation experiments (OSSE)	April 2014–March 2016	\$250,119
NA14NES4830001	Enhanced management of and access to Hurricane Sandy ocean and coastal mapping data	May 2014–April 2016	\$882,000
NA14NWS4830010	MADIS transition to NWS operations	June 2014–May 2016	\$349,076
NA14NWS4830033	GSI enhancement for variational ensemble cloud assimilation	July 2014–June 2016	\$107,783
NA14OAR4830123	HIWPP assimilation, ensemble stochastic physics and parameterization development	July 2014–June 2017	\$1,222,036



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